CANALLS
AGROECOLOGICAL PRACTICES FOR SUSTAINABLE TRANSITION

D2.6 Holistic Agroecology Assessment Framework – Final version

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Executive Summary

The promotion of agroecology is closely aligned with global and regional development agendas, particularly the United Nations Sustainable Development Goals. This study presents the baseline assessment of agroecological transition across eight Agroecological Living Labs (ALLs) implemented under the CANALLS project in Burundi, Cameroon, the Democratic Republic of Congo (DRC), and Rwanda. The assessment applied the FAO Tool for Agroecology Performance Evaluation (TAPE), integrating four steps namely STEP 0 (contextual analysis), STEP 1 (Characterization of Agroecological Transition – CAET), and STEP 2 (performance assessment), and provides a robust evidence base for STEP 3 (validation and use of results).

The key findings of this study show that:

All Living Labs exhibit substantial agroecological potential, rooted in existing practices such as agroforestry, crop–livestock integration, recycling of organic matter, and strong food and cultural traditions. However, this potential is constrained by several factors including land tenure insecurity, labour pressure, weak extension systems, partial policy–practice misalignment, and limited market integration, particularly in the conflict-affected and lowland areas of eastern DRC.

The CAET results indicated that most systems fell within the "in transition" category (50–70%), with none consistently reaching advanced agroecological status across all dimensions. Sites in eastern DRC (Uvira, Bunia, Kabare, Biega) and Rwanda (Kamonyi) performed relatively better, while Burundian sites (Bujumbura and Giheta) consistently lag across most agroecological elements.

Across all ALLs, biological and functional diversity scores remained below 50%, representing a systemic vulnerability that undermines resilience and long-term sustainability. In contrast, co-creation of knowledge, socio-cultural values, and circular economy practices showed comparatively stronger performance, indicating a solid social foundation for transition.

Statistical and expert-based typologies demonstrated that farm household type explains agroecological performance more strongly than the location of the Living Lab alone. Smallholder subsistence-oriented farms dominated and showed the lowest CAET and performance levels, while labour-intensive family farms achieved intermediate scores. Large land-endowed farms, though rare, exhibited the highest agroecological integration. The strong interaction between farm type and territorial context suggested the need for farm-type-specific transition pathways.

Productivity outcomes varied widely and were not always aligned with sustainability. Some ALLs achieved high short-term productivity through unsustainable practices, while others displayed moderate productivity with stronger ecological foundations. Income and added-value analyses revealed widespread economic vulnerability, with farmers' perceptions highlighting strong regional disparities. These findings confirmed that economic performance under agroecology cannot be interpreted independently of market failures and governance constraints.

Land tenure insecurity, especially for women, emerged as a major barrier to agroecological investment and long-term sustainability. The Kamonyi ALL stands out as a positive example of gender-equitable land access. Youth employment in agriculture remained largely

unsustainable in all ALLs, reinforcing migration pressures and threatening intergenerational continuity of agroecological practices.

As a baseline, this assessment demonstrates that the agroecological transition is underway, yet remains fragile and shaped by persistent structural constraints. Advancing CANALLS implementation and informing future interventions will require strategies that are context-specific, farm-type-differentiated, gender-responsive, and grounded in local institutional dynamics, rather than uniform technical prescriptions. The findings provide a solid basis for participatory validation and adaptive planning under TAPE STEP 3.

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List of Terms and Definitions

Table 1: Terms and Definitions

Abbreviation	Definition
AKIS	Agricultural Knowledge and Innovation Systems
ALL	Agroecological Living Laboratory
CAET	Characterisation of agroecological transition
CANALLS	Driving agroecological transitions in the humid tropics of Central and Eastern Africa through traNsdisciplinary Agroecology Living LabS
CIRAD	Centre de Cooperation Internationale en Recherche Agronomique pour le Developpement
DRC	The Democratic Republic of Congo
ETHz	Eidgenoessische Technische Hochschule Zuerich
IITA	International Institute of Tropical Agriculture
INERA	Institut National pour l'Etude et la Recherche Agronomiques
ISABU	Institut des Sciences Agronomiques du Burundi
IRAD	Institut de Recherche Agricole pour le Developpement
ODK	Open data kit
ONA (Ona Data)	online data collection and management platform built on ODK technologies
RAB	Rwanda Agriculture and Animal Resources Development Board
RIKOLTO	Rikolto International
TAPE	Tool for Agroecology Performance Evaluation
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
UCB	Universite Catholique de Bukavu

Chapter 1. INTRODUCTION

1.1. Context and Justification

The humid tropical regions of Eastern and Central Africa constitute some of the most strategically significant agricultural landscapes for addressing contemporary and future challenges related to food and nutrition security at local, regional, and global scales (European Union, 2023). These regions encompass a wide diversity of agroecological zones, high levels of biological and genetic diversity, generally favorable climatic conditions, and soils with substantial productive potential when appropriately and sustainably managed (Tittonell, 2014; FAO, 2021). Agriculture remains the backbone of rural livelihoods in these contexts, with more than 60% of the population in sub-Saharan Africa (SSA) depending directly or indirectly on farming for food provision, income generation, and social stability (IFAD, 2019; FAO, 2020; World Bank, 2023; FAO et al., 2023; AfDB, 2023).

Despite these comparative advantages, agricultural systems in the humid tropics of Central and Eastern Africa continue to face persistent structural, environmental, and socio-economic constraints (IPCC, 2022). Widespread land degradation, declining soil fertility, deforestation, climate variability, and increasing frequency of extreme weather events constrain agricultural productivity and stability. These challenges are further exacerbated by poor rural infrastructure, limited access to markets and financial services, insecure land tenure, and entrenched socio-economic inequalities (De Schutter, 2017; Altieri & Nicholls, 2020; IPCC, 2022). In this region, smallholder farmers who dominate agricultural production systems often operate under severe resource constraints and limited institutional support, restricting their capacity to adopt and sustain long-term sustainable practices. They face a pronounced finance and input gap (World Bank, 2023; AGRA, 2023), while extension services and markets often fail to reach them (IFAD, 2023; Tambo et al., 2023). These systemic failures reinforce a persistent poverty trap, making investments in sustainability economically out of reach for many (Barrett et al., 2022; FAO, 2023). Conventional agricultural intensification models, largely reliant on external inputs and standardized technological packages, have shown limited and uneven effectiveness in these contexts. While short-term yield increases have been documented in some cases, such approaches frequently increase farmers' dependency on costly inputs, heighten production risks, and contribute to the degradation of ecosystem services, including soil fertility regulation, biodiversity conservation, and climate resilience (Vanlauwe et al., 2014; Tittonell et al., 2018). These limitations highlight the need for alternative development pathways that reconcile productivity objectives with environmental sustainability and social equity.

In this context, agroecology has emerged as a promising and increasingly recognized framework for the transformation of agricultural and food systems in SSA. Agroecology applies ecological principles to the design and management of farming systems while explicitly integrating social, cultural, economic, and institutional dimensions (Méndez et al., 2013; Gliessman, 2015; Pimbert, 2018). Beyond a set of technical practices, agroecology encompasses a scientific discipline, a social movement, and a policy approach aimed at enhancing food sovereignty, ecosystem integrity, and rural livelihoods. Within this broader paradigm, the CANALLS project *("Driving agroecological transitions in the humid tropics of Central and Eastern Africa through transdisciplinary Agroecology Living Labs")* positions agroecology as a strategic entry point for addressing food insecurity, climate vulnerability, biodiversity loss, and rural poverty, while fostering transdisciplinary research and innovation partnerships between African and European actors.

1.2. Rationale for Agroecology in Eastern and Central Africa

The promotion of agroecology in Eastern and Central Africa is closely aligned with global and regional development agendas, particularly the United Nations Sustainable Development Goals (SDGs), including SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land). Agroecological approaches are also consistent with the European Union's commitments to sustainable food systems, biodiversity protection, and climate action, while responding to the specific vulnerabilities and opportunities of tropical smallholder agriculture (European Commission, 2020; European Union, 2023).

Climate change poses a major and growing threat to agricultural systems in SSA, manifested through rising temperatures, increasing rainfall variability, and a higher incidence of droughts and floods. Agroecology offers pathways for climate adaptation and mitigation by enhancing soil organic matter, promoting functional biodiversity, improving water-use efficiency, and reducing greenhouse gas emissions through decreased reliance on synthetic inputs (Altieri et al., 2015; HLPE, 2019; IPCC, 2022).

From an environmental perspective, agroecological practices contribute to the conservation and sustainable management of natural resources by limiting deforestation, reducing soil erosion, maintaining agrobiodiversity, and strengthening ecosystem resilience; key prerequisites for long-term agricultural productivity in the humid tropics (FAO & UNEP, 2021; European Commission, 2020). Socio-economically, agroecological transitions have demonstrated potential to enhance livelihood resilience by diversifying income sources, reducing production risks, strengthening local value chains, and reinforcing social cohesion and food security, particularly among smallholder and vulnerable farming households (De Schutter, 2017; FAO, 2020).

At regional and global market levels, strategic crops such as coffee, cocoa, maize, rice, and cassava play a central role in both domestic food systems and export economies. Agroecological management of these commodities provides opportunities to align production with emerging environmental, social, and ethical standards, while maintaining competitiveness and market access (European Union, 2023). Moreover, agroecology serves as a platform for strengthening international research collaboration and knowledge exchange, facilitating the co-creation of context-specific, scalable, and socially embedded innovations (Klerkx et al., 2020).

However, agroecological transitions require supportive policy, institutional, and governance environments. Many SSA countries still lack coherent policy frameworks, incentive structures, and extension systems that adequately recognize and support agroecology. Addressing these gaps through evidence-based dialogue, institutional strengthening, and stakeholder engagement constitutes a central justification for initiatives such as CANALLS ("*Driving agroecological transitions in the humid tropics of Central and Eastern Africa through transdisciplinary Agroecology Living Labs*") (Pimbert, 2018; HLPE, 2019).

1.3. Driving agroecological transitions in the humid tropics of Central and Eastern Africa through transdisciplinary Agroecology Living Labs, CANALLS Project

The CANALLS initiative is an international research and innovation project designed to accelerate agroecological transitions in smallholder farming systems of SSA. The project responds to the urgent need to transform food systems that are currently characterized by ecological degradation, climate vulnerability, and persistent socio-economic inequalities.

CANALLS adopts Agroecology Living Labs (ALLs) as its core operational framework. ALLs are participatory, real-life innovation spaces where farmers, researchers, extension services, civil society organizations, private sector actors, and policymakers collaboratively co-design, test, and adapt agroecological practices to local agroecological and socio-economic conditions. By embedding scientific inquiry within farmers' realities and local knowledge systems, the Living Labs approach bridges the gap between research, practice, and policy.

The project is implemented across eight Agroecology Living Labs located in four countries including Burundi, Cameroon, the Democratic Republic of Congo (DRC) and Rwanda. These ALLs focus on strategic crops, central to food security and economic sustainability namely coffee (Biega & Kabare in DRC and; Giheta in Burundi), cocoa (Bunia in DRC; Ntui in Cameroon), rice (Uvira in DRC), maize (Bujumbura in Burundi), and cassava (Kamonyi in Rwanda). The diversity of crops and contexts provides a robust basis for comparative analysis and cross-learning on agroecological transitions in the humid tropics.

Based on literature rewiew we know that the implementation of agroecological principles within the selected ALLs: (1) improve soil fertility, enhance biodiversity conservation, and strengthen climate adaptation capacities of farming systems (Tittonell, 2014; Altieri et al., 2015); (2) increase farmer participation, collective learning, and knowledge exchange, thereby accelerating the adoption of sustainable agricultural practices (Pretty et al., 2018); (3) reinforce agroecological networks and local value chains, improving market access and rural economic viability (HLPE, 2019); and (4) reveal key socio-economic, institutional, and environmental barriers such as financial constraints, policy limitations, and infrastructural gaps that may hinder large-scale agroecological adoption, thereby informing the design of targeted interventions (De Schutter, 2017).

1.4. Hypothesis

This baseline study is grounded in the hypothesis that the eight ALLs of the CANALLS project display heterogeneous levels of agroecological transition, shaped by interacting biophysical, socio-economic, institutional, and organizational factors. It is expected that:

i Agroecological practices are already partially implemented across the ALLs, though with varying degrees of integration into farming systems, influencing current level of soil fertility management, on-farm biodiversity, and climate-related risk management practices (Tittonell, 2014; Altieri et al., 2015);

ii Variability in farmer organization, participation, collective learning, and access to knowledge significantly affects agroecological performance and farmers' capacity and willingness to adopt and sustain agroecological practices (Pretty et al., 2018);

iii The strength of local agroecological networks, market linkages, and value chain integration shapes existing incentives for adoption, particularly through access to inputs, markets, and income-generating opportunities (HLPE, 2019);

iv Constraints such as limited financial resources, weak institutional support, policy and governance gaps, and inadequate infrastructure hinder the scaling of agroecology, making their identification at baseline essential for designing context-specific interventions (De Schutter, 2017).

Building on these assumptions, the study further posits that the ALLs' differing levels of agroecological transition can be systematically assessed using the FAO Tool for Agroecology Performance Evaluation (TAPE). These differences are expected to reflect both in the extent of agroecological practice adoption (TAPE Step 1: CAET) and in the ecological, economic, and social performance of farming systems (TAPE Step 2: Performance Criteria) in the study areas.

1.5. Objectives of the Study

1.5.1.General Objective

The overall objective is to: i) conduct a systematic and comparative baseline assessment of the level and performance of agroecological transition across eight ALLs using the FAO Tool for Agroecology Performance Evaluation (TAPE), in order to inform the design, targeting, and monitoring of CANALLS project interventions; ii) critically evaluate TAPE itself as an operational framework for measuring agroecological transition in multi-country and heterogeneous contexts, by examining its applicability, adaptability, and analytical robustness based on lessons learned during field implementation.

This evaluation draws on both strengths and limitations observed in the collected data and implementation process, with the objective of formulating evidence-based recommendations for improving the framework and its use in future monitoring cycles.

1.5.2. Specific Objectives

The specific objectives of the study are to:
-characterize baseline levels of agroecological transition across the targeted ALLs using the CAET, with explicit reference to the FAO's 10 Elements of Agroecology (Tittonell, 2014; FAO, 2018).
-assess the ecological, economic, and social performance of farming systems at baseline using the TAPE performance criteria (Step 2), and examine their relationships with CAET transition levels across and within ALLs (HLPE, 2019; FAO, 2021).
-identify and analyze key enabling and constraining factors influencing agroecological adoption and performance across ALLs, including biophysical, socio-economic, institutional, and governance dimensions (De Schutter, 2017; Pimbert, 2018).

-establish a robust and comparable baseline reference framework for monitoring changes in agroecological practices, performance outcomes, and enabling environments throughout the CANALLS project lifecycle (Tittonell, 2014; FAO, 2021).
-generate evidence-based insights and recommendations to support adaptive project implementation, stakeholder learning, and policy dialogue at local, national, and regional levels (Pretty et al., 2018; HLPE, 2019).
-critically assess the TAPE framework as an operational monitoring and evaluation tool in multi-country and heterogeneous agroecological contexts, by examining its applicability, comprehensiveness, and practicality during field implementation, including the usability of indicators, scoring procedures, and thresholds.
-formulate methodological recommendations for improving or adapting TAPE to the specific needs and constraints of the CANALLS project, including proposals for context-sensitive indicators, simplified descriptors, facilitation protocols, and data collection procedures.

1.6. Aim of the Baseline Study

The aim of this baseline study is double. First, it seeks to generate robust and comparable empirical evidence to guide the CANALLS project in facilitating agroecological transitions in Eastern and Central Africa. By establishing a detailed understanding of agroecological adoption, performance outcomes, and enabling conditions within the target ALLs, the research aims to identify key drivers, constraints, and leverage points for sustainable transformation of farming systems.
Second, this reserach aims to critically assess the TAPE as an operational framework for measuring and monitoring agroecological transition in diverse, multi-country contexts. Through its systematic application across contrasting agroecological, socio-economic, and institutional settings, the baseline evaluates the tool's applicability, analytical coherence, and practical usability, while identifying areas requiring adaptation or refinement.
Implemented through participatory and transdisciplinary research approaches, the study actively engages farmers, extension services, researchers, and policy actors in the co-production of both empirical evidence and methodological learning. In doing so, it strengthens local ownership of results while enhancing the relevance and legitimacy of agroecological monitoring processes.
Beyond its contribution to CANALLS project implementation, this baseline study contributes to the broader agroecological research and practice agenda by generating comparative evidence and methodological insights on the use of TAPE in humid tropical regions of Africa, thereby supporting the development of scalable, context-sensitive monitoring frameworks (Pretty et al., 2018).

1.7. Relevance of the Baseline Study for Monitoring and Evaluation

The baseline study constitutes a central pillar of the CANALLS project's monitoring, evaluation, and learning framework. It provides the reference point against which future changes in agroecological practices, farming system performance, and socio-economic outcomes will be assessed throughout the project.

Through the FAO Tool for Agroecology Performance Evaluation (TAPE)**,** the baseline delivers a standardized yet context-sensitive assessment of i) current levels and trajectories of agroecological transition; ii) ecological, economic, and social performance of farming systems and; iii) stakeholder perceptions, capacities, and enabling environments. This information is essential for tracking progress, guiding adaptive management, identifying context-specific entry points for interventions, and informing policy dialogue at local, national, and regional scales.

Ultimately, the baseline ensures that agroecological transitions promoted by CANALLS are measurable, accountable, and responsive to local realities, while contributing to the global evidence base on sustainable food system transformation in the humid tropics of Africa.

Chapter 2. MATERIALS AND METHODS

2.1. Site description

The study was carried out in eight Agroecological Living Laboratories (ALLs) which constitute the implementation area of the project. These ALLs comprise Bujumbura and Giheta located in Burundi; Ntui in Cameroon; Biega, Bunia, Kabare and Uvira in DRC; and Kamonyi in Rwanda (Figure 1). The ALLs were strategically chosen for their agroecological diversity and their significance in local and regional food security. They are actively collaborating and empowering more than 20,000 farmers, as well as various value chain actors, by fostering a co-creative approach. The various stakeholders are working together towards identifying, implementing, and optimizing combinations of agroecological practices tailored to the specific needs and conditions of each ALL. Efforts are centered on enhancing the production and sustainability of the key crops, including cocoa, coffee, cassava, rice, and maize, which are not only critical for local subsistence but also play a pivotal role in driving economic development within these communities. This initiative underscores the importance of integrating scientific research with practical, community-driven solutions to address the unique challenges faced by farmers in each area (European Union, 2023).

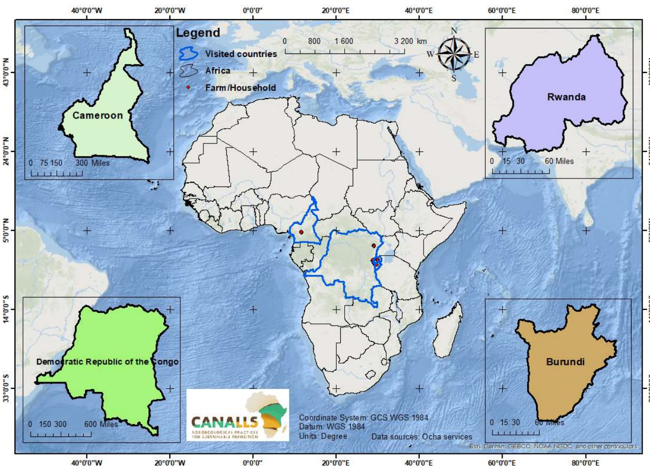


Figure 1. Distribution of the 8 Agroecological living laboratories of the project across the sub-Saharan Africa regions

2.1.1. Altitude and soil

The variation in altitude across the ALLs directly impacts temperature, rainfall, and soil characteristics, which in turn influence the cropping systems and agroecological practices in the study area. Higher altitudes generally support cooler climates and more fertile soils,

favoring crops like coffee and tea, while lower altitudes require innovative soil management to sustain crop productivity.
In DRC, the Bunia ALL is located at an altitude of approximately 1,200 m asl, benefits from a moderate highland climate. The soils are predominantly volcanic, offering high fertility, which supports diverse cropping systems, including coffee, cassava, and maize. The altitude fosters cooler temperatures, ideal for crops requiring such conditions.
The Biega ALL situated at 1,500 m asl, experiences cooler temperatures and higher rainfall. Its soils are rich in organic matter due to the dense forest cover, making it suitable for agroforestry practices and many crops.
Kabare ALL is located at an altitude of about 1,400 m asl, features fertile volcanic soils. This region supports intensive intercropping systems due to the favorable soil and climatic conditions. Uvira with a lower altitude of approximately 800 m asl, has a warmer climate and sandy soils which are more prone to erosion and less fertile compared to the highland regions, necessitating soil conservation practices.
Like Uvira, Bujumbura ALL is also located at low altitude (around 800 m asl). Its warmer lowland climate supports many crops but soil fertility is a challenge, requiring sustainable management practices to maintain productivity. Giheta ALL in Burundi in the contrary is situated at a higher altitude of about 1,500 m asl. This ALL enjoys cooler temperatures and fertile soils, ideal for coffee and tea cultivation. The region also supports diverse agroforestry systems.
The Ntui ALL (Cameroon) is Situated at an altitude of approximately 600 m asl and has a tropical lowland climate. The soils are lateritic, requiring careful management to sustain crops like cocoa and cassava.
Kamonyi (Rwanda) is ALL that has around 1,400 m asl of altitude and benefits from fertile volcanic soils and a temperate climate. This region supports diverse cropping systems, including beans, maize, and banana.

2.1.2. Agricultural Focus and Practices

In Burundi, the living labs focus on small and medium-scale agriculture. Bujumbura's primary crop is maize, grown by 75% of households while Giheta specializes in coffee farming, although women have limited involvement. The agricultural challenges in both ALLs include land degradation, poor soil health, and high or moderate climate change impacts. Farmers are adopting a mixture of organic and mineral fertilizers, compost, and agro-sylvopastoral systems to improve soil health. However, further education and training are needed in plant and animal diseases control, soil management, and irrigation practices (WP1 Report, 2024).

The Ntui living lab in Cameroon emphasizes on cocoa farming, with 76.7% of farmers cultivating this crop. Other local cultivated crops include cassava, maize, and yams. The community faces challenges related to land access, especially for women and indigenous groups. Climate change exacerbates issues such as irregular rainfall, extreme temperatures, and increases in pest incidence. Farmers use a combination of traditional agricultural practices, such as crop rotation and agroforestry, alongside using some organic inputs. However, there is a significant need for capacity building in sustainable agricultural practices, including pollinator management, animal feed, and irrigation and water resources management (WP1 report, 2024).

Agriculture is vital in DRC. Bunia ALL holds significant potential for agricultural development due to its fertile soils and favorable climate. In one hand, staple crops consist of cassava, maize, rice, and plantains. These crops are widely cultivated for subsistence farming. In the other hand cash crops are mainly coffee and cocoa, though their production is often limited by infrastructure and market access challenges. Yams, beans, and groundnuts are also common in this ALL. Bunia faces additional challenges due to conflict, affecting market access and food security. In Biega and Kabare, coffee, beans, maize, cassava, and sweet potatoes are key crops. These ALLs face significant challenges of climate changes, including erratic rainfall, drought duration and intensity, and pest's emergence. While farmers still rely on traditional farming methods such as crop rotation and agroforestry, they lack knowledge in sustainable farming practices like soil health management and biological control of plant pests and diseases. There's urgent need for training in areas like soil health and recycling practices.
Kamonyi district in Rwanda focuses on diverse agricultural production, including cereals, legumes, fruits, and root crops. Although 92% of farmers are aware of agroecology, adoption rates remain low due to poor agronomic practices, limited mechanization, and inadequate access to inputs. Climate change impacts such as floods and droughts also challenge the production. Farmers need further training on agroforestry, integrated chemical inputs, and animal husbandry to enhance agroecological practices.

2.1.3. Agricultural and Tax Policies

Agricultural policies across the four countries of the project are expected to impact agroecology use and performance. In Burundi, agriculture is a priority under the National Agricultural Strategy, which invests over 20% of the annual budget in the sector. However, the lack of emphasis on organic fertilizers may limit agroecology's issues promotion. In Cameroon, agroecology is not explicitly mentioned in official documents, although agroforestry and soil fertility management programs support sustainable farming. DRC's Sustainable Agricultural Policy promotes agroecology through agroforestry and sustainable land management. Rwanda actively supports agroecological practices, especially through subsidies for organic fertilizers.

Fiscal and tax policies also influence agroecological practices. In Rwanda, organic fertilizers are subsidized, while DRC and Burundi there is no favor subsidies for conventional agricultural products, making agroecology less economically viable in some cases.

2.1.4.Economic Context

Agriculture plays a central role in the economies of all four countries. Burundi faces economic difficulties, but agriculture remains the primary economic activity, particularly in cash crops like coffee. Cameroon relies on cocoa exports, but slow economic growth limits farmers' access to resources. DRC has a rich potential for sustainable agriculture, particularly through its participation in regional trade networks, which offer opportunities for agroecological practices despite internal conflicts. Rwanda's economy is stronger, bolstered by mining and agriculture, though it still faces infrastructure and climate challenges.

2.1.5.Food Systems, Value Chains and Markets

Agriculture is the backbone of Burundi's economy, with coffee as a key export product. However, farmers face challenges such as low productivity and poor market access. Strengthening market linkages, improving product quality, and fostering regional trade integration are essential to enhance agroecological outcomes.

Agriculture employs 70% of the population in Cameroon. However, farmers struggle with inadequate infrastructure, limited access to inputs and financial resources. To improve food systems, strengthening cooperatives and promoting agroecological products are essential steps on the forward pathway.

Agriculture is also central in DRC's economy, but challenges such as internal conflict, inadequate infrastructure and lack of access to finance hinder food security. Strengthening agricultural policies, supporting cooperatives creation and strengthen them as well as improving market access are key to enhance food systems in this country.

Rwanda's food systems suffer from inadequate infrastructure, especially in storage and transportation. However, the government's focus on agroecology, mechanization, and financial services holds promise for improving smallholder farmers' productivity and market access.

2.2. Selection of sites and stakeholders

The project established eight Agroecology Living Labs (ALLs) across four countries: Burundi, Camerooon, the Democratic Republic of the Congo, and, Rwanda. The methodology for selecting these sites and their associated stakeholders, as detailed across Work Packages (WP) 1 and 3, was designed to be inclusive and rigorous.

Site selection was conducted by national research partners (INERA, ISABU, IRAD, RAB) using a set of defined criteria. These included agroecological representativeness, relevance to focal value chains, the presence of existing local initiatives, feasibility for sustained multi-actor engagement, and positioning along relevant forest-agriculture transition gradients.

Stakeholder identification employed a mixed-methods approach to ensure comprehensive representation. This involved desk studies, farming system and value chain mapping, and extensive field interview including farmers, value chain actors, and policymakers. Additional methods such as AKIS (Agricultural Knowledge and Innovation Systems) mapping and multi-actor focus groups were instrumental in identifying key participants from across sectors.

This systematic process guaranteed the inclusion of farmers, cooperatives, advisory services, private sector representatives, policymakers, and civil society organizations actively engaged in agroecological transitions. The final composition of both sites and stakeholder groups was validated through participatory co-creation workshops and formally ratified during the establishment phase of the Living Labs under WP3. Contextual nuances for each country are provided in Table 1.

Table 1. Summary of Site & Stakeholder Selection Criteria per Country

Country	ALL	Agroecological & Farming System criteria	Institutional & Operational criteria	Stakeholder selection criteria

Burundi ISABU & CAPAD sites	Bujumbura and Giheta	Highland humid tropics; intensive smallholder systems; importance of coffee, maize,cassava; agroecology already promoted by cooperatives	Existing of IITA initiatives with a strong presence of ISABU & CAPAD; existing farmer networks; stable security context enabling ALL operations	Cooperatives affiliated with CAPAD; women-led groups; value chain actors in rice/maize; local policymakers for food system governance
Cameroon (IRAD, CAMFAS, SCOOPMAN sites)	Ntui	Diverse humid agroecological zones; cocoa & coffee value chains; forest margins with high biodiversity	Strong IRAD presence; active advisory networks via CAMF; existing producer organizations	Cocoa/coffee cooperatives; advisory services mapped under AKIS; market actors & SMEs; local authorities & certification bodies
DR Congo IITA, Rikolto and INERA sites	Mambasa, Kabare, Biega and Uvira	Representation of humid tropical agroecosystems; presence of key crops (cocoa, coffee, Rice); forest–agriculture transition gradients; high vulnerability to climate	Existing initiatives by IITA, INERA, UCB, APDIK, GASD; access to communities already engaged in agroecology	Farmers from cooperatives & informal groups; value chain actors in Cocoa, coffee, Rice; local authorities & customary leaders; extension agents & NGOs; women & youth inclusion
Rwanda (RAB & COPED sites)	Kamonyi	Highland humid tropics with intensive land use; maize, beans, coffee systems; strong national agroecology agenda	Strong institutional capacity via RAB; existing innovation platforms; good accessibility for multi-actor engagement	Farmer groups linked to RAB; youth agripreneurs; value chain actors in coffee/maize; policy actors at district & national level

Prior to the field data collection phase, a comprehensive literature review was undertaken to inform and validate the selection of the TAPE (Tool for Agroecology Performance Evaluation) framework as the primary methodology for assessing the state of agroecological transition within the established living labs. The findings from this foundational review are documented in *D2.2 Holistic Agroecology Assessment Framework_Initial version*.

2.3. TAPE approach

The TAPE methodology employs a structured, four-step process that integrates qualitative and quantitative data collection at both household/farm and community/territorial scales:

1) Step 0: Contextualization
This preliminary phase establishes the contextual foundation for the assessment. Through desk reviews and key informant interviews, it analyzes the external enabling environment including relevant policies, institutional support services, market conditions, and socio-economic factors. The purpose is to identify the principal drivers and barriers influencing agroecological adoption, thereby mapping the "playing field" in which local farming systems operate (FAO, 2029).

2) Step 1: Characterization of Agroecological Transition (CAET)
This step diagnoses the degree of agroecological integration within farming systems. Using on-farm surveys, it evaluates the application of the FAO's 10 agroecological elements (e.g., Diversity, Synergies, Resilience, Co-creation of knowledge). Each element is scored on a descriptive scale (0-4), classifying farms along a continuum from conventional to agroecological. This characterization provides the essential entry point for the subsequent performance evaluation (FAO, 2019).

3) Step 2: Performance Evaluation
Building on Step 1, this phase quantifies the multi-dimensional impacts of the transition. It measures sustainability outcomes against 10 core criteria spanning environmental, social, and economic dimensions such as agro-biodiversity, soil health, dietary diversity, income stability, and gender equity. The result is a holistic performance profile for each farm, enabling comparative analysis across different contexts, value chains, and transition levels (FAO, 2019).

4) Step 3: Participatory Analysis and Interpretation
The final step scales the analysis from individual farms to a territorial synthesis. Results from Steps 0, 1 and 2 are validated and reinterpreted with local stakeholders including farmers, policymakers, and private sector actors through focus groups and participatory workshops. This collaborative process aims to produce a shared diagnosis, identify systemic levers and barriers, and inform collective action plans for territorial agroecological transformation (FAO, 2019).

In TAPE quantitative surveys, qualitative interviews, participatory assessments, and biophysical measurements are combined to capture both the breadth and depth of agroecological dynamics, with national partners leading implementation across the eight Agroecology Living Labs (ALLs).

2.4. Sampling and data collection methods

2.4.1. Overall Approach

Data collection was carried out in close adherence to the FAO Tool for Agroecology Performance Evaluation (TAPE) protocol, which organizes evidence generation into four sequential components: Step 0 (Context), Step 1 (Characterization), Step 2 (Performance), and Step 3 (Territorial Synthesis).

To ensure representativeness, farmers in each ALL were randomly identified, after which data were collected using standardized questionnaires outlined in Annex 2 of the TAPE protocol (FAO TAPE). After applying some minors changes such as regarding the names of the study area, languages, …, the questionnaires were digitalized and uploaded to the IITA ONA platform, an Open Data Kit (ODK) based online system for mobile data collection and management, thereby enabling centralized management, harmonization, and subsequent data processing.

The timeline of data collection unfolded in successive phases. The initial stages; covering Steps 0, 1, and 2 took place between August 2024 and January 2025 in Burundi, Cameroon, the Democratic Republic of Congo, and Rwanda. Building upon this foundation, Step3 workshops were conducted in July 2025, specifically in the DR Congo ALLs and in Cameroon (Ntui ALL), to consolidate and expand the dataset. Finally, the process culminated with last ALLs in December 2025 and Januray 2026 in the Burundi and Rwanda ALLs.

A. STEP 0. Description of the context and enabling environment of agroecology across the living labs

A.1. Data collection methods

This step consisted of i) a desk review of national and regional policies, climate vulnerability, land tenure systems, and value chain structures; ii) key informant interviews with policymakers and institutional actors (10 per ALL); iii) mapping of advisory and innovation systems (AKIS) through interviews with extension services, NGOs, and cooperatives; and iv) spatial and landscape analysis to characterize forest–agriculture gradients, land use, and environmental pressures. WP1 and WP4 have already gathered important information capitalized in the description of this step.

A.2. Sampling strategy

Consultation with key stakeholders was conducted through participatory workshops to fill the gap of the literature review previously conducted. Stakeholder groups included farmer organizations, government ministries, research institutions, academic institutions, NGOs, value chain actors, and civil society. Total sample: 40–50 stakeholders per ALL, ensuring representation across sectors (Table 2).

Table 2. Stakeholder groups involved in the analysis of the context during the interview

Stakeholders' groups	Sampling (n) and specifications	
Farmer organizations /cooperatives/associations	8-10	Men and women farmers (including youth), lead farmers, chairpersons, farmer promoters

Government ministries (e.g. Ministry of Agriculture, water, or other agencies)	4-5	Experts (e.g., agriculture, water, food sectors), extension workers, policy makers/planners
Research institutions and/or innovation platforms	4-5	Researchers, scientists, innovators, consultants
Academic institutions (universities, colleges, schools)	4-5	Teachers, rectors, students,
Non-government organizations (local, international)	4-5	Development agencies (UN, regional organizations, forums), local NGOs managers.
Value chains actors:	4-5	Input suppliers (e.g., seeds, fertilizers, pesticides, farm machinery)
	8-10	Processors, manufacturers, retailers, wholesalers, consumers
Civil society	4-5	Media (journalists, activists) or others (religious, village leaders)
Total	40-50	-

Source: Adapted from CANALLs WP3 sampling scheme

Prior to the sampling process, a basic farm typology study was carried out in the 8 ALLs of the project based on expert knowledge (Table 3). The key criteria used were also identified by the experts involved in the concerned ALL (local partners of CANALLS) and varied from one ALL to another. These included (1) *Agricultural criteria* (farm size: small, medium or large; agricultural systems: monocrop, intercropping, agroforestry, silvopastoralism, agrosylvopastoralism, etc.; agroecological practices: intercropping, crop rotation, use of organic fertilizer, biopesticide, shade management, pruning, etc.; primary farming objective: subsistence, commercial or hybrid); (2) *Environmental criteria (*Agroecological zones; edaphology: soil texture, type, organic matter content, pH, etc.; topography: valley, slope, plateau, etc.; rainfall distribution: bimodal rainfall, one season, etc.; types of natural areas: forest, grasslands, wetlands, … among others. Creating farm typologies involves identifying different homogeneous groups of farms (farm types) within an ALL to capture agricultural diversity, and which is important to adapt or contextualize the sampling scheme.

Furthermore, socioeconomic characteristics of the farms and surveyed households were collected during Step 1 data collection using the same methodological frame.

A.3. Data analysis

The analysis of the favourable and unfavourable environment for agroecological transition focused on identifying public policies at both local and national levels, as well as the range of actors and institutions that can either support or constrain agroecological change. Particular attention was given to elements of the local economy and to power relations among actors, as these shape access to resources, decision-making processes, and market opportunities for local producers.

Within this framework, the STEP 0 analysis aimed to characterise the broader institutional, socio-economic, environmental and market conditions shaping agroecological transitions

across the eight CANALLS Agroecology Living Labs (ALLs). STEP 0 drew on multiple sources of evidence, including policy and strategy documents, key informant interviews, AKIS mapping exercises, value chain assessments and landscape-level data. Given this diversity of sources, the analytical approach combined qualitative and semi-quantitative methods in order to produce a coherent and context-specific territorial diagnosis.
The analysis of policies and institutions, AKIS and governance arrangements, markets and value chains, environmental and landscape conditions, and cross-country comparisons was conducted through thematic content analysis, actor mapping and comparative synthesis. National development strategies, sectoral policies and regulatory frameworks were systematically reviewed alongside interview transcripts with policymakers, public institutions and implementing agencies. Coding procedures focused on distinguishing enabling versus constraining policy measures, identifying institutional gaps, overlaps and coordination failures, and assessing the degree of alignment between national frameworks and core agroecological principles.
Interview data and institutional inventories were further used to assess the coverage, accessibility and coordination of advisory and extension services, the influence and connectivity of key actors within Agricultural Knowledge and Innovation Systems (AKIS), and critical bottlenecks in knowledge flows and innovation support. In parallel, interviews with traders, processors and consumers were triangulated with desk-based market analysis to identify constraints limiting market participation, opportunities for value addition, and existing or potential incentives for agroecological products.
Finally, comparative outputs were synthesised and presented through structured tables, typology grids, allowing for systematic interpretation of STEP 1 (CAET results) and even, STEP 2 (performance outcomes).

Farm typologies were identified using hierarchical cluster analysis based on standardized socio-economic variables collected at farm/households level during the survey. Euclidean distance and Ward's linkage method were applied. The optimal number of clusters was determined using dendrogram inspection and confirmed by within-cluster variance. Clusters were then characterized and validated using descriptive statistics and significance tests. Data were standardized before the analysis because variables are on different scales by using equation 1 to ensure that variable farm size does not dominate the classification.

$Z = \frac{X - \bar{X}}{SD}$ where X = observed value, $\bar{X}$= mean of the variable and SD = standard deviation

Eq1. Data standardization formula

B. STEP 1. Characterization of Agroecological Transition (CAET)

B.1. Sampling size and strategy

The sampling strategy for the baseline study was designed to ensure representativeness across the eight Agroecological Living Labs (ALLs) while remaining consistent with FAO recommendations and project resource constraints. Two complementary rationales guided the definition of the final sample size.

The FAO Tool for Agroecology Performance Evaluation (TAPE) recommends a minimum of 20 households per farm typology to achieve sufficient statistical power and comparability. Within the CANALLS project, three farm typologies were identified per ALL, resulting in a target of 60 households per ALL. With eight ALLs across four countries, this design yielded a total sample size of 480 households. This approach ensured balanced representation across heterogeneous farming systems while remaining feasible within the available budget and logistical capacity.

The chosen sample size also aligns with standard sample size calculations for finite populations. To find a minimum statistical sample size, equation 2 was used.

$$n = \frac{\left(\frac{z^2 * p(1-p)}{e^2}\right)}{1+\left(z^2 * \frac{p(1-p)}{e^2 * N}\right)}$$ ***Eq2.*** *Calculation of sample size*

where:z=1.96 (95% confidence level),p=0.5 (maximum variability assumption),e=0.05 (margin of error of 5%),N=20,000 (number of farmers that are to be targeted by CANALLs activities as described in WP1).

the resulting minimum sample size is approximately 377 households. The adopted sample size of **480 households** therefore exceeds the statistical minimum, providing greater precision and robustness while safeguarding against potential non-response or incomplete data.

Considering the fact that each living lab is heterogeneous landscape and has its typology, we propose to use a one stage sampling scheme to collect data from farms and households within each living lab. At the living lab level, the sampling consists of identifying farms within each component of typology of agricultural system (Table 3).

Table 3. Sample size distribution across the 8 ALLs

Country	ALL	Expert typology	Nr of farmers/HH (Fields)	Total
Burundi	Bujumbura	Type 1	21	63
		Type 2	21	
		Type 3	21	
	Giheta	Type 1	21	61
		Type 2	20	
		Type 3	20	
Cameroon	Ntui	Ehondo	20	62
		Koussé	20	
		Nguila	20	
	Biega	Type 1	20	54
		Type 2	20	
		Type 3	20	
DR Congo	Kabare	Type 1	20	66
		Type 2	20	
		Type 3	20	
	Uvira	Type 1	15	61
		Type 2	15	

		Type 3	15	
		Type 4	15	
		Type 1	20	
	Mambasa	Type 2	20	65
		Type 3	20	
		Type1	20	
Rwanda	Kamonyi	Type2	20	62
		Type3	20	
Total				**494**

B.2. Data collection activities

Structured CAET interviews with farmers per site were conducted. Enumerators followed harmonized TAPE guidelines, translated into local languages (Swahili, Kirundi, Kinyarwanda or French). The characterization of agroecology transition (CAET) was completed through the collection of information by researchers and through a self-assessment of producers.

Each of the 10 AE elements is described by 3 or 4 indexes, with a total number of 36 indexes in the CAET listed in TAPE (Table 4). All CAET indexes contain descriptions on the agroecological practices considered in the assessment (HLPE, 2019; FAO, 2019). The CAET indexes also provide information on the different dimensions of sustainability including environment (e.g. elements of synergies, efficiency, recycling) (FAO, 2019).

Table 4. List of the 36 indicators of the 10 selected agroecology element in TAPE framework

#	Elements of Agroecology	CAET Index
1	Diversity	1. Crops 2. Animals (including fish and insects) 3. Trees (and other perennial crops) 4. Diversity of economic activities
2	Synergies	5. Integration of crops-livestock-aquaculture 6. Soil-plant system management 7. Integration with trees (agroforestry, silvopastoralism, agro-silvopastoralism) 8. Connectivity between agroecosystem elements and the landscape
3	Efficiency	9. Use of external inputs 10. Soil fertility management 11. Management of pests and diseases 12. Productivity and household needs
4	Recycling	13. Recycling of biomass and nutrients 14. Water preservation and conservation 15. Management of seeds and animal genetic resources 16. Renewable energy (use & production)
5	Resilience	17. Stability of production and capacity to withstand disturbances 18. Presence of social mechanisms to reduce vulnerability 19. Environmental resilience and adaptability to climate change 20. Average result of the Diversity element
6	Food Cultures & Traditions	21. Appropriate diet and nutritional awareness 22. Local or traditional identity and awareness (peasant/indigenous) 23. Use of local varieties/breeds and traditional knowledge (peasant and indigenous) for food preparation
7	Co-creation & Knowledge Sharing	24. Social mechanisms for horizontal creation and transfer of knowledge and good practices 25. Access to agroecological knowledge and producers' interest in agroecology 26. Participation of producers in networks and grassroots organizations
8	Human & Social Values	27. Women's empowerment 28. Work (production conditions, social inequalities) 29. Youth emancipation and migration 30. Animal welfare [if applicable]
9	Circular & Solidarity Economy	31. Products and services marketed locally (or through fair trade) 32. Producer networks, relations with consumers and intermediaries 33. Local food system
10	Responsible Governance	34. Producers' empowerment 35. Organizations and associations of producers 36. Producers' participation in the governance of land and natural resources

Source: FAO (2019)

*B.3.*Data cleaning and analysis

Dataset was reviewed for completeness and accuracy. Any missing or inconsistent responses were identified and addressed following the TAPE guidelines (FAO, 2019). Duplicate records were removed, and incorrect data entries were cross-checked with field notes. The cleaned data was analyzed using descriptive statistics to summarize key trends and patterns. The sustainability indicators from the TAPE tool were computed as per the recommended methodology. Statistical software R was used to perform frequency analysis, mean comparisons, and correlation tests where applicable. The results were then interpreted to assess the sustainability performance of the surveyed farms.

Data analysis of STEP 1 consisted of displaying results on a radar chart (also known as a spider chart). These charts help to assess how well an agroecological system is performing based on multiple factors (environmental, economic, and social dimensions). The interpretation is shown is in the annex section (Annex 3).

C. STEP 2. Performance Assessment of Agroecology

C.1. Data collection

Data collection for STEP 2 (assessment of the performance of agroecology) was conducted after the completion of the CAET (STEP 1)**,** using the same sampling scheme described in Table 3 to ensure consistency and comparability across steps. This sequential approach allowed performance outcomes to be interpreted in direct relation to the level of agroecological transition previously assessed.

The STEP 2 survey combined multiple data collection modalities. Part of the data was collected through household-level interviews, with specific modules administered to women to capture indicators related to women's empowerment**.** In addition, several variables were collected in a sex-disaggregated manner, including land tenure arrangements, dietary diversity, and youth employment, to capture intra-household dynamics and social equity dimensions of agroecological performance. Complementary information was collected through transect walks across farms and their surrounding landscapes**,** with a particular focus on agrobiodiversity and environmental conditions. These transect observations also served as a verification tool, helping to cross-check and validate self-reported survey data on issues such as exposure to pesticides, land tenure arrangements, and indicators of soil health. Quantitative farm surveys captured a wide range of performance indicators, including agricultural yields, production costs, labour use and farm income; household food security and dietary diversity; on-farm biodiversity, including species counts and agroforestry inventories; resilience-related indicators, such as exposure to pesticides and coping strategies. In addition, biophysical measurements were conducted, notably soil physical analyses, to complete survey data with objective indicators of environmental performance. The assessment is structured around ten core performance criteria**,** which capture economic, environmental and social dimensions, as well as health, nutrition and governance aspects (Table 5), in line with the FAO TAPE framework.

Table 5. Performance of selected criteria in 5 dimensions of sustainability

Dimensions	Criteria	Assessment method	Thresholds
1.Governance	1. Secure land tenure	Existence of: legal recognition of access to land, formal document with name on it, right to sell, bequeath, and inherit land Perception of security of access to land	Green: Has a formal document with the name of the holder on it AND has perception of secure access to land AND has at least one right to sell/bequeath/inherit any of the parcel of the holding; Yellow: Has a formal document with the name of the holder on it AND perception of insecure access to land AND/OR no right to sell/bequeath/inherit the land OR Has a formal document even if the name of the holder is not on it OR has no document but has perception of secure land AND has at least one right to sell/ bequeath/inherit the land; Red: No document possessed AND perception of insecure access to land AND/OR no right to sell/bequeath/inherit the land.
2.Economy	2. Productivity	Farm output value per hectare Farm output value per person	Green: Productivity value per ha is ≥ 2/3 of the national average value of production per hectare/ year; Green: Productivity value per person is ≥ 2/3 of the national average value of production per person; Yellow: Productivity value per ha is ≥ 1/3 and < 2/3 of the national average value of production per hectare/year; Yellow: Productivity value per person is ≥ 1/3 and < 2/3 of the national average value of production per person; Red: Productivity value per ha is < 1/3 of the national average value of production per hectare/ year; Red: Productivity value per person is < 1/3 of the national average value of production per person.
	3. Agricultural income	Outputs – inputs – operating expenses – depreciation + others incomes	**Green:** Perception that income is increasing AND > average income in the region **Yellow :**Perception that income is stable AND = average income in the region **Red:** Perception that income is decreasing OR < average income in the region

	4. Added value	Net income + rent + taxes + interests – subsidies	Green: Gross added value/family worker > 1.2 x median gross added value in similar agroecosystem (e.g. from farm monitoring systems) OR (if not available) > 1.2 x national agricultural GDP per agricultural worker (FAOSTAT); Yellow: Gross added value/family worker < 1.2 x median gross added value in similar agroecosystem (e.g. from farm monitoring systems) AND > 0.8 x median gross added value in similar agroecosystem OR (if not available) < 1.2 x national agricultural GDP per agricultural worker (FAOSTAT) AND > 0.8 x national agricultural GDP per agricultural worker (FAOSTAT); Red: Gross added value/family worker < 0.8 x median gross added value in similar agroecosystem (e.g. from farm monitoring systems) OR (if not available) < 0.8 x national agricultural GDP per agricultural worker (FAOSTAT).
3.Health and Nutrition	5. Exposure to pesticides	Quantity applied, area, toxicity and existence of risk mitigation equipment and practices	Green: Quantity of organic pesticides used ≥ Quantity of synthetic pesticides used AND pesticides of class I and II (highly and moderately toxic) are not used AND at least 4 of the listed mitigation techniques are used when applying chemical pesticides; OR Chemical pesticides are not used AND organic pesticides AND/OR other integrated techniques for pest management are used; Yellow: Quantity of synthetic pesticides used > quantity of organic pesticides used AND producers do not use pesticides of class I (Highly toxic) AND at least 4 of the listed mitigation techniques are used when applying the chemicals AND organic pesticides and/or other integrated techniques are also used; Red: Producers use highly hazardous pesticides (Class I) and/or illegal pesticides OR producers use pesticides of class II and/or III (Moderately toxic and Slightly or relatively non- toxic) with less than 4 of the listed mitigation techniques OR producers use chemical pesticides of any class AND no organic pesticides and no other integrated techniques are used.
	6. Dietary diversity	Minimum Dietary Diversity for Women: from 10 food groups consumed over the preceding 24 hours	Green: MDD score ≥ 7 Yellow: 5 ≥ MDD score < 7 Red: MDD score < 5

4. Society and Culture	7. Women's empowerment	Abbreviated Women's Empowerment in Agriculture Index (A-WEAI): productive decisions, access to land decision making about productive resources, control over use of income, leadership in the community and time use	Green: A-WEAI ≥80%; Yellow: A-WEAI ≥60% and <60%; Red: A-WEAI <60%.
	8. Youth emancipation	Access to jobs, training, education, emigration and access to opportunities	Green: Score ≥70%; Yellow: Score ≥50% and <50%; Red: Score <50%.
5. Environment	9. Agrobiodiversity	Relative importance of crops varieties, livestock breed, trees and semi-natural environments on farm, including beekeeping, area for natural vegetation and presence of pollinators	Green: Average score is ≥70%; Yellow: Average score is ≥50% and <50%; Red: Average score is <50%.
	10. Soil health	Adapted SOCLA. Rapid and farmer friendly agroecological method to assess soil health: soil structure, compaction, depth, residues status, color and organic matters, cover, erosion, invertebrates and microbial activity	Green: Average score is ≥3.5; Yellow: Average score is ≥2.5 and <2.5; Red: Average score is <2.5.

Source: FAO (2019)

C.2. Data analysis

The steps 2 that determines performance of agroecology was assessed using the "traffic light" approach, in which three sustainability levels are considered for each sub-indicator: **Green: desirable; Yellow: acceptable and Red: unsustainable.**

This approach allows identification, for each theme, of conditions of critical unsustainability (red), conditions that can be considered desirable (green) and, in between, intermediate conditions that are considered acceptable but would need to improve (yellow).

D. STEP 3. Validation and Multi-Actor Synthesis of Agroecological Data

D.1. Preparatory Phase

Before the territorial and multi-actor synthesis could take place, each Agroecological Living Lab (ALL) engaged in a preparatory phase designed to ensure clarity, accessibility, and inclusiveness. During this stage, summary results of Step 0 (context analysis), Step 1 (CAET characterization), and Step 2 (performance assessment) were carefully prepared, formatted into simple, farmer-friendly visuals (traffic-light scoring systems, radar diagrams, and bar charts) to facilitate understanding. The intention was to make complex data interpretable by diverse stakeholders. A two to three-page synthesis was produced for each ALL and served as the discussion document during the validation sessions. To guarantee full comprehension, materials were either translated or orally explained in locally used languages such as Kirundi, Kinyarwanda, Swahili, and French. The Catholic University of Bukavu (UCB) team prepared the initial drafts in English, while partners involved in each ALL played a crucial role in contextual translation and facilitation, ensuring that farmers and community representatives could actively engage with the content.

D.2. Sampling & Stakeholder Composition

The validation workshops were designed to be participatory and representative, involving a minimum of 40 stakeholders per Agroecological Living Lab (ALL). The sampling followed the same scheme described in Table 2, with increased emphasis on inclusivity and balance. Priority was given to households that had participated in the data collection process to ensure continuity and ownership of results.

Farmers constituted at least 60% of participants (approximately 24 individuals per ALL). The remaining 40% comprised other key territorial actors, including farmer organizations and cooperatives (20%, about 8 participants), local NGOs, extension agents, local authorities, and policymakers (10%, approximately 4 participants), as well as researchers and technical or project staff (10%, approximately 4 participants). This multi-actor composition ensured that the validation process captured diverse perspectives across the agroecological system, including producers, service providers, private-sector actors, researchers, and public authorities. Bringing together these groups created an inclusive space for dialogue, enabling collective validation and synthesis of results that reflect the realities of multiple stakeholders engaged in agroecological transitions.

D.3. Validation workshop

A validation workshop was conducted in each ALL, generally lasting one full day, though in the case of DRC, two days were required due to security reasons. These workshops were structured to maximize community participation and ownership of the results. A variety of participatory tools were employed, including SWOT cards, prioritization matrices, coloured voting stickers, and flipcharts, which encouraged active dialogue and collective decision-making.

The workshop unfolded in two main sessions. Session 1 focused on presenting the results of Step 1 and Step 2, followed by small-group validation exercises. To avoid influence of male gender or elder view, these groups were sometimes separated by gender or age weh discussing aspect linked to women or youth to ensure that different perspectives were voiced. Participants discussed whether the presented results accurately reflected local realities, identified missing or underestimated aspects, and proposed adjustments directly on the result posters.

The Session 2 moved into a deeper collective analysis of the results. In plenary discussions, participants identified strengths, weaknesses, synergies (such as biodiversity–resilience interactions), and trade-offs (for example, income gains versus biodiversity losses). This stage also contextualized the results using Step 0 findings, examining how enabling or limiting conditions (such as market access, land tenure, climate variability, or cultural norms) shaped agroecological performance. Each group then formulated priority actions related to training needs, service provision, policy support, collective initiatives, or market organization (Annex 2). These proposed actions were consolidated and subjected to community voting, which identified the top three to five priorities. Workshops concluded with a summary of validated results, agreed-upon priorities, and the establishment of follow-up mechanisms such as community committees or farmer groups to ensure continuity and accountability.

D.4. Analytical Procedures

To develop comparative tables across the eight ALLs, a unified analytical approach was applied, combining systematic document review, comparative case study analysis, and qualitative thematic synthesis. The objective was not only to extract information from individual TAPE Step 3 validation reports, but also to organize it within a coherent analytical framework capable of capturing both site-specific dynamics and cross-cutting patterns of agroecological transition at regional level. The analysis was based on an in-depth review of the Step 3 validation reports from the 8 ALLs, each of which contains structured evidence covering the Step 1 CAET indicators related to the ten elements of agroecology, Step 2 performance criteria across the five sustainability dimensions, Step 0 contextual factors, including enabling and constraining conditions and the participatory SWOT analyses and action-planning outcomes. Relevant information was extracted from each report to ensure that data from all Living Labs were captured in a standardized and comparable format.

Given the heterogeneity of reporting formats and levels of details across sites, the extracted information was normalized using a common analytical matrix. Qualitative narratives and quantitative values were harmonized into shared categorical levels (for example, narrative assessments such as “weak recycling” and numerical values such as “40% recycling” were both classified under a common category of "low recycling"). Terminology was aligned across ALLs to ensure consistency, with equivalent expressions (e.g. "strong efficiency" and "100% efficiency") treated as comparable categories. Throughout this process, a clear distinction was maintained between expert-based assessments and results derived from participatory validation or statistically supported typologies emerging from farmer workshops.

The normalized data were then organized into comparative matrices, with ALLs represented as rows and agroecological elements or performance dimensions as columns. This structure enabled systematic cross-case comparison and facilitated the identification of strengths, weaknesses, and vulnerabilities across sites, as well as recurring patterns such as high diversity, low recycling performance, or fragile resilience. Following a classical comparative case study logic, the analysis emphasized both convergence and divergence among ALLs. A final analytical step involved comparing expert assessments with farmer-validated results obtained during participatory workshops, revealing, in several cases, notable discrepancies that were documented and discussed as part of the validation process. In parallel, SWOT analyses from each Living Lab were subjected to thematic coding. Strengths and opportunities were grouped as enabling factors while weaknesses and threats were classified as barriers (e.g. insecurity, weak recycling systems, poor infrastructure, climate change, youth migration, and gender-based land tenure constraints). This thematic synthesis enabled qualitative evidence to be compared systematically across sites. Finally, findings were synthesized across all Living Labs to identify regional trends in agroecological transition.

2.5. Evaluation of the TAPE Framework During Implementation

Beyond its use as the primary instrument for baseline data collection, the Tool for Agroecology Performance Evaluation (TAPE) was systematically assessed throughout its implementation. The CANALLS project explicitly integrated a methodological evaluation of TAPE into its research design, with the dual objective of generating baseline evidence on agroecological transition and critically examining the performance of the framework when applied across diverse multi-country contexts.

The evaluation of TAPE was fully integrated into the methodological architecture of this research. Each data collection activity simultaneously served two purposes: generating baseline evidence on agroecological transition and testing the robustness of the framework itself. Lessons learned during implementation (such as the need for simplified descriptors, context-sensitive thresholds, or strengthened facilitation protocols) were treated as methodological outputs and systematically synthesized to inform recommendations for refining the framework in future monitoring cycles.

2.5.1.Embedded evaluation approach

The evaluation of TAPE was conducted through an embedded, process-oriented approach rather than as a stand-alone assessment. Each of the four steps of the TAPE framework—contextual characterization, Core Agroecological Elements of Transition (CAET), performance evaluation, and territorial synthesis—was implemented in the eight Agroecological Living Labs (ALLs) with the explicit intention of observing their operational feasibility, clarity of guidance, and adaptability to contrasting agroecological, socio-economic, and institutional settings.

Throughout implementation, research teams documented how prescribed procedures and indicators functioned in practice, including challenges encountered, adjustments made, and conditions under which the framework proved more or less effective. This real-time observation allowed the evaluation to be grounded in actual field use rather than post hoc reflection.

2.5.2.Documentation of adaptations

Any deviation from the original FAO TAPE protocol was systematically recorded as part of the methodological process. These adaptations included, among others, the organization of additional participatory workshops, the integration of locally relevant farm typologies, translation of tools into local languages, and the digitalization of questionnaires to improve data quality and efficiency. The rationale, scope, and implications of each adaptation were documented to assess whether such modifications enhanced or compromised the coherence and comparability of the framework.

2.5.3.Evaluation criteria

The performance of TAPE was assessed against three interrelated criteria:

1.Applicability: the extent to which TAPE steps, indicators, and scoring procedures could be operationalized across heterogeneous agroecological and socio-economic contexts without excessive methodological distortion.

2.Comprehensiveness: the degree to which the framework adequately captured the multidimensional nature of agroecological transition, including environmental, social, economic, and governance dimensions.

3.Practicality: the usability of tools, descriptors, and traffic-light thresholds by enumerators, farmers, and stakeholders under real field conditions, including time requirements, clarity of concepts, and facilitation needs.

2.5.4.Participatory validation and feedback

Stakeholder feedback constituted a central component of the evaluation process. Farmers, producer organizations, extension agents, researchers, and local policymakers were engaged through validation workshops, focus group discussions, and semi-structured interviews. These interactions were used to assess the perceived relevance, clarity, and legitimacy of TAPE indicators, scoring thresholds, and composite indices. Particular attention was paid to identifying elements that were difficult to interpret, culturally misaligned, or insufficiently sensitive to local realities.

2.6. Data Quality Assurance and Ethical Considerations

To ensure full adherence to the TAPE protocol, a comprehensive quality-assurance system was implemented throughout data collection. Enumerators participated in standardized TAPE

training coordinated by UCB and CIRAD, ensuring consistent understanding of concepts, scoring procedures, and field protocols. The data-collection tools were pilot-tested in the Kabare Living Lab to verify clarity, feasibility, and contextual relevance. Translation procedures were applied to guarantee conceptual equivalence across languages, with partner institutions responsible for validating terminology and meaning. Field supervisors conducted systematic spot checks and back checks to verify accuracy and consistency. All datasets underwent centralized cleaning following a structured quality-control workflow.
All TAPE-related data collection complied with CANALLS ethical requirements, including: i. informed consent, 2. voluntary participation, and, 3.confidentiality and secure data storage and, 4.sensitivity to gender, youth, and vulnerable groups. These measures ensured methodological rigor, participant protection, and alignment with international standards for responsible research involving human participants.

2.6. Methodological limits and biases

The literature review (WP2.2) and the participatory discussions conducted during Step 3 brought to light a range of methodological challenges and limitations associated with the application of the TAPE framework. Agroecology remains a relatively unfamiliar concept for large segments of the target population, which affected both comprehension and engagement. In some cases, survey questions were not fully adapted to local languages or cultural references, making them difficult to explain clearly and consistently. This occasionally led to ambiguities in responses and interpretation.

The economic dimension was particularly constrained by the lack of recent, reliable primary data on crop productivity and household income in several Living Labs in the Democratic Republic of Congo, necessitating reliance on secondary sources. Similarly, the indicator on youth employment and migration was weakened by insufficient data on young people's working hours, their actual involvement in agricultural activities, and the socio-economic drivers of migration. Step 3 validation workshops were conducted several months after data collection due to staheholders diverse agendas and episodes of socio-political instability, which may have affected recall and continuity. Furthermore, variations in facilitation quality across countries and among enumerators influenced both the depth of dialogue and the consistency of scoring. Differences in language, translation choices, and cultural interpretation also shaped how agroecological concepts were understood and discussed. Finally, the inherently transdisciplinary nature of TAPE requires strong coordination across disciplines and institutions—an aspect that remains uneven in multi-country implementation settings.

Despite its strengths, the participatory and transdisciplinary approach also introduces potential biases. Power relations within communities may limit the participation of women, youth, or marginalized groups, underscoring the need for careful facilitation and inclusive engagement strategies.

Chapter 3. RESULTS OVERVIEW

3.1. Description of the context and production systems across the living lab

3.1.1. Living Lab Profiles

Table 6 summarize the conditions context of the 8 ALLs. These profiles from desk study give the contextual analysis and provide an integrated foundation for interpreting the CAET results (STEP 1), performance assessments (STEP 2) and better understand multi-actor validation and use of results (STEP 3). Each ALL profile combines enabling and constraining factors, the structure of agricultural Knowledge and Innovation System (AKIS), policy–practice alignment, market readiness and landscape vulnerability linked to agroecological potential.

Table 6. STEP 0 Contextual analysis

ALLs	Context & Farming Systems	Enabling & Constraining Factors	AKIS Structure & Gaps	Policy–Practice Alignment	Market Readiness	Landscape vulnerability and Agroecological potential
			Cameroon			
Ntui	Forest–savannah transition; cocoa agroforestry & food crops	Indigenous knowledge, crop diversity; constraints: low agroecology awareness, land inequality, climate variability	Research present but low farmer awareness; weak advisory reach	Low alignment; agroecology weakly reflected in national policy	Low–medium; storage & processing gaps	High vulnerability; medium–high potential
			Burundi			
Bujumbura	Maize-based systems with livestock and diversified crops	Recycling, composting, training; constraints: subsidy bias, soil degradation, weak disease management	Extension exists but focuses on conventional inputs; partial agroecology knowledge	Partial misalignment: diversification supported but input reduction discouraged	Medium; urban demand but weak product differentiation	Medium–high vulnerability; high agroecological potential
Giheta	Coffee-based highland system with banana & cassava	Strong cooperatives, coffee husk recycling; constraints: gender exclusion, limited pest management	Cooperatives as advisory hubs; limited technical agroecology training	Policies support coffee exports but do not reward agroecological quality	Medium; cooperative access but limited premium markets	Medium vulnerability; high agroecological potential
			DR Congo			
Biega	Highland agroecological zone with coffee, beans, maize, cassava, vegetables; Batwa & Bantu coexistence	Fertile volcanic soils, agroforestry, composting; constraints: land tenure insecurity, weak extension, poor roads, climate variability	Strong research presence but weak farmer transmission; NGOs as intermediaries; weak feedback loops; limited integration of indigenous knowledge	Policies support agroecology but subsidies and weak enforcement create partial misalignment	Low–medium; regional markets exist but limited by roads, storage, and lack of quality differentiation	High vulnerability but very high agroecological potential due to altitude, biodiversity, agroforestry
Kabare	Highland coffee systems with beans, maize, cassava, vegetables; proximity to Bukavu	Agroecological traditions, strong farmer organisations; constraints: land inequality, climate variability, pests, weak mechanisation	Research & NGOs present; uneven extension; strong farmer-to-farmer learning but weak formal advisory resources	Moderate alignment; policies recognise agroecology but incentives insufficient	Medium; supported by cross-border trade but limited by standards & infrastructure	High vulnerability; very high agroecological potential

Mambasa	Humid lowland forest zone; cassava, maize, rice, cocoa agroforestry; insecurity	Fertile soils, rainfall; constraints: insecurity, no primary extension, poor markets, post-harvest losses	Fragmented AKIS dominated by NGOs/humanitarian actors; weak coordination; no farmer–research feedback	Agroecological orientations exist but implementation minimal due to insecurity	Low; informal markets, weak aggregation, poor infrastructure	Very high vulnerability; high potential if stability and advisory systems improve
Uvira	Lowland rice–cassava systems with maize & beans; agriculture employs 65%	Irrigation potential, willingness to reduce chemicals; constraints: floods, droughts, land inequality, gender constraints, limited finance	Weak extension; sporadic NGO presence; minimal research linkage	Policy support exists but poorly translated locally	Low–medium; constrained by infrastructure and price volatility	Very high vulnerability; medium–high potential with water-smart practices
			Rwanda			
Kamonyi	Densely populated cassava-based systems with diversified crops	High agroecology awareness, gender equity, strong extension; constraints: climate extremes, price volatility	Strong AKIS with farmer promoters & public extension	Strong alignment between soil health policies and farmer practices	Medium–high; limited by processing & storage capacity	Medium vulnerability; high agroecological potential

AKIS: Agricultural Knowledge and Innovation System

These results reveals high agroecological potential across all Living Labs driven by: i) existing agroforestry systems (Biega, Kabare, Giheta, Ntui) and , 2) strong recycling practices (Burundi, Rwanda), high farmer willingness to reduce external inputs (Table 6) . This confirms that agroecology is not an external imposition, but builds on existing practices. Hovever, the high potential contrast with persistent structural vulnerabilities to biophysical, socio-economic and institutional conditions exacerbated by climate perturbation that exposed lowlands and conflict affected zones suggesting that transition constraints may be structural rather than technical. AKIS is the weakest systemic dimension. In general, across the ALLs research and NGOs are present but extension coverage is weak or uneven, farmer–research feedback loops are limited, indigenous knowledge is insufficiently formalized. Knowledge circulation, not knowledge availability, is the main bottleneck. Partial policy practice alignment is observed. Even where agroecology is recognized policy and practice misalignment is recurrent: fertilizer subsidies, export-oriented policies, weak local enforcement, undermine input reduction and diversification. Farmers often practice more agroecology than policies reward. Markets lag behind production systems. Market readiness is mostly low to medium, limited by: poor infrastructure, lack of quality differentiation, absence of price premiums. This show that Economic performance cannot be interpreted independently from market failures.

3.1.2. Agroecological, socio-economic, and institutional characteristics of HH and farms

Household Composition

Households across the eight Living Labs are generally large and characterized by high dependency ratios. The average number of children per household is 2.5, with marked inter-site variation. Uvira records the highest average (4.18 children per household), followed by Biega (3.07), while Kamonyi reports significantly lower values (1.41) ($F = 9.8$, $p < 0.001$) (Table 7). The number of resident adult men varies significantly, ranging from 0.61 in Giheta to 2.38 in Uvira ($F = 6.9$, $p < 0.001$). In contrast, resident adult women show less variation across sites, fluctuating between 0.75 in Uvira and 1.20 in Kabare, with no statistically significant differences ($p > 0.05$).

Youth presence is substantial in several Living Labs. Young males peak at 2.03 per household in Bunia, while young females reached 1.45 in the same site. These figures contrast sharply with Bujumbura, where both young male and female averages remain below 0.7 ($F = 4.8$, $p < 0.01$; $F = 3.9$, $p < 0.01$).

Overall, households are dominated by children and youth, supported by relatively small adult cores (Table 7). This demographic configuration implies strong medium-term labour potential but also considerable short-term consumption pressure. Within the TAPE framework, this helps explain why relatively high agroecological engagement observed in STEP 1 does not always translate into immediate economic gains under STEP 2, particularly in high-vulnerability contexts such as eastern DRC.

Table 7. socio economic characteristics of surveyed households across the ALLs

Parameters	BIEGA	BUJUMBURA	BUNIA	GIHETA	KABARE	KAMONYI	NTUI	UVIRA	F/KW Test	Pvalue
Household members (number)										
Men	0,80	0,67	1,23	0,61	1,17	0,92	1,85	2,38	6.9	<0.001
Women	0,93	0,78	1,12	0,77	1,20	1,03	0,94	0,75	1.4	>0.05
Young male	1,50	0,92	2,03	1,23	1,32	0,87	1,31	1,30	4,8	<0,01
Young female	1,35	0,68	1,45	1,33	1,03	0,86	1,16	1,18	3,9	<0,01
Children	3,07	2,54	2,02	2,02	2,42	1,41	2,48	4,18	9.8	<0.001
No family member living with HH (number)										
Man>18	0,31	0,35	1,72	0,10	0,19	0,65	1,02	0,32	31	<0,001
Woman>18	0,26	0,40	1,26	0,20	0,19	0,67	0,35	0,36	24	<0,01
Boy<18	0,78	0,56	0,78	0,15	0,67	0,56	0,52	0,66	19	<0,05
Girl<18	0,96	0,41	0,70	0,33	0,72	0,52	0,37	0,98	21	<0,01
People work in the agricultural production of the system assessed (number)										
Men	0,95	0,74	1,16	0,86	1,17	0,90	1,13	0,94	3,6	<0,01
Women	0,98	0,81	0,94	0,89	1,00	1,01	0,93	1,02	–	>0,05
Young male	1,11	0,91	1,37	0,53	1,35	1,03	1,19	1,00	4,1	<0,01
Young female	1,12	0,71	1,02	0,76	1,26	0,79	0,69	0,85	3,3	<0,05
Children	0,38	0,93	0,59	0,15	0,64	0,09	0,98	0,31	28	<0,001
Exteranal workers	0,85	0,83	0,62	0,50	0,88	0,83	0,89	0,98	–	>0,05
TOTAL people engaged in activities	4,28	3,59	4,94	2,52	4,86	3,43	4,56	4,03	8.6	<0,001
Area (in Ha) under										
Agriculture	29020,03	0,86	3,88	1,91	5012,80	1,48	3,56	5333,13	$\chi^2 \approx 47$	<0,001
Permanent pasture	9635,59	0,02	0,98	0,27	1103,90	0,49	0,02	1662,80	39	<0,001
Nautural vegatation	9900,98	0,10	2,72	0,21	664,27	0,35	1,88	6,81	42	<0,001

HH = household, F = fisher

Household Mobility

Significant differences emerge with respect to non-resident household members, reflecting diverse mobility and livelihood strategies. Absent adult men are particularly numerous in Bunia (1.72 per household) and Ntui (1.02), compared to fewer than 0.2 in Kabare and Giheta ($F = 31, p < 0.001$). Absent adult women are also more prevalent in Bunia (1.26) and Kamonyi (0.67) ($F = 24, p < 0.01$).

Children's mobility is notable, with more than 0.9 girls per household absent in Biega and Uvira ($F = 21, p < 0.01$). These patterns likely reflect seasonal migration, insecurity, schooling, or livelihood diversification strategies. While external mobility may serve as an important coping mechanism in fragile contexts, it can simultaneously reduce on-farm labour availability and weaken intergenerational knowledge transmission.

From a TAPE perspective, such mobility patterns help explain uneven CAET scores, particularly for labour-intensive practices and governance-related dimensions. These dynamics must therefore be explicitly considered during STEP 3 validation, as lower adoption levels may reflect labour constraints rather than limited interest or commitment to agroecological practices.

Agricultural Labour Availability

Labour availability for agricultural activities differs significantly across Living Labs (Table 7). Total agricultural labour averages 4.28 persons per household in Biega, 4.94 in Bunia, and 4.86 in Kabare, compared to only 2.52 in Giheta ($F = 8.6, p < 0.001$).

Gender participation is relatively balanced, with women consistently contributing around one agricultural worker per household across all sites, and no significant differences observed ($p > 0.05$). Youth labour plays a particularly important role in Bunia (1.37 young men and 1.02 young women) and Kabare (1.35 young men and 1.26 young women) ($F = 4.1, p < 0.01$; $F = 3.3, p < 0.05$).

Children's involvement in agricultural activities is highly variable, ranging from 0.98 per household in Ntui to only 0.09 in Kamonyi ($F = 28, p < 0.001$). The use of external labour remains moderate overall, with the highest values observed in Uvira (0.98) and Kabare (0.88), although differences are not statistically significant ($p > 0.05$) (Table7).

These findings confirm that agroecological transition across the Living Labs is primarily family-based and labour-intensive, relying heavily on women and youth. This structural configuration supports relatively high CAET scores in diversification and recycling (STEP 1), but also helps explain why productivity gains and economic performance (STEP 2) remain modest in contexts where labour is constrained or highly variable.

Land-Use Patterns

Land endowment varies sharply across Living Labs (Table 7). Aggregated agricultural land reaches 29,020 ha in Biega and 5,333 ha in Uvira, while remaining below 2 ha in Giheta, Kamonyi, and Bujumbura ($\chi^2 \approx 47$, $p < 0.001$).

Permanent pasture is highly concentrated in Biega (9,635 ha) and Uvira (1,663 ha), and is almost negligible in Ntui and Bujumbura (less than 0.05 ha) ($\chi^2 = 39$, $p < 0.001$). Natural vegetation follows a similar pattern, with extensive areas recorded in Biega (9,901 ha) and Kabare (664 ha), compared to less than 0.4 ha in the Rwanda and Burundi sites ($\chi^2 = 42$, $p < 0.001$).

These contrasts reflect differing population densities, land pressure, and farming system structures. The presence of extensive natural vegetation in Biega and Kabare indicates strong agroecological potential, particularly for biodiversity-based practices, while also implying constraints related to protected areas or land-use regulations. Smaller landholdings in Rwanda and Burundi are consistent with intensification strategies under conditions of land scarcity.

Diversification and “Other” Outputs

The presence of alternative or “other” outputs (such as beekeeping, compost production, bakery products, or shade-related ecosystem services) varies significantly across sites. This uneven distribution suggests that diversification and innovation niches are highly context-specific, emerging where enabling conditions, knowledge systems, and market access converge, rather than being uniformly distributed across Living Labs.

Table 8. Characterisation of the Agricultural activities across the 8 ALLs

PARAMETERS	BIEGA	BUJUMBURA	BUNIA	GIHETA	KABARE	KAMONYI	NTUI	UVIRA
Crops and crops products								
False	1,9	0,0	6,2	1,6	0,0	0,0	0,0	0,0
True	98,1	100,0	93,8	98,4	100,0	100,0	100,0	100,0
Animals and animal products								
False	9,3	52,4	90,8	41,0	13,6	22,2	72,6	3,3
True	90,7	47,6	9,2	59,0	86,4	77,8	27,4	96,7
Fruit tress								
False	11,1	65,1	84,6	39,3	6,1	50,8	8,1	49,2
True	88,9	34,9	15,4	60,7	93,9	49,2	91,9	50,8
Timber trees								
False	7,4	82,5	95,4	55,7	7,6	63,5	46,8	80,3
True	92,6	17,5	4,6	44,3	92,4	36,5	53,2	19,7
Non timber								
False	77,8	82,5	98,5	96,7	71,2	95,2	41,9	98,4
True	22,2	17,5	1,5	3,3	28,8	4,8	58,1	1,6
Other output								
shade (baobab	0,0	0,0	0,0	0,0	0,0	0,0	1,6	0,0
Beekeeping	1,9	0,0	0,0	0,0	0,0	1,6	0,0	0,0
Bakery	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,6
Unspecifyied	0,0	0,0	0,0	0,0	0,0	1,6	0,0	0,0
Vegetable	0,0	1,6	0,0	0,0	0,0	0,0	0,0	0,0
Waste for compost	0,0	0,0	0,0	0,0	0,0	1,6	0,0	0,0
Total	1,9	1,6	0,0	0,0	0,0	4,8	1,6	1,6
Agricultural production destination								
Sale	1,9	7,9	67,7	0,0	0,0	0,0	4,8	0,0

Mostly sale and a small part of self-consumption	7,4	30,2	27,7	4,9	22,7	31,7	93,5	65,6
Equally sale and self-consumption	18,5	6,3	3,1	4,9	19,7	20,6	1,6	18,0
Mostly self-consumption and a small part of sale	70,4	38,1	1,5	49,2	57,6	44,4	0,0	16,4
Self-consumption	1,9	17,5	0,0	41,0	0,0	3,2	0,0	0,0

Table 8 provides a comparative analysis of production systems, diversification, market orientation, and land use across the eight Agroecological Living Labs (ALLs). These dimensions are fundamental for interpreting the levels of agroecological transition (TAPE Step 1), subsequent performance outcomes (Step 2), and the context-specific pathways discussed in the participatory synthesis (Step 3). Three overarching patterns emerge: i) systems are biophysically diversified yet economically constrained; ii) production is primarily oriented toward food security and resilience over commercialization; iii) market and value chain integration is highly uneven and context-dependent.

Crops and Livestock

Crop production is near-universal (>93% of households), forming the livelihood backbone across all sites. The integration of livestock, however, varies significantly. Strong crop-livestock integration in ALLs like Uvira and Biega supports nutrient recycling and system resilience, whereas crop-dominated systems (e.g., Bunia, Ntui) face limitations in soil fertility management, impacting ecological and economic performance.

Trees and Agroforestry

The adoption of fruit and timber trees is widespread but uneven, reflecting local traditions and agroecological potential. High integration in Kabare, Biega, and Ntui enhances biodiversity and long-term resilience. However, the limited development of Non-Timber Forest Products (NTFPs) indicates weak economic valorization of biodiversity, constraining income diversification.

Other Outputs and Market Orientation

Innovative or value-added activities (e.g., beekeeping, processing) remain marginal (<5% prevalence), highlighting a focus on primary production. Market orientation varies sharply along a subsistence–market continuum. While Bunia and Ntui are strongly market-oriented, production in Giheta, Bujumbura, and Biega is dominated by self-consumption, underscoring agroecology's primary role in food security.

Land-Use Structure

Fundamental differences in land endowment shape transition pathways. Sites like Biega and Kabare feature larger landholdings with extensive natural vegetation, presenting high ecological potential but also degradation risks. In contrast, the land-scarce contexts of Burundi and Rwanda favor labor-intensive intensification. These structural factors critically influence both the characterization of agroecological transition (Step 1) and the interpretation of performance results (Step 2), necessitating tailored, context-specific pathways in Step 3.

3.1.3. Farms typologies across the living labs

Figure 3 presents the results of a Factor Analysis of Mixed Data (FAMD) followed by Hierarchical Clustering on Principal Components (HCPC), conducted to classify farms based on their socio-economic characteristics and agricultural activity profiles across the eight Agroecological Living Labs (ALLs).

Results show the FAMD–HCPC factor map, highlighting three distinct clusters of farms differentiated mainly along the first dimension (Dim 1), which reflects contrasts in socio-economic characteristics and agricultural activity profiles. Cluster 2 (red) groups farms with relatively similar and less diversified profiles, concentrated around negative values of Dim 1, while Cluster 3 (green) includes farms with more diversified and economically differentiated activities, extending towards positive values of Dim 1. Cluster 1 (black), smaller and more distant, represents a marginal group of farms with atypical characteristics, clearly separated from the main clusters. Despite the low variance explained by Dim 1 (2.39%), the clustering reveals meaningful structural differences among farm types across the eight Agroecological Living Labs as synthetized in Table 9.

Figure 3: Farm household typologies identified in the 8 ALLs using FAMD–HCPC.

The FAMD–HCPC analysis identified three distinct farm household types across the CANALLS Agroecological Living Labs (Figure 3 and Table 9). A dominant smallholder subsistence-oriented type was observed across all sites, reflecting widespread land and labour constraints. A second type comprised labour-intensive family farms, particularly over-represented in Bunia, characterized by high involvement of men, women, youth and children in agricultural activities. A third, rare type consisted of large land-endowed farms, observed exclusively in Biega, with substantial agricultural, pasture and natural vegetation areas. Although farm types were significantly associated with ALLs (χ^2 test, $p < 0.001$), typologies largely cut across sites, highlighting strong within-ALL heterogeneity and the need for farm-type-specific agroecological transition pathways.

Table 9. Farm household typology derived from FAMD–HCPC analysis

Farm type	Share	Key characteristics	Dominant ALLs	TAPE relevance
Type 1 Large land-endowed agroecological farms	Rare (n=6)	Very large agricultural, pasture and natural vegetation areas	Biega only	High diversity & landscape potential
Type 2 Smallholder subsistence-oriented farms	Majority	Small land size, limited household labour, low resource base	All ALLs	Priority for transition support
Type 3 Labour-intensive family farming systems	Moderate	Large households, high family labour involvement	Bunia (over-represented)	Strong social capital, labour constraints

While statistical typologies derived from multivariate analyses (e.g., PCA, cluster analysis) provide objective, reproducible groupings based on quantitative data; the expert-based typology (Table 10) captures local knowledge, institutional realities, and ecological diversity. The integration of both approaches is therefore crucial. The classification was developed ex ante by local experts prior to data collection, ensuring that locally relevant production systems, socio-economic conditions, and agroecological practices were adequately represented.
In both Bujumbura and Giheta ALLs, the typology emphasizes commercialization and household food security. Semi-commercial producers coexist with subsistence farmers, with cooperative membership serving as a critical factor for access to inputs, extension services, and markets. In Gihéta, the inclusion of "smallholders" as an intermediate category reflects gradual transitions between subsistence and semi-commercial farming (Table 10).

For Ntui, classification is primarily agro-ecological and biophysical, structured along forest, forest–savannah transition, and savannah zones (Table 10). This zoning underscores the influence of ecological context on production systems and agroecological options, beyond socio-economic differentiation.

In DR Congo ALLs, farms' typologies are highly localized and diverse. In Kabare and Biega, coffee-based systems are classified by coffee tree numbers, land ownership, livestock integration, and agroecological practice intensity (Table 10), reflecting different stages of agroecological transition. In Bunia (Mambasa), cocoa systems are differentiated by farm size, shade management, intercropping, and agroforestry intensity while in Uvira, rice-based systems are defined by farm size and cooperative affiliation, with limited crop rotation linked to land scarcity (Table 10).

In Kamonyi ALL, farm types combine land size with soil health practices, enabling comparisons between farmers with similar resource endowments but different management strategies.

This expert-based typology provides a robust analytical foundation for subsequent TAPE assessments (Steps 1–3). By anchoring the analysis in locally meaningful production realities, it avoids one-size-fits-all classifications and ensures that agroecological transition pathways are interpreted within their territorial specificities.

Table 10: Farm typologies based on expert knowledge

COUNTRY	ALLs	Type	Description
BURUNDI	BUJUMBURA	1	Semi- commercial producer
		2	Subsistence producer affiliated to cooperative
		3	Subsistence producer not affiliated to a maize cooperative
	GIHETA	1	Semi-Commercial Producer
		2	Smallholder
		3	Subsistence Producer not affiliate to cooperative
CAMEROON	NTUI	1	Forest zone
		2	Forest-Savannah transition zone
		3	Savannah zone
DR CONGO	KABARE and BIEGA	1	<200 plants of coffee trees. use agroforestry, mulching, intercropping and manure as AE. They own their fields and have livestock
		2	> 200 coffee trees and are owners of their fields and raise livestock. Low practice of AE such as agroforestry and mulching. However, they intercrop coffee, apply manure and prune coffee trees.
		3	> 200 coffee trees and are owners of their fields and raise livestock. Practice of AE such as agroforestry and mulching. No subsistence crop integration
	BUNIA	1	smallholders' farmers that intercrop cocoa with subsistence and food crops
		2	same as group1 but here producers use palm trees for shade.
		3	Farmers with >> ha (size fields of cocoa). Producers practice agroforestry and often don't intercrop.
	UVIRA	1	smallholder's farmers that practice less crop rotation due to lack of space, they can own or no their fields but they are members of rice cooperatives
		2	Same characteristics as those in group 1 but are not affiliated with cooperatives
		3	farmers that has big size of fields (>1ha), they own their fields and are members of cooperatives
		4	Same characteristics as group3 but are not affiliated with cooperatives
RWANDA	KAMONYI	1	Farmers with < 0.5 ha, not practicing soil health
		2	Farmers with<0.5 Ha, Using soil health practices
		3	Farmers with > 0.5 ha, not practicing soil health
		4	Farmers with > 0.5 ha practicing soil health.

3.2. Characterization of agro-ecological transitions (CAET)

The characterisation of agroecological transitions (CAET) was determined based on the 10 elements of agroecology. Visualization of the results of CAET across the 8 selected ALLs before the intervention of CANALLS project is shown in Figure 4. The same results of CAET are presented using the traffic light colours incorporated to highlight the transition level an ALL has achieved per targeted element (Table 11).

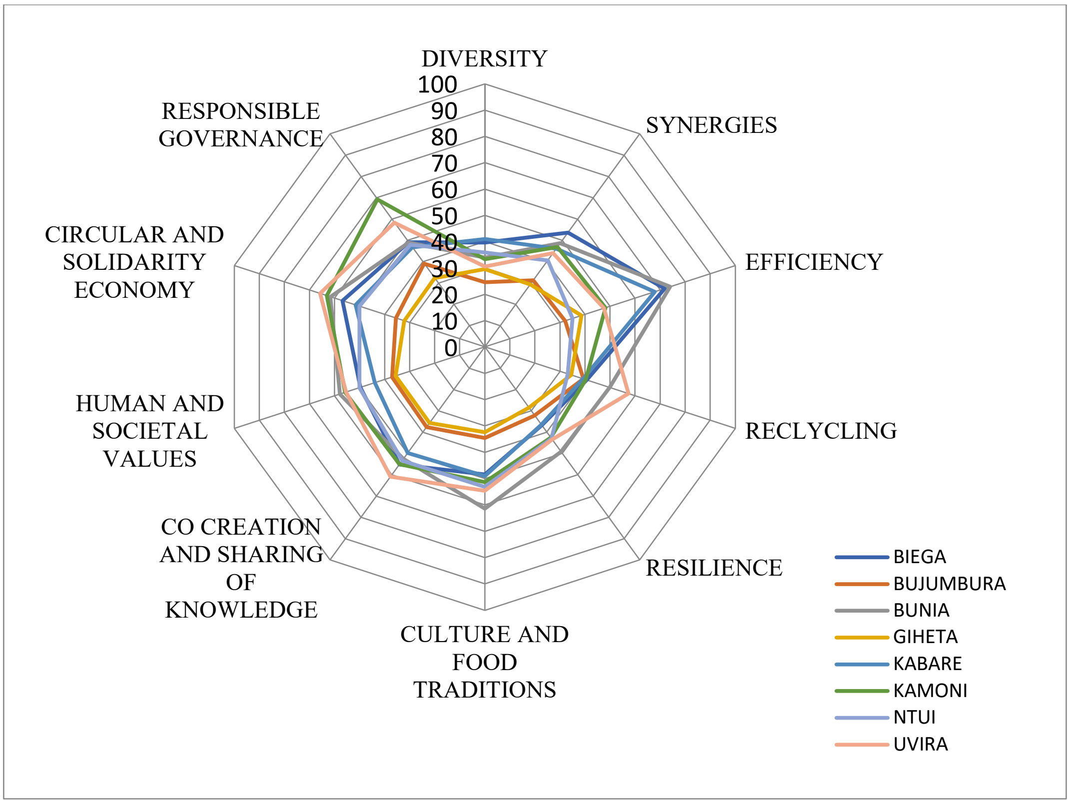


Figure 4. Visualization of the results of the CAET based on the 10 elements of agroecology for the *8 selected ALLs at the beginning of the CANALLS project activities*

Table11. CAET with traffic light colours highlighting the transition level across the ALLs

	Bujumbura	Giheta	Ntui	Biega	Bunia	Kabare	Uvira	Kamonyi	**Mean**
Diversity	24,60	29,61	35,84	39,70	33,94	41,05	30,48	33,28	33.6
Synergies	31,35	29,41	40,68	53,70	48,70	46,12	44,01	46,97	42.6
Efficiency	32,06	38,58	35,03	71,76	73,94	67,80	47,54	48,12	51.9
Recycling	39,31	34,58	33,11	40,68	49,81	39,25	57,33	40,33	41.8
Resilience	32,16	28,48	43,02	36,81	49,21	36,53	43,52	42,58	39.0
Culture and food traditions	34,48	32,31	53,16	48,38	61,35	48,99	54,58	51,26	48.1
Co-creation and sharing of knowledge	37,63	35,66	53,36	55,17	52,56	49,75	60,86	55,09	50.0
Humans and societal values	37,10	35,66	50,10	49,71	57,88	43,89	55,38	55,80	48.2
Circular and solidarity economy	35,48	32,17	50,07	56,87	61,67	51,64	65,78	63,16	52.1
Responsible governance	39,11	32,31	48,05	49,23	49,10	46,78	58,40	69,31	49.0
Mean	34.3	32.9	44.2	50.2	53.8	47.2	51.8	50.6	45.6

Following the CAET scores, it is assumed that scores <50% correspond to non-agroecological systems (such as market-oriented conventional agriculture and subsistence farming), scores between 50-70 % correspond to systems in transition, and scores > 70% correspond to systems that are advanced in terms of agroecology.

The analysis of the ten core agroecological indicators reveals a clear gradient in transition levels and performance across the eight Living Labs. While all regions require targeted support, a distinct pattern emerges as sites in the Democratic Republic of the Congo (notably Uvira, Bunia, Biega, and Kabare) and Kamonyi in Rwanda demonstrate stronger, more systemic progress. In contrast, the Burundian sites of Bujumbura and Giheta are consistently the most vulnerable, lagging across nearly all dimensions (Figure 4 and Table 11).

Overall performance is led by Bunia and Uvira, which show notable strengths in efficiency, socio-cultural values, and circular economy practices. Kamonyi excels particularly in responsible governance. Kabare and Biega also perform adequately in several areas, though they reveal specific challenges such as low resilience. Conversely, Bujumbura and Giheta face compounded challenges, with critically low scores in efficiency, resilience, recycling, and socio-economic governance (Figure 4 and Table 11).

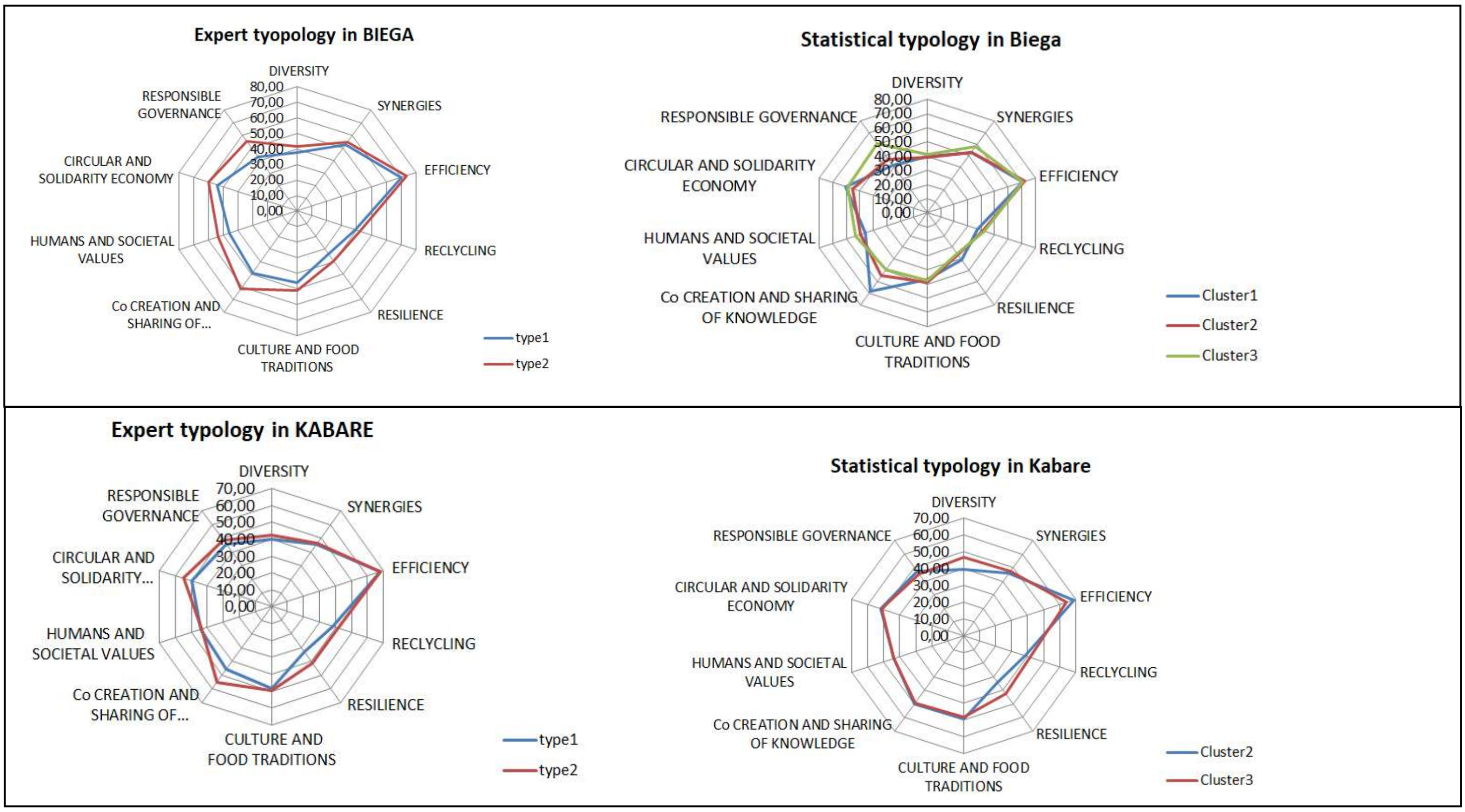
A general weakness across all sites is low diversity (all scores <50), underscoring a fundamental constraint to ecological resilience (Table 11). The significant variation in synergies, recycling, and resilience highlights major differences in system integration and adaptability. Notably, co-creation of knowledge, human values, and circular economy indicators are areas of relative strength for most sites except Bujumbura and Giheta in Burundi, suggesting a solid social pillar for transition.

The composite mean score for each region, which synthesizes all ten indicators, provides the overarching ranking of agroecological performance. These results confirm that effective intervention strategies must be context-specific, moving beyond uniform recommendations to address the distinct structural and socio-ecological bottlenecks identified in each Living Lab.

3.3. Influence of expert typology on CAET

A linkage between farm household typologies with CAET may differentiate agroecological transition pathways. Across the Agroecological Living Labs (ALLs), fig5 results highlight marked heterogeneity in the level and nature of agroecological transition among farms. Some farm typologies consistently appear more advanced than others, reflecting differences in ecological practices, social organization, governance, and cultural integration. These contrasts underline the existence of differentiated transition pathways rather than a single linear trajectory toward agroecology. In Ntui, three distinct farm types illustrate complementary yet uneven transition profiles. Type 1 farms exhibit a relatively balanced agroecological performance, characterized by strong knowledge sharing and co-creation processes, as well as well-developed synergies among system components. This group appears to combine ecological and social dimensions in a relatively integrated manner. Type 2 farms perform particularly well in efficiency, resilience, and the preservation of food culture and traditions, suggesting systems that are well adapted to local contexts and oriented toward stability and cultural continuity. Type 3 farms stand out for their stronger performance in responsible governance and relatively high diversity, comparable to Type 1. However, they show the lowest scores in efficiency and recycling, indicating governance-driven systems that have not yet fully translated institutional strengths into technical and resource-use efficiency.

efficiency.


Expert tyopology in BIEGA
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF...
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
80,00
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
type1
type2
Statistical typology in Biega
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF KNOWLEDGE
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
80,00
70,00
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10,00
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Cluster1
Cluster2
Cluster3
Expert typology in KABARE
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF...
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY...
RESPONSIBLE GOVERNANCE
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type1
type2
Statistical typology in Kabare
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF KNOWLEDGE
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
70,00
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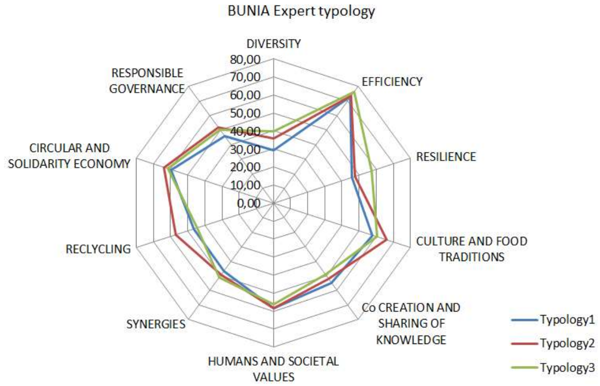
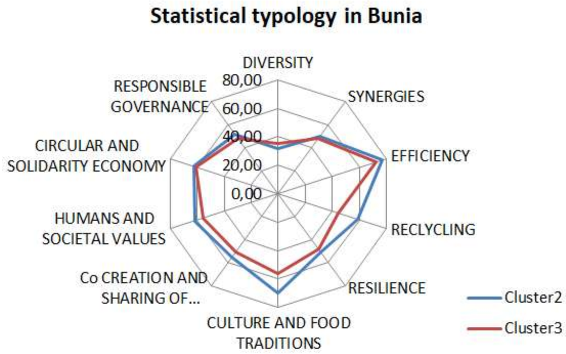
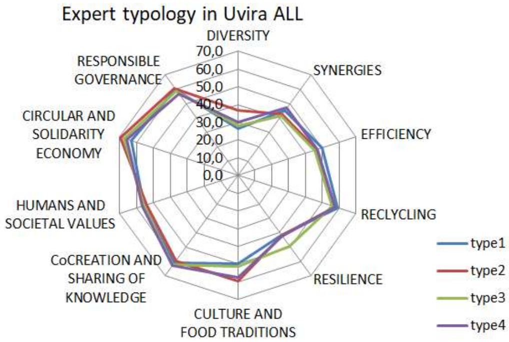
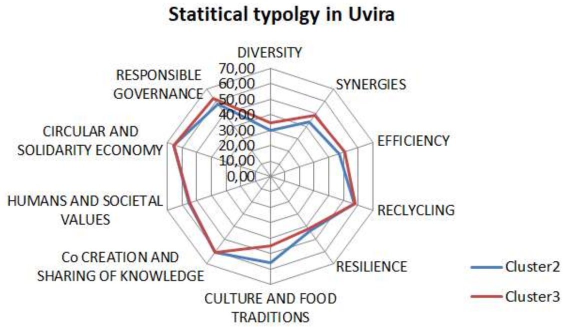
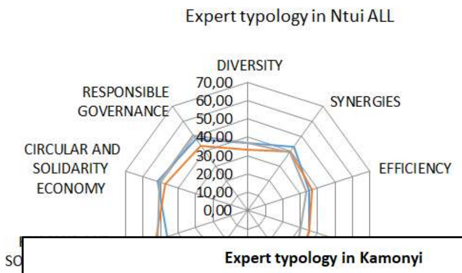
Cluster2
Cluster3

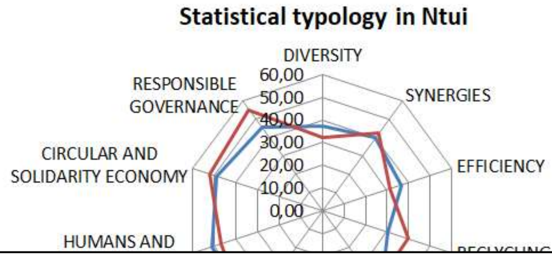

BUNIA Expert typology
DIVERSITY
EFFICIENCY
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF KNOWLEDGE
HUMANS AND SOCIETAL VALUES
SYNERGIES
RECLYCLING
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
Typology1
Typology2
Typology3


Statistical typology in Bunia
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF...
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
Cluster2
Cluster3


Expert typology in Uvira ALL
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
CoCREATION AND SHARING OF KNOWLEDGE
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
type1
type2
type3
type4


Statitical typolgy in Uvira
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF KNOWLEDGE
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
Cluster2
Cluster3


Expert typology in Ntui ALL
DIVERSITY
SYNERGIES
EFFICIENCY
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE


Statistical typology in Ntui
DIVERSITY
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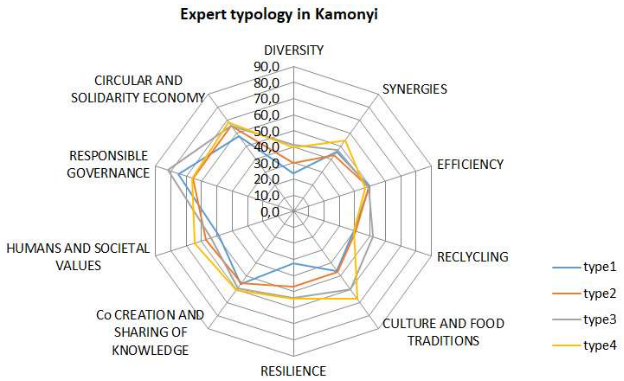
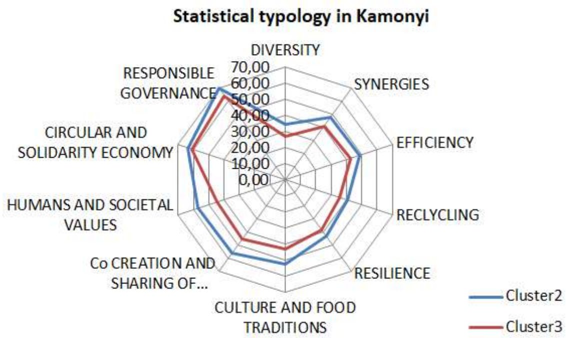
EFFICIENCY
HUMANS AND
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE


Expert typology in Kamonyi
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
CULTURE AND FOOD TRADITIONS
RESILIENCE
Co CREATION AND SHARING OF KNOWLEDGE
HUMANS AND SOCIETAL VALUES
RESPONSIBLE GOVERNANCE
CIRCULAR AND SOLIDARITY ECONOMY
type1
type2
type3
type4


Statistical typology in Kamonyi
DIVERSITY
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EFFICIENCY
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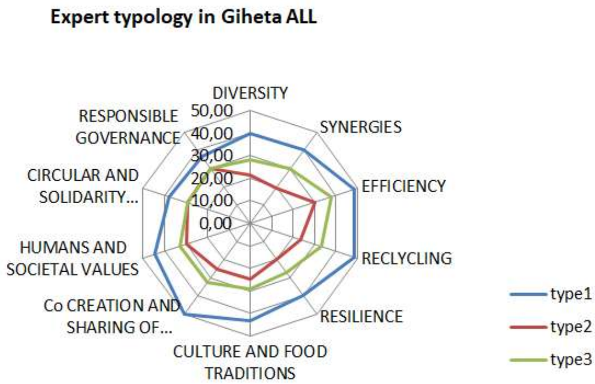
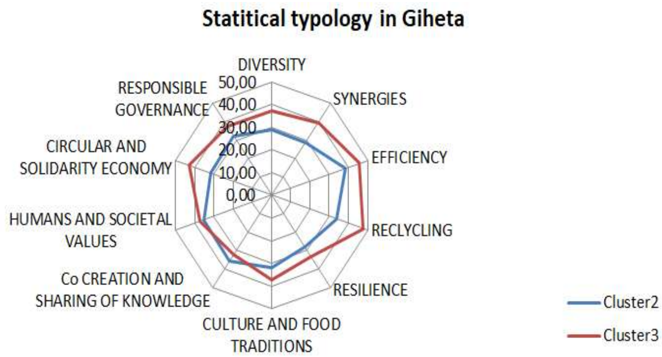
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF...
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
Cluster2
Cluster3


Expert typology in Giheta ALL
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF...
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY...
RESPONSIBLE GOVERNANCE
type1
type2
type3


Statitical typology in Giheta
DIVERSITY
SYNERGIES
EFFICIENCY
RECLYCLING
RESILIENCE
CULTURE AND FOOD TRADITIONS
Co CREATION AND SHARING OF KNOWLEDGE
HUMANS AND SOCIETAL VALUES
CIRCULAR AND SOLIDARITY ECONOMY
RESPONSIBLE GOVERNANCE
Cluster2
Cluster3

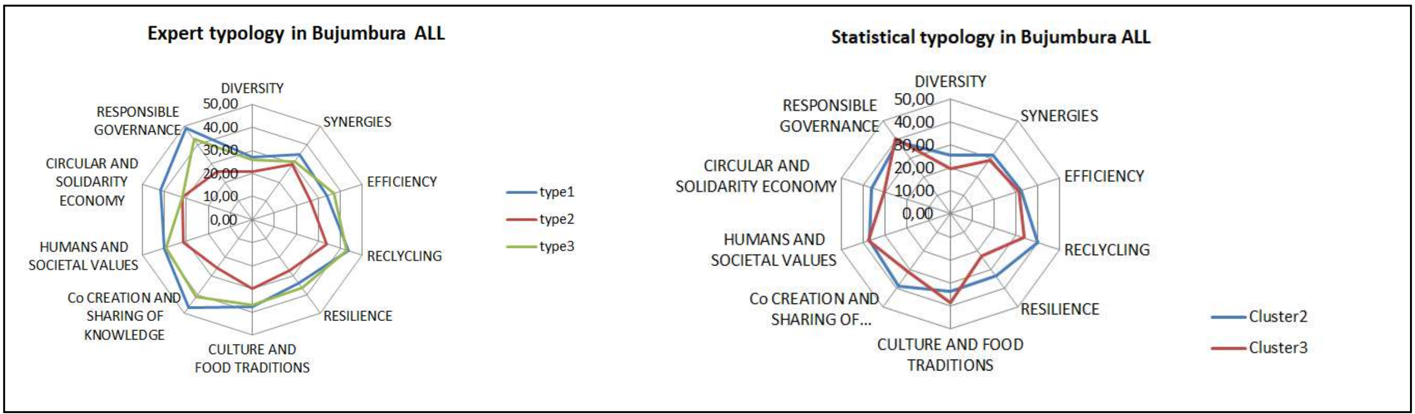


Figure 5: Influence of typologies on the CAET in targeted living labs of CANALLS

In Biega, typological differences reveal a clearer gradient in agroecological advancement. Type 2 farms emerge as having high score than those for Type 1. This was particulary observed in co-creation and knowledge sharing (+12.5 points), responsible governance (+12.6 points), and human and societal values (+7.5 points), highlighting the importance of social organization and institutional engagement in driving transition processes. When considering the three typologies in greater detail, Type 3 farms display particularly strong ecological performance, with high levels of diversity, efficiency, resilience, and synergies, suggesting productive and robust agroecosystems. Type 2 farms are more strongly associated with cultural dimensions, recycling practices, solidarity-based economic activities, and governance, reflecting a socially embedded transition pathway. Type 1 farms, by contrast, rank highest mainly in co-creation and knowledge sharing, indicating early social engagement but weaker integration of ecological and economic dimensions. Overall, Type 3 appears to represent the most ecologically advanced group in Biega, characterized by productive, diversified, and resilient systems.

In Kamonyi, the typology reveals a progressive sequence of agroecological transition stages. Type 4 farms represent the most holistic transition pathway, combining strong ecological performance with well-developed social and governance dimensions. This group reflects a mature form of agroecology, where technical practices, social organization, and values are well aligned. Type 3 farms show strong ecological performance but remain less integrated socially, suggesting a need to strengthen collective action, governance, and knowledge-sharing mechanisms. Type 2 farms appear to be on an intermediate or transitional path, having adopted some agroecological practices but without full systemic integration. Type 1 farms represent an early stage of transition, with limited adoption of key agroecological principles and a clear need for targeted support to strengthen foundational practices and capacities.

Figure 5 results show that large land-endowed farms display higher CAET scores and diversified outputs, reflecting stronger ecological integration. Smallholder subsistence-oriented farms consistently show lower CAET levels and weaker performance across productivity and resilience indicators, highlighting structural constraints. Labour-intensive family farms achieve intermediate to high CAET scores, supported by strong social and cultural practices, but rely heavily on household labour, particularly women and youth. These results demonstrate that agroecological performance is more strongly associated with farm type than with site (ALL), underscoring the need for farm-type-specific transition strategies within CANALLS living labs.

3.4. Cross-analysis of the CAET in the targeted areas

Results of this snalysis suggested that the factor cluster is the primary source of differentiation across groups, while the factor ALL alone does not produce significant differences (Table 12). However, the interaction between ALL and cluster is consistently significant, indicating that the way clusters differ depends strongly on the level of ALL.

Table 12a.Variations of the 10 agroecology elements between the typologies (cluters) across the ALLs

ALL	Cluster	DIVERSITY	SYNERGIES	EFFICIENCY	RECLYCLING	RESILIENCE	CULTURE AND FOOD TRADITIONS	Co CREATION & SHARING OF KNOWLEDGE	HUMANS & SOCIETAL VALUES	CIRCULAR& SOLIDARITY ECONOMY	RESPONSIBLE GOVERNANCE	Average CAET
Biega	Clust1	40,1±16,3	53,1±29,8	70,8±11,6	37±10,5	40,9±16,4	46,5±15,5	68,1±11,1	45,8±10	60,4±22,3	41,7±24,2	**50,4±12,4**
	Clust2	39,1±11,6	52,6±17,5	72,2±10,3	40,9±13,6	36,4±13,5	48,9±12,5	54,8±17	49,3±15,5	55,6±17,9	47,1±21,9	**49,7±10,5**
	Clust3	41,5±11,4	57,7±19,3	70,7±18	42±10,5	35,9±14,2	47,7±14,1	49,2±24,6	53,1±12,6	59,1±16,9	60,6±22,9	**51,8±11,6**
Buja	Clust1	25,3±10,8	31,7±12,8	32,2±13,4	40,2±14	33,5±13,7	33,9±18,2	38,6±23,2	37±11,2	36,3±13,6	38,9±20,3	**34,8±10,5**
	Clust2	19,5±7,8	28,9±13,3	31,3±14,9	33,6±18,9	22,9±9,8	38,5±11,7	31,3±14,6	37,5±16	30,2±18,3	40,6±15,1	**31,4±8,6**
Bia	Clust1	31,6±18,5	50,3±19,8	77±20,9	58,7±24,7	50,5±23,3	70±24,6	55,4±25,5	61,8±21,8	62,5±21,5	51,4±28,5	**56,9±16,8**
	Clust2	35,3±14,5	47,8±17,2	72,2±17,9	44,6±21,5	48,4±14,8	56,3±19	50,9±21,1	55,6±16,8	61,2±20,1	47,8±22,1	**52±12,3**
G' t a	Clust1	29,2±15,7	28,9±14,9	38,2±15,8	33,9±21,9	28,2±14,8	32±16,3	35,8±19	35,6±12,4	31,6±14,8	32±14,8	**32,6±11,4**
	Clust2	37,5±16,5	39,6±9,5	45,8±13	47,9±9,5	33,3±14	37,5±15	31,9±20,6	37,5±13,6	43,1±19,7	37,5±11	**39,2±9,7**
Kbr	Clust1	39,2±12,2	45,7±19	68,9±10,3	38,5±12,5	34,4±13,7	49,2±16,3	49,9±22,4	43,9±13	51,8±20,6	47,4±25,1	**46,9±12,1**
	Clust2	46,5±16,2	47,2±19,1	64,5±13,1	41,4±13,5	42,6±20	48,3±15,4	49,3±23,2	43,8±14,7	51,2±21,5	45,1±19,8	**48±14,1**
K' y i	Clust1	34,1±15,6	47,7±15	48,8±15,8	40,9±15,8	43,1±20,1	52,3±18,9	56,3±23,1	57,2±15,8	63,5±15,7	69,9±16,7	**51,1±10**
	Clust2	26,8±9,4	41,1±9,4	42,4±11,4	35,7±7	38,4±12,5	42,9±22,8	45,2±27,6	44,6±12,2	60,7±15,7	64,3±22,4	**44,2±6,1**
Ntui	Clust1	37,4±13,5	40,1±15	36,4±14,9	30,3±12,7	44±14	52,7±20,5	52±18,6	51,4±14,7	49,2±15,3	45,2±21	**43,9±8,6**
	Clust2	32,1±11,1	42,2±15,7	31,6±12,2	39,9±12,8	40,7±9,7	54,2±18	56,7±20,8	46,9±15,9	52,1±15,3	55,1±16,8	**45,1±5,5**
Uvr	Clust1	29,9±12	43,4±13,2	47,1±13,3	57,2±11,6	43,8±15	55,8±14,9	60,9±16,1	55,5±10,3	65,8±13,3	57,9±20,1	**51,7±9,3**
	Clust2	34,8±8	48,7±18	50,9±15,1	58±10,7	41,7±8,6	45,2±14,3	60,7±14,2	54,5±8,6	65,5±13,1	62,5±20,6	**52,3±9,5**

Buja: Bujumbura; Bia: Bunia; G'ta: Giheta; Kbr: kabare, K'yi: Kamonyi; Uvr: Uvira

Table12b. *summary of the analysis of variance*

Variable	F_ALL	F_ALL: Cluster	F_Cluster	df_ ALL	df_ALL: Cluster	df_ Cluster	p-value_ ALL	p-value_ ALL:Cluster	p-value_ Cluster
CIRCULAR AND SOLIDARITY ECONOMY	4,98E-14	16,68618	3,902452	7	14	2	1	1,92E-33	0,02084
Co CREATION AND SHARING OF KNOWLEDGE	1,97E-13	5,747377	2,312944	7	14	2	1	2,11E-10	0,100078
CULTURE AND FOOD TRADITIONS	1,67E-13	10,76388	1,390063	7	14	2	1	2,12E-21	0,250067
DIVERSITY	-1,1E-12	5,387294	2,287758	7	14	2	1	1,33E-09	0,102606
EFFICIENCY	4,75E-13	39,83394	17,23935	7	14	2	1	4,37E-71	5,91E-08
HUMANS AND SOCIETAL VALUES	2,4E-13	11,84172	0,754991	7	14	2	1	1,12E-23	0,470576
RECLYCLING	-1,4E-13	9,097275	0,457107	7	14	2	1	8,27E-18	0,633389
RESILIENCE	1,81E-13	6,254541	2,194887	7	14	2	1	1,56E-11	0,112495
RESPONSIBLE GOVERNANCE	-3,5E-14	9,749898	0,950041	7	14	2	1	3,17E-19	0,387456
STEP1résumé	-2,8E-15	16,23698	4,174752	7	14	2	1	1,43E-32	0,015945
SYNERGIES	1,84E-15	7,89495	4,61242	7	14	2	1	3,58E-15	0,010375

From the tables 12 a et b, results show that cluster 2 demonstrates significantly higher efficiency scores compared to both Cluster 1 and Cluster 3, suggesting that Cluster 2 is consistently more effective in mobilizing resources and achieving outcomes. Cluster 2 also outperforms Cluster 3 in terms of synergies, highlighting its stronger capacity to foster collaboration and integration across dimensions.

Cluster 2 scores significantly higher than Cluster 3, reflecting a stronger orientation toward sustainable and solidarity-based economic practices.

Other dimensions (Diversity, Recycling, Resilience, Culture and Food Traditions, Co-creation and Sharing of Knowledge, Humans and Societal Values, Responsible Governance): No statistically significant differences were observed between clusters, suggesting relative homogeneity across groups for these variables.

The factor ALL alone does not differentiate groups ($p \approx 1$ across all variables). Nevertheless, the interaction ALL × Cluster is highly significant for most variables, meaning that cluster differences are not uniform but vary depending on the level of ALL. This underscores the importance of considering contextual conditions when interpreting cluster performance. Cluster2 emerges as the strongest profile, consistently outperforming other clusters on efficiency, synergies, circular economy, and overall CAET average.Cluster3 appears as the weakest profile, particularly in efficiency and synergies, indicating areas requiring targeted reinforcement. Cluster1 occupies an intermediate position, but remains below Cluster2 on efficiency and average CAET. The absence of significant differences for ALL alone suggests that structural or contextual factors captured by ALL are not sufficient to explain performance variations, but they interact meaningfully with cluster membership.

These results highlight the need to prioritize Cluster3 for capacity-building interventions, while leveraging Cluster2 as a benchmark of good practices. The strong interaction between ALL and Cluster suggests that policy and programmatic strategies should be tailored to specific contexts, rather than assuming uniform effects across clusters.

3.5. Core performance criteria of the systems

3.5.1. Land tenure

Figure 5 reflects land tenure data for men and women across 8 ALLs, based on the agroecology performance.

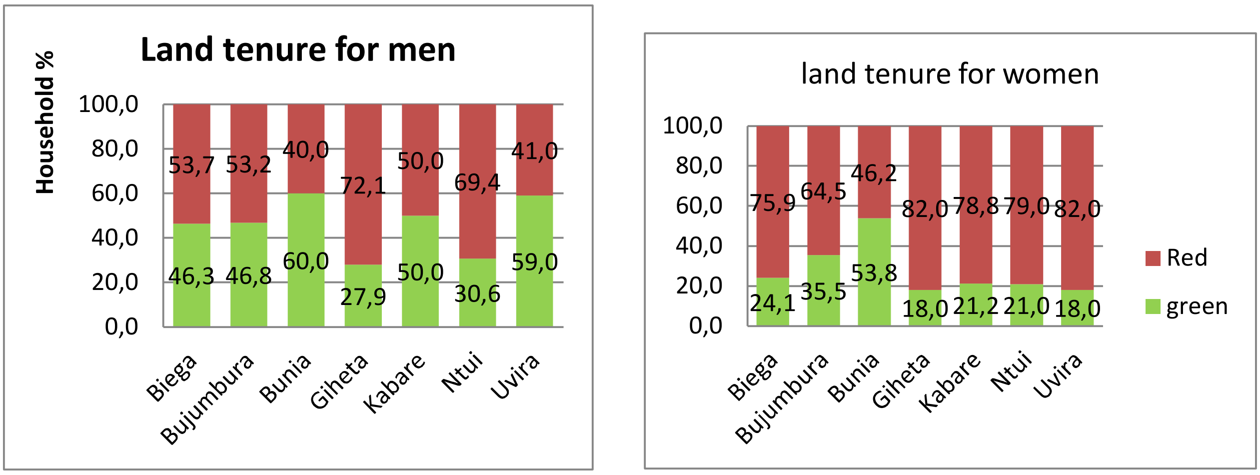


Fig6.Aggregate land tenure across the targeted living lab for men and women tenure. *Legend: green is desirable, yellow acceptable and unsustainable*

Land tenure security is generally low across the Agroecological Living Labs (ALLs), with few households holding formal documentation and full rights. The results reveal a distinct regional hierarchy and significant gender disparities.

As regional performance shown in the graph above, Kamonyi is the standout performer, demonstrating the most sustainable land tenure. Notably, 66.7% of men and 81% of women have secure access, making it the only site where women's security surpasses men's. Bunia and Uvira follow, with over half of households enjoying secure tenure, though 40-41% remain insecure. Kabare shows a balanced 50/50 split between secure and insecure households while Biega and Bujumbura have near-equal proportions, indicating a critical need for formalization for the insecure majority. Finally, Giheta and Ntui are in the most critical state, with a majority lacking rights and requiring urgent tenure reforms.

A pronounced gender gap persists in all regions except Kamonyi. Overall, men have significantly higher tenure security (46% secure) compared to women (27.6% secure). This widespread inequality underscores the need for targeted interventions to strengthen women's land rights, taking lessons from Kamonyi's positive example.

3.5.2. Economic dimension

The performance of the economic dimension of characterized systems comprises productivity, income and added value.

a) Productivity

In order to better account for productivity in large extensive systems, farm output value per ha (Figure 7) with an addition of farm output value per person working on holding (table5) were calculated. Revenue data about the top 10 most important crops, 10 most important animal products, and the 10 most important activities/services within the system assessed were calculated according to the area of land used for agriculture et number of persons living in the household (Table 5 and Figure 3)

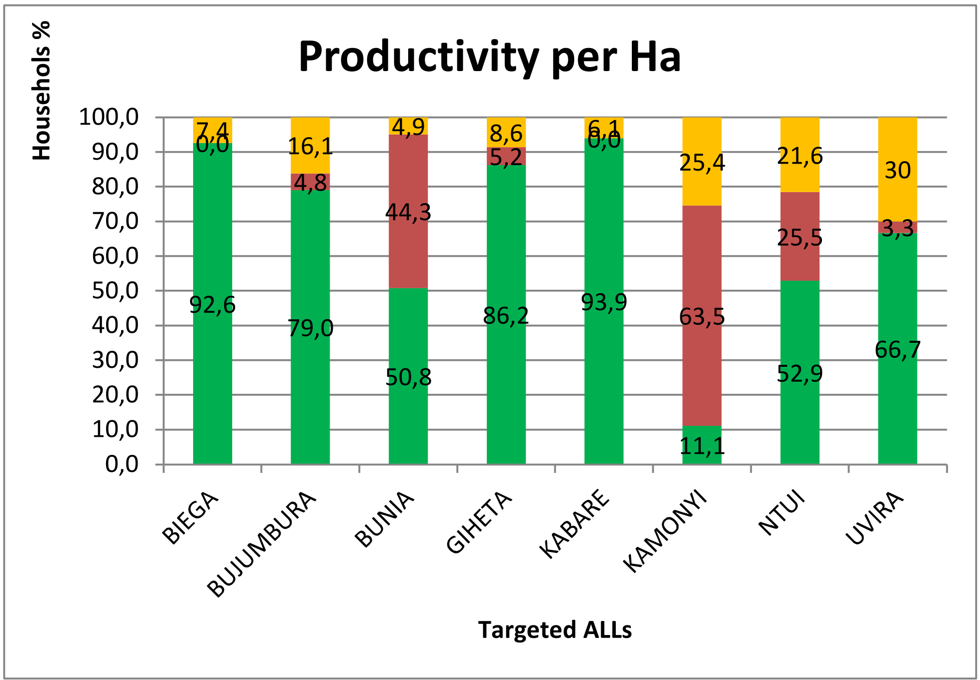


Figure 7. Farm output value per ha across the selected ALLs. *The* ***Green*** *category represents sustainable productivity practices where households efficiently use resources like land, labor, capital, and water to generate output while maintaining ecological balance for long-term productivity. In contrast, the* ***Red*** *category reflects unsustainable practices, where resources are overused or mismanaged, leading to negative environmental impacts such as soil degradation, water overuse, and loss of biodiversity. Over time, these practices can reduce the land's capacity to produce, diminishing overall productivity.* ***Yellow*** *is an intermediary case where sustainable productivity practices within the households are not yet efficiently used and resources like land, labor, capital, and water to generate output and maintain ecological balance for long-term productivity are not optimal and need significant progress for optimization*

Table 13. Farm output value per person

ALLs	$/person
BIEGA	296,0
BUJUMBURA	541,6
BUNIA	1121,7
GIHETA	466,1

KABARE	644,3
KAMONYI	450,5
NTUI	1869,1
UVIRA	739,2
Average	749,0

Analysis of the ALLs with the highest productivity reveals a strong link between sustainability and high output (Figure 7 and Table 13). Results indicated that Biega ALL has 92.6% of households follow sustainable practices (Green), and the productivity per person is $296.0. This moderate productivity reflects a well-balanced and sustainable system, ensuring stable long-term productivity. With 93.9% of households in the Green category, Kabare ALL shows nearly universal sustainability. Its productivity per person is $644.3, which is relatively high, demonstrating that high output can be achieved without overusing resources. This is a model of balancing productivity with sustainability. In Giheta, 86.2% of households practice sustainable techniques (Green), and productivity per person is $466.1, reflecting a solid agroecological system, where moderate productivity is supported by sustainable practices, ensuring long-term stability.

These ALLs show that focusing on Green practices contributes to consistent and sustainable productivity, where high sustainability directly correlates with moderate to high output, and long-term agricultural performance is maintained.

However, BUNIA and KAMONYI ALLs present a different pattern where high or moderate productivity coexists with significant portions of households in the Red category, indicating a disconnect between output and sustainability. In BUNIA, 50.8% of households are in the Green category, but 44.3% fall in the Red category, indicating a substantial portion of unsustainable practices. Despite this, productivity per person is $1121.7, which is notably high. This suggests that while high output is achieved, much of it is unsustainable, likely due to overuse of resources such as land or water, which may undermine long-term productivity.

Only 11% of households practice sustainable methods (Green), while 63.5% of households follow unsustainable practices (Red) in Kamonyi ALL. Productivity per person is $450.5, which is moderate but lower than some other regions. The high percentage of Red households raises concerns about the long-term viability of productivity in this area, as the overuse of land and inefficient resource management may lead to diminishing returns over time.

In Bunia and Kamonyi ALLs, the disconnect between high or moderate productivity and unsustainable practices suggests that while output may be high in the short term, future productivity is uncertain. The overuse of resources and unsustainable methods can result in land degradation, reducing productivity in the long run.

To improve sustainability in these 2 later ALLs, it's crucial to address the inefficiencies and unsustainable practices in the Red regions. By promoting green practices and improving resource management, it may be possible to increase sustainable productivity and ensure that resources are used more effectively while still achieving high output.

Additionally, while the productivity data does not directly break down gendered implications, the differing percentages of households in each category may have gendered impacts, particularly in regions where land tenure and access to resources are inequitably distributed across genders. The unequal distribution of sustainable practices could exacerbate gender disparities in agricultural outcomes.

Overall, promoting sustainable practices in ALLs with high Red percentages is essential for ensuring long-term productivity and minimizing resource degradation.

b) Revenue or Income

An important part of sustainability in agriculture is the economic viability of the system. The method of assessment needs to capture whether the level of income earned by the producer is reasonable while taking into account factors of production and assets employed. Incomes from all productive activities should be included, which are all likely important in the context of assessing the sustainability of living in rural areas.

Table 14. Revenue in $ calculated for each ALL

ALLs	Revenus ($)
BIEGA	-11801,6
BUJUMBURA	-27743,1
BUNIA	666,6
GIHETA	-994,0
KABARE	-9263,6
KAMONYI	1879,3
NTUI	-150989,0
UVIRA	-124015,4
Average	**-37070,9**

The negative values in the table indicate losses for ALLs, while positive values (like in BUNIA and KAMONYI) show profits or positive revenue. The average revenue across all ALLs suggests that, overall, the studied ALLs are operating at a financial loss.

FAO recommend that if data for the calculation of income is scarce and/or data to compare to average income in similar system or at national level is not available, to a method based on the perception of income by farmers.

Hence, to determine desirable, acceptable and unsustainable cases across the ALLs, we used the alternative method based on the perception of income (fig 8) as data for the calculation of income were not clear and data to compare to average income in similar system or at national level were scarce.

income were not clear and data to compare to average income in similar system or at national

level were scarce.

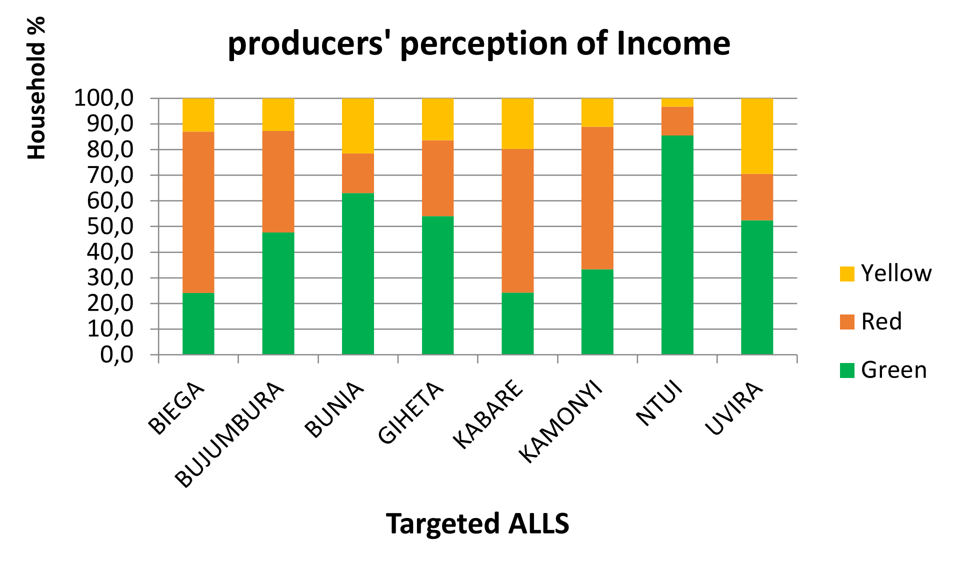


Fig8.perception of producers on their income.

Results deplay 3 trends (Fig8):

- Regions with the highest proportion of "Green" (successful) where Ntui stands out with 85.5%, followed by Bunia, Giheta and Uvira with relatively more than 50% in the green category, indicating strong adoption and success of agroecological practices in these zones.

-Regions with the highest proportion of "Red" (unsustainable) with Kabare, Biega, Kamonyi and Bujumbura having the highest percentages of farmers reporting income decreases or below average (over 55%).

-Regions with the most balanced outcomes with Bujumbura, Giheta, Uvira, Bunia and Ntui having a more equilibrated balanced outcome, with significant portions of farmers in both the green and yellow categories while red portion is low, suggesting more variation in the impact of agroecology.

In general, agroecology appears to be more successful in some regions (e.g., Ntui, Bunia, Giheta), leading to income growth, while in other areas (e.g., Biega, Kabare), farmers still facing significant challenges. This variability highlights the importance of context-specific factors (such as crops, local resources, support systems, and climate conditions, etc). To determine the success of agroecological practices, specificity of these ALLs are important to consider.

c) Added value

The analysis of income can be completed by the added value, after removing subsidies and income from renting land or other assets, and adding taxes, interest on loans and salaries paid for labo (Table 14).

Table 14: added value across the 8 targeted ALLs

ALLs	Added value ($)
BIEGA	2601,1

BUJUMBURA	4245,2
BUNIA	3040,5
GIHETA	2184,5
KABARE	3523,1
KAMONYI	2758,1
NTUI	2307,1
UVIRA	2050,0
Average	**2880,5**

The table suggests that regions with higher proportions of farmers in the green category are more likely to see successful economic outcomes through agroecological practices. The yellow category is less common, indicating that most regions have either positive or negative economic outcomes, with few farmers reporting neutral (stable) income levels.

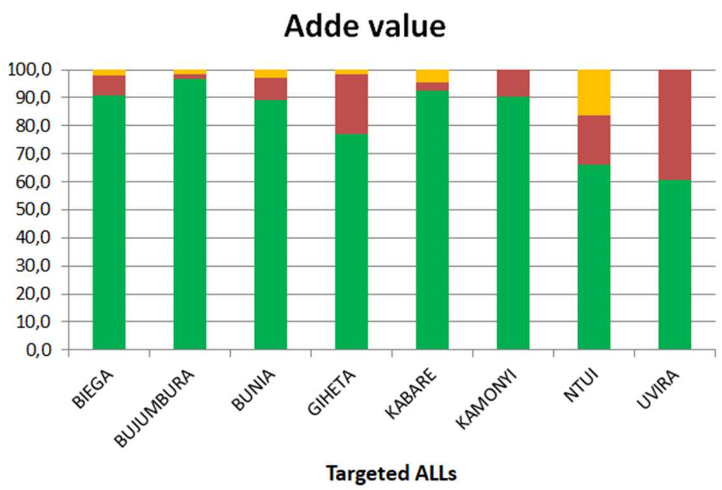


Figure 9. Added value from farming activities across the ALLs. Red Category (Unsustainable), Yellow Category (Acceptable) and Green Category (Desirable).

Globally, the added value is good (desirable) with some differences among sites (Figure 9). Agroecological living labs such as Bujumbura, Biega, Bunia, Kabare and Kamonyi (score over 80) show highly successful agroecological practices with high percentages of farmers reporting positive income changes. In contrast, Uvira and Ntui ALLs face more significant challenges, with a larger portion of farmers (30-40) perceiving their income as unsustainable or declining. This may require targeted interventions and policies to improve agroecological outcomes in those regions. ALLs with higher percentages in the **Red** category (such as Uvira and Ntui) might need more support to shift towards more desirable agroecological models.

3.5.3. Health & nutrition dimension

a) Exposure to pesticides

While some regions are having a strong commitment to agroecology with minimal pesticide use, like in Bunia, Biega, Kabare and Giheta, with more than 80% of farmers not using pesticides , others sites like Ntui, Uvira and Kamonyi, showed a strong dependence and use of chemical pesticides in their cropping systems (Figure 10), which may pose environmental and health risks where local farmers usually have a weak awareness on chemical products characteristics and use. This could guide policy and interventions to promote more sustainable farming practices and reduce pesticide exposure by providing training interventions to build farmers capacity on pesticides and their use as well as ecological alternatives to pesticides' use in the cropping and production systems.

Figure 10 highlights the variation in pesticide use and agroecological practices across 8 targeted agroecological living labs

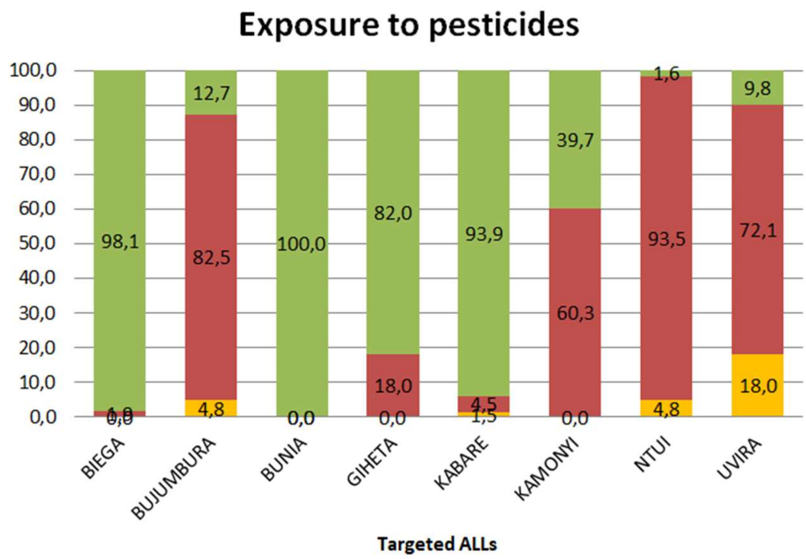


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Figure 10. Variation in pesticide use and agroecological practices across the 8 agroecological living labs. Red Category (Unsustainable), Yellow Category (Acceptable) and Green Category (Desirable).

b) Food security

Regarding the food security parameters as analysed by the TAPE questionnaire, the following situation were observed (Table 15):

-Biega and Kabare have shown the most problematic situation of food insecurity among the 8 Alls surveyed. Globally more than 70% of farmers declared to be usually (sometimes and often) exposed to food insecurity problems. They are permanently worried to face insufficient food in the households, do not consume healthy and nutritious food, they ate few kinds of food, regularly experienced skipped meal, and most of time they eat less food than required. They also mentioned that many times they are facing run out of food in the households resulting in many times households' members went out home without eating for a whole day. This means, only 30% of this area population scored for good characteristics on food security parameters.

-Bunia All, has showed the most interesting food security situation. More than at least 75% (75 to 90) have never or rarely faced food insecurity issues while less than 25% (10 to 25) recognized to have regularly experienced food insecurity issues.

-Only Ntui All is intermediary with approximately half of its farmers declared to have faced food insecurity issues and a half declared to have not experienced food insecurity problems.

-The rest of the others ALLs, for example Bujumbura, Giheta, Kamonyi and Uvira have approximately more people in good food security situation (60%) against those who are in food insecurity situation who are representing approximately 40%.

Table.15. Perception of producers on food security parameters in their households

Food security parameters				**ALLs**					
WORRIED	**BIEGA**	**BUJUMBURA**	**BUNIA**	**GIHETA**	**KABARE**	**KAMONYI**	**NTUI**	**UVIRA**	***average***
0	9,4	27,1	26,2	38,3	11,5	38,3	32,3	19,7	25,2
1	26,4	32,2	64,3	17,0	18,0	21,7	29,0	41,0	30,3
2	39,6	33,9	9,5	27,7	41,0	31,7	27,4	23,0	29,9
3	24,5	6,8	0,0	17,0	29,5	8,3	11,3	16,4	14,6
HEALTHY AND NUTRITIOUS									
0	1,9	11,9	24,3	29,8	6,6	37,7	22,0	16,4	18,5
1	7,7	33,9	51,4	23,4	16,4	21,3	22,0	41,0	26,3
2	61,5	40,7	21,6	25,5	37,7	29,5	37,3	31,1	36,2
3	28,8	13,6	2,7	21,3	39,3	11,5	18,6	11,5	19,0
FEW FOODS									
0	1,9	20,7	36,1	26,1	9,8	41,0	27,6	11,5	21,2
1	19,2	29,3	38,9	23,9	18,0	19,7	19,0	47,5	26,6
2	36,5	34,5	19,4	39,1	34,4	32,8	34,5	26,2	32,6
3	42,3	15,5	5,6	10,9	37,7	6,6	19,0	14,8	19,6
SKIPPED MEAL									
0	3,9	44,1	30,6	44,4	6,7	54,1	31,6	10,0	28,0
1	17,6	32,2	47,2	22,2	18,3	16,4	26,3	41,7	27,0
2	41,2	16,9	22,2	17,8	40,0	26,2	21,1	33,3	27,7
3	37,3	6,8	0,0	15,6	35,0	3,3	21,1	15,0	17,2
EAT LESS									
0	7,7	25,9	41,7	31,1	3,3	41,7	23,2	13,3	22,5
1	13,5	43,1	33,3	35,6	20,0	16,7	26,8	41,7	28,6
2	61,5	24,1	22,2	22,2	43,3	40,0	39,3	31,7	36,3
3	17,3	6,9	2,8	11,1	33,3	1,7	10,7	13,3	12,6
RUN OUT OF FOODS									
0	15,4	50,9	34,3	53,3	11,7	72,9	41,1	18,3	37,0
1	30,8	35,1	54,3	24,4	20,0	11,9	28,6	38,3	29,2
2	32,7	12,3	11,4	15,6	40,0	13,6	19,6	30,0	22,6
3	21,2	1,8	0,0	6,7	28,3	1,7	10,7	13,3	11,1
HUNGRY									
0	11,5	43,9	37,1	51,1	8,2	71,7	48,2	11,5	34,9
1	21,2	40,4	54,3	22,2	18,0	16,7	21,4	39,3	28,1
2	44,2	14,0	5,7	20,0	54,1	11,7	25,0	37,7	27,9
3	23,1	1,8	2,9	6,7	19,7	0,0	5,4	11,5	9,1
WHOLE DAY									
0	9,6	58,9	41,2	55,6	10,2	78,3	58,9	14,8	40,7
1	26,9	32,1	41,2	20,0	23,7	15,0	12,5	39,3	25,8
2	50,0	8,9	14,7	15,6	42,4	6,7	25,0	32,8	25,1
3	13,5	0,0	2,9	8,9	23,7	0,0	3,6	13,1	8,5

Legend: 0: never; 1: Rarely; 2: Sometimes and 3: Often.

The interpretation of this Table results globally mean that 0 and 1 are in good food security situation while 2 and 3 are in the bad food security situation.

c) Diet diversity

Results suggest that there is a significant variation in dietary diversity among the 8 agroecological living labs (Figure 11). Only Bunia showed an acceptable situation with approximately 74% of respondents with desirable situation, while in some regions, for example Giheta, Kamonyi, Kabare and Biega, the dietary diversity is in critical situation with more than 50% is in unsustainable position. Otherwise, some regions such as Ntui and Biega where a high population proportion are in acceptable position can easily shift to desirable situation and considerably modify the dietary diversity score globally.

Agroecological practices might need to be further adjusted to enhance dietary diversity, particularly in regions with high "red" percentages, as this would likely improve overall nutrition and food security.

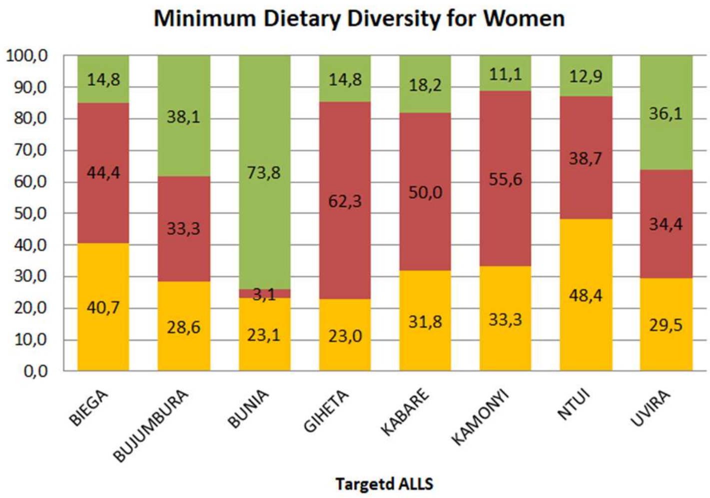

Figure 11. Minimum Dietary Diversity for Women among the 8 agroecological living labs. Red Category (Unsustainable), Yellow Category (Acceptable) and Green Category (Desirable).

3.5.4. Social dimension

a) Women empowerment

Overall, all the living labs have predominantly unsustainable situation regarding women empowerment with more than 50% of respondents reported an unsustainable situation, except Kamonyi where approximately 20% of respondents described an unsustainable situation (Figure 12). Kamonyi is the only ALL where approximately 30% of respondents reported a desirable and 50% an acceptable situation.

The results suggested therefore that, except in Kamonyi, women empowerment interventions should urgently be initiated to ensure women are capacited and involved in agroecology' technologies and practices implementation towards the sustainable and desirable empowerment of women in agroecological systems.

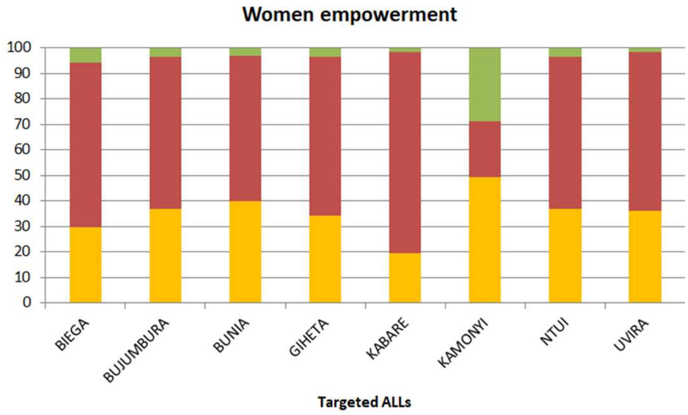

Figure 12. Women empowerment in the 8 agroecological Living Labs. Red Category (Unsustainable), Yellow Category (Acceptable) and Green Category (Desirable).

b) Youth and emigration

Rsults on youth employment indicate that all the agroecological areas are facing unsustainable conditions for youth employment in agriculture, with very few areas falling into the "Green" (desirable) category, around 1,5% in Uvira, Ntui, Giheta and Bunia (Figure 13). Otherwise Kabare, Kamonyi, Ntui and Uvira have some minimal percentage of acceptable situation which may be improved (8-11%). The high percentage of "Red" categories (86 to 100%) across all the sites suggests a need for significant improvements in deploying interventions focusing on youth engagement, employment, and conditions in agriculture. Efforts towards sustainable agriculture and decent work for youth are crucial for improving these scores.

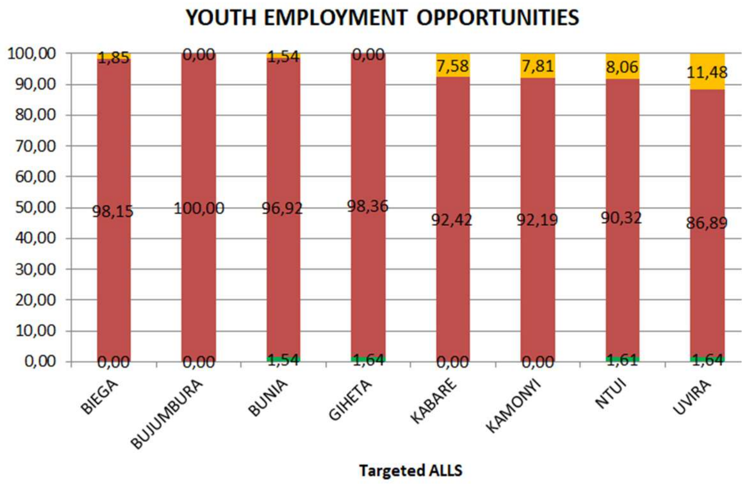

Figure 13. Youth employment in the 8 Agroecological Living Labs. Red Category (Unsustainable), Yellow Category (Acceptable) and Green Category (Desirable).

3.5.5. Environment dimension

a) Agricultural biodiversity

Agricultural biodiversity results showed that (Figure 14), only Biega and Kabare have relatively good characteristics as a total of desirable and acceptable proportion are respectively 74% and 70%. The intermediate ALLs like Ntui (65%), Kamonyi (51%) and Uvira (49%) have an averaged situation which may require some improvement. The less diversified agriculture was reported in Bunia, Bujumbura, Giheta where there is a serious need for agriculture diversification.

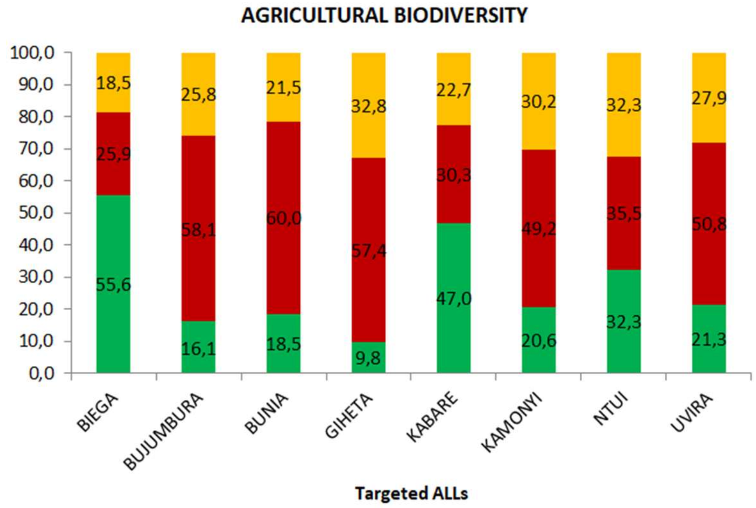

Figure 14. Agriculture biodiversity in the 8 Agroecological Living Labs. Red Category (Unsustainable), Yellow Category (Acceptable) and Green Category (Desirable).

b) Soil health

Uvira, Ntui and Bunia have a positive situation as 77; 64,5 and 53,8 % of farmers respectively reported having good soil health characteristics (desirable situation) and 23; 33,9 and 41,9 % situatd their soils in the acceptable situation (Figure 15). Kabare, Bujumbura and Giheta with respectively 33,3; 33,3 and 32,8 % of desirable soil health situation are the intermediate sites as they also associate 60; 50 and 37 % of soils with acceptable situation which may facilitate sustainable production systems. Kamonyi and Bujumbura have the highest rates of unsustainable situation regarding healthy soils and are in the highest need of developing soil fertility management technologies. Challenges may be found in Giheta, Kamanyi and Biega that showed large portions of their land (over 60% in some cases) in the Yellow category, suggesting that while soil conditions are acceptable, improvements are still necessary. Bujumbura has a concerning 15.9% of land in Red, suggesting unsustainable soil health in some areas. Focus areas for improvement include ALLs like Giheta and Kamonyi which require attention due to significant portions of land in Red and Yellow, signaling unsustainable soil health characteristics.

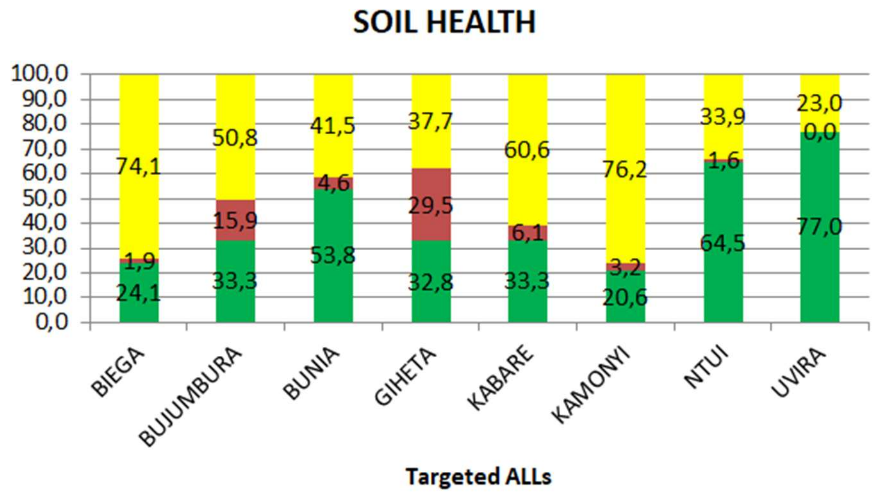

Figure 15. Soil health characteristics in the 8 Agroecological Living Labs. Red Category (Unsustainable), Yellow Category (Acceptable) and Green Category (Desirable)

3.5. Effects of agroecological dimensions on performance indicators

The nature of agroecological transitions as characterized by trade-offs between productivity, labor, income, and social outcomes are given in the Table 16. The details on the analysis are shown in Annex 4.

Table 16. Summary of significant effects of agroecological dimensions on performance outcomes (linear mixed-effects models)

Performance outcome	Significant positive effects ($p < 0.05$)	Significant negative effects ($p < 0.05$)	Marginal effects ($0.05 \leq p < 0.10$)	ALL random effect
Total productivity	—	—	Human & Social Values (+)	High
Productivity per person	—	Recycling (–)	Resilience (+); Culture (+)	None (singular)
Revenue	—	Circular Economy (–)	Responsible Governance (+); Co-creation (–)	Moderate
Agricultural diversity	Diversity (+)	Resilience (–)	Culture (+); Responsible Governance (+)	Moderate
Diet score	—	—	—	Low
Women empowerment	Co-creation (+)	Culture (–)	Efficiency (+); Responsible Governance (+)	Moderate
Youth engagement	—	—	Diversity (–); Resilience (+); Culture (+); Co-creation (–)	Moderate
Soil condition	—	Diversity (–)	—	Low

Notes:*Signs (+/–) indicate direction of effects. Models include ALL as a random intercept. Marginal effects correspond to $0.05 \leq p < 0.10$.*

Linear mixed-effects models were used to assess the relationships between agroecological dimensions and multiple performance outcomes, while accounting for contextual variability across Agroecological Living Labs (ALLs) through a random intercept. Overall, the results reveal heterogeneous and outcome-specific effects, rather than uniform relationships across all dimensions and indicators.

For total productivity, none of the agroecological dimensions showed statistically significant effects. However, a positive marginal association was observed for *Human and Social Values*, suggesting that socially inclusive systems may contribute indirectly to higher aggregate production. The presence of a convergence warning and large variance components indicates high collinearity among agroecological dimensions and substantial scale heterogeneity across ALLs, warranting cautious interpretation.

In contrast, productivity per person was significantly and negatively associated with *Recycling*, indicating that systems emphasizing nutrient and biomass recycling may increase labor requirements, thereby reducing labor productivity. Marginal positive effects of Resilience and Culture suggest that socially embedded and risk-buffering practices may enhance labor efficiency. The absence of variance at the ALL level indicates limited contextual differentiation for this indicator.

Regarding household revenue, Circular Economy practices showed a significant negative association, while Responsible Governance exhibited a marginal positive effect. These results suggest a potential trade-off between internal resource circularity and short-term market integration, partially offset by governance arrangements that facilitate collective organization and access to markets.

Agricultural diversity was positively influenced by the Diversity dimension itself, confirming internal coherence within the agroecological framework. Conversely, Resilience was negatively associated with diversity, indicating that resilience-oriented systems may prioritize a smaller set of robust species. Marginal positive effects of Culture and Responsible Governance further highlight the role of social norms and institutions in shaping diversification strategies.

No agroecological dimension was significantly associated with dietary diversity, suggesting that nutrition outcomes are mediated by factors beyond production systems, such as income, food markets, and intra-household allocation.

For women’s empowerment, Co-creation showed a strong positive effect, emphasizing the importance of participatory processes in enhancing women’s agency. In contrast, Culture had a significant negative effect, reflecting the persistence of restrictive gender norms. Marginal positive associations were also observed for Efficiency and Responsible Governance.

The youth engagement score displayed several marginal associations. *Diversity* and *Co-creation* tended to reduce youth engagement, while *Resilience* and *Culture* showed positive trends, suggesting that stability and social embeddedness may be more attractive to younger actors than complex diversification strategies.

Finally, soil condition was negatively associated with *Diversity*. This result suggests potential short-term soil management trade-offs in highly diversified systems, particularly where diversification is not accompanied by soil-specific conservation practices.

3.6. Validation, Explanation and Contextualization of Agroecological Performance

3.6.1 Evaluation and Validation of CAET (Step 1)

Most responses reflected reality, though participants suggested minor adjustments to agroecological elements and performance criteria (Table 17). Across nearly all ALLs, diversity was seen as underevaluated. Despite widespread mixed cropping and agroforestry, scores remained moderate to low due to: (i) functional rather than structural diversity, (ii) economic specialization in crops such as coffee, cacao, and rice, and (iii) land pressure in peri-urban areas like Bujumbura. Diversity is present but constrained by seasonality, land access, market orientation, and production specialization—confirming farmers' view that it is practiced yet limited in scale and scope. Ntui was unique, with full (100%) validation across all elements, showing rare alignment between experts and farmers. In contrast, Giheta revealed the widest gap, where experts underestimated adoption while farmers reported much higher levels of agroecological practice.

Table17.perceptions of stakeholders of CAET

ALLs	Diversity	Synergies	Efficiency	Recycling	Resilience	Food Traditions	Co-creation	Human & Social Values	Circular Economy	Governance
Bunia/Mambasa (DRC)	Acceptable	Crop-livestock integration (poultry, goats, fish)	Limited external inputs, biopesticides promoted	Weak (~40%), poor training	Shade trees for climate adaptation	Diet diversity weak (<50%)	Farmer-to-farmer exchange	Women marginal, youth in mining	Cooperatives exist (UPCCO, Okapi)	Producers excluded from decisions
Uvira (DRC)	Diversity = Red (weak)	Synergies = Red	Efficiency = Red (low, pesticides used)	Recycling = Yellow	Resilience = Red	Food traditions = Yellow	Co-creation = Yellow	Human/social = Yellow	Circular economy = Yellow	Governance = Yellow
Kabare (DRC)	Diversity ~41 (low)	Synergies ~46 (medium)	Efficiency ~68 (strong)	Recycling ~39 (weak)	Resilience ~36 (weak)	Food traditions ~50 (medium)	Co-creation ~50 (medium)	Human/social ~46 (medium)	Circular economy ~51 (medium)	Governance ~46 (medium)
Biega (DRC)	Diversity ~40 (coffee + associated crops + animals)	Synergies ~54	Efficiency ~72 (strong)	Recycling ~41 (weak)	Resilience ~37 (weak)	Food traditions ~48	Co-creation ~55	Human/social ~71 (strong)	Circular economy ~57	Governance ~49
Ntui (Cameroon)	Diversity ~66% (confirmed, economic diversity improving)	Synergies 100% (integration crops-livestock)	Efficiency 100% (fertility, pest mgmt, productivity)	Recycling 100% (biomass, water reserves, seeds)	Resilience 100% (climate adaptation, social mechanisms)	Food traditions 100%	Co-creation 100%	Human/social 100% (women, youth, work)	Circular economy 100%	Governance 100% (land issues noted)
Giheta (Burundi)	Diversity underestimated (29.6 → adjusted ~50)	Synergies underestimated (29.4 → ~60)	Efficiency underestimated (38.6 → ~55)	Recycling underestimated (34.6 → ~65)	Resilience confirmed low (~28.5)	Food traditions underestimated (32.3 → ~72)	Co-creation underestimated (35.7 → ~65)	Human/social underestimated (35.7 → ~80, women strong)	Circular economy underestimated (32.2 → ~70)	Governance underestimated (32.3 → ~78, producers active)
Bujumbura	Underestimated: farmers highlighted wide diversity.	Confirmed: results reflect reality	Adjusted: strong use of pesticides and hybrid seeds	Confirmed: recycling practices validated	Confirmed: production stability and social	Adjusted: traditional practices present but	Adjusted: knowledge sharing networks	Underestimated: women and youth involved but inequalities	Confirmed: local markets exist but limited	Adjusted: cooperatives exist but access to resources

	score adjusted from 24.6 to 57.85		→ score raised to 37.5		mechanisms validated	dominated by conventional. score raised to 40.55	partially developed. recalculated to 40	persist. score raised to 58.3		limited → score raised to 40.8
Kamonyi	Adjusted: diversity confirmed, score raised from 33.3% to ~57%	Confirmed: synergies limited, results realistic	Debated: chemical input use varies (32–63%), adjusted around 33–48%	Adjusted: recycling underestimated, should be ~50%	Adjusted: resilience overrated, revised to ~35–40%	Confirmed: traditions present at moderate level (~40–51%)	Underestimated: strong cooperative organization and networks → adjusted to 70–75%	Underestimated: women's land rights and representation → adjusted to ~70%	Confirmed: close to reality, adjusted to ~57%	Underestimated: strong legal framework, adjusted to ~85%

3.6.2. Evaluation and validation of performance criteria (Step2)

All performance indicators were fully validated (100%) in Ntui, Kabare and Biega (Table 18). In Giheta, however, a major disconnect emerged between expert and farmer perceptions as farmers reported stronger social and agroecological performance, while economic indicators such as income and food security remained weak. In Bunia, productivity was acceptable, but low income and social fragility, especially affecting women and youth, were evident.

In Uvira, most low-rated dimensions were accepted except for land tenure (Table 18). Farmers contested the notion of gender disparity, noting that women's names are legally recognized on land purchase documents. The predominance of men's names on farm titles was attributed to religious norms that designate men as heads of households, rather than exclusion of women, who retain the right to purchase land independently.

Across the ALLs, farmers consistently highlighted the importance of reliable and equitable land titles, particularly for women and youth. Secure tenure is regarded as the foundation for long-term investment in agroecological practices and resilience.

Table 18.perceptions of stakeholders of performance criteria

Living Lab	Governance	Economy	Health & Nutrition	Social	Environment
Bunia/Mambasa (DRC)	Land tenure: women marginalized; civil society capacity building recommended	Productivity 300–600 kg/ha cacao; income ~350 USD/ha/year; added value = organic cacao	No pesticides; food security moderate; diet diversity <50%	Women marginal; youth in mining, outsiders farm cacao	High agrobiodiversity; fertile forest soils
Uvira (DRC)	Land tenure: men = yellow, women = red	Productivity = yellow; income = red; added value = red	Pesticide use = red; food security = yellow; diet diversity = yellow	Women empowerment = red; youth/emigration = yellow	Agrobiodiversity = yellow; soil health = green
Kabare (DRC)	Land tenure insecure for both men & women; governance weak	Productivity declining (climate, varietal degeneration); income low; added value weak	Pesticide use low; food security fragile; diet diversity poor	Women & youth weak	Agro-biodiversity moderate; soil fertility threatened
Biega (DRC)	Land tenure validated	Productivity validated; income validated; added value validated	Pesticide use avoided; food security validated; diet diversity validated	Women empowerment validated; youth/emigration validated	Agrobiodiversity validated; soil health validated
Ntui (Cameroon)	Land tenure 100% confirmed (men & women); governance strong	Productivity 100%; income 100%; added value 100%	Pesticide use avoided; food security 100%; diet diversity 100%	Women empowerment 100%; youth emancipation 100%	Agrobiodiversity 100%; soil health 100%
Giheta (Burundi)	Land tenure secure for men; improving for women	Productivity underestimated (cash crops only); income negative (-994); added value	>80% avoid pesticides; food security underestimated (seasonal hunger);	Women empowerment underestimated (actually strong);	Agrobiodiversity robust (10+ species); soil health fragile but improving

		underestimated (local processing exists)	diet diversity ~50%	youth partially engaged	
Bujumbura	Confirmed**:** land access limited for women, customary rights for men, lack of official documents	Confirmed**:** unstable income, high costs, lack of storage → added value positive but overall income negative	Underestimated**:** pesticide use >50%, food security moderate (60% secure, 40% insecure), diet diversity critical	Confirmed**:** women's empowerment weak, youth migration common	Underestimated**:** soils fertile, biodiversity diversified → diversity score adjusted to 57.85%
Kamonyi (rawanda)	Adjusted: land tenure confirmed, score raised from 69.5% to ~86% (legal equality but cultural constraints remain)	Mixed: productivity good, but income low (30%) and added value limited (40%) due to lack of storage	Debated: pesticide use considered high but variable; food security validated (60–70%); diet diversity poor (~40%)	Moderate: women empowerment ~55.8%, youth migration to cities	Validated: agrobiodiversity and soil health moderate (~61–65%), generally positive

3.6.3. Contextual enablers and barriers shaping agroecological transition

Stakeholders in Ntui and Giheta benefit from strong enabling conditions—fertile soils, high adoption rates, and supportive institutions—yet still face economic and market barriers. In Bunia/Mambasa and Kabare, fertile soils and farmer motivation are also present, but insecurity, poor infrastructure, and weak governance (common to all four ALLs in DR Congo) hinder agroecological transitions. From farmers' perspectives, Uvira is the most constrained, with multiple disabling factors including limited inputs, weak governance, and low resilience. Biega occupies an intermediate position, showing strong integration but limited resilience and recycling capacity.

Table 19. Favorable and disablings conditions for agroecology across the ALLs

ALL	Enablers (favorable conditions)	Barriers (disabling conditions)
Bunia/Mambasa (DRC)	- Fertile forest soils supporting cacao and food crops - Presence of cooperatives (UPCCO, Okapi) facilitating market access - Favorable climate for perennial crops - NGO support for farmer training	- Insecurity (ADF, armed groups) - Poor rural roads limiting market access - Weak recycling practices - Youth migration to mining, women marginalized in cacao value chain
Uvira (DRC)	- Potential for irrigation and water management - Farmer cooperatives emerging - Local knowledge of rice systems	- Fragile governance (land tenure insecurity, esp. for women) - Heavy reliance on external inputs (pesticides) - Low efficiency and resilience - Weak youth retention, women excluded from decisions
Kabare (DRC)	- Farmer motivation and long experience in coffee production - Family labor availability	- Climate change impacts (varietal degeneration, yield decline) - Weak farmer organizations - Poor tools/infrastructure for processing

Biega (DRC)	- Partner support (NGOs, research) - Favorable climate for coffee -low external input - Strong crop-tree-animal integration (coffee + agroforestry) - Low external inputs - Active farmer networks - Fertile soils	- Low youth interest in coffee - Governance disconnected from farmer realities - Weak recycling practices - Low resilience to climate shocks - Limited diversification of economic activities - Youth migration pressures
Ntui (Cameroon)	- Fertile soils, largely forested agroecosystem - Strong integration of crops, livestock, aquaculture - Farmers adopting organic practices - High ambition and project capacity - Favorable policy support (MINADER, extension services)	- Low economic diversity - Lack of recycling knowledge - Inappropriate chemical use persists - Poor soil management in some areas - Limited adaptation to climate change - Weak market organization for AE products
Giheta (Burundi)	- High adoption of agroecological practices across all 10 elements - Strong crop-animal-tree diversity - Active women's participation in production & marketing - Robust local knowledge systems and peer learning - Partnerships with University of Burundi, COCOCA, Naturland - Favorable national policy context	- Economic vulnerability (negative net income, weak market access) - Seasonal food insecurity - Fragile natural resource base (erosion, soil degradation) - Insecure land tenure for women - Youth disengagement and migration - Limited local processing/value addition - External expert assessments underestimate local capacities
Bujumbura (Burundi)	- Farmers' willingness to adopt agroecological practices - Active involvement of women in production and marketing - Existing cooperatives and farmer associations (CAPAD, ISABU) - Support from NGOs and national research institutions - Proximity to large urban markets (hotels, restaurants in Bujumbura) - Availability of extension services and multi-stakeholder partnerships	- Climate variability (droughts, erratic rainfall) - High production costs and weak market access for agroecological products - Soil degradation pressure - Limited youth involvement in agriculture (migration) - Land tenure constraints for women (customary/traditional laws) - Lack of storage facilities and poor branding of agroecological products - Limited access to agricultural credit
Kamonyi (Burundi)	- Strong legal framework guaranteeing equal land rights for women - Active farmer cooperatives and networks - Government subsidies for	- Climate change impacts (droughts, variability) - Cultural norms and traditions limiting women's influence in decision-making - Low infrastructure and post-harvest

	seeds and fertilizers - Presence of agronomists, facilitators, and extension services - Knowledge-sharing platforms (local radio, cooperatives) - Willingness of farmers to increase production and self-development - Access to markets and participation in price regulation through cooperatives	facilities (storage, processing) - Limited capital and access to credit - Lack of crop and animal insurance - Weak knowledge of organic manure and traditional pest control - Youth migration to cities seeking jobs

3.6.4. perception of strength, weakness, opportunities and threats of surveyed productions systms

The SWOT provides a diagnostic overview by takeholders (Table 20).

Table 20. SWOT Synthesis table

Dimension	Strengths	Weaknesses	Opportunities	Challenges/Threats
Bunia/ Mambasa (DRC)	Favorable climate and fertile soils; Adoption of the coa-tree intercropping; Existence of cooperatives; organic cacao production	Weak recycling; women marginalization; youth migration to mining; poor roads	NGO and other partners' support	Insecurity (mainly by ADF armed group); pests/diseases; exclusion from governance
Uvira (DRC)	Farmers knowledge of irrigated rice production technologies; Huge potential of irrigation; ALL location at border of 3 conuntries	Low diversity and synergies in rice production; Reliance on pesticides; weak resilience	NGOs; cooperatives structuring	fragile governance; youth disengagement, insecurity
Kabare (DRC)	Farmer motivation; Existence of family labor; farmers coffee production experience	Climate impacts; varietal degeneration; weak farmer organizations; poor tools	Existence of external markets; NGO support	Climate change; unstable prices; youth disinterest; weak national governance
Biega (DRC)	Existence of farmsStrong crop-tree-animal integration; high efficiency; social values; fertile soils	Weak recycling; low resilience; limited diversification	partner support, Farmer networks; agroforestry expansion	Climate change vulnerability; youth migration pressures
Ntui (Cameroon)	Fertile soils; full integration crops-livestock-aquaculture; organic adoption; strong institutions	Low economic diversity; poor soil management in some areas	Policy support (MINADER); extension services; farmer ambition	Climate adaptation gaps; weak AE market organization
Giheta (Burundi)	High adoption of AE practices; strong women's participation; robust local knowledge; partnerships (University, COCOCA, Naturland)	Economic vulnerability; seasonal food insecurity; fragile soils; youth migration	Growing demand for AE products; agroforestry scaling; NGO & research support	Land tenure insecurity (women); climate variability; limited value addition; external misperceptions
Bujumbura (Burundi)	- Farmers' willingness to adopt agroecological practices - Active involvement of women in production and marketing - Existing cooperatives and farmer associations (CAPAD, ISABU) - Support from NGOs and national research institutions - Proximity to large urban markets (hotels, restaurants in Bujumbura) - Availability of extension services and multi-stakeholder partnerships	- High production costs and underdeveloped market access for agroecological products - Soil degradation pressure - Limited youth involvement in agriculture (migration) - Land tenure constraints for women (customary/traditional laws) - Lack of storage facilities and poor branding of agroecological products - Limited access to agricultural credit	- Located near large consumer markets - Support from NGOs and national institutions - Potential for certification and fair pricing of agroecological products - Farmer training and knowledge exchange platforms	- Climate variability (droughts, erratic rainfall) - Land scarcity and pressure - Risk of seed dependency - Migration of youth reduces labor force - Lack of agri-food industries
Kamonyi (Rwanda)	- Strong legal framework guaranteeing equal land rights for women - Active farmer cooperatives and networks - Government subsidies for seeds and fertilizers	- Cultural norms and traditions limiting women's influence in decision-making - Low infrastructure and post-harvest facilities (storage, processing)	- Knowledge-sharing networks and multiple stakeholders engaged - Financial institutions open to supporting farmers	- Climate change impacts (droughts, variability) - Market volatility and price fluctuations - Low availability of infrastructure - Persistent cultural norms restricting

	- Presence of agronomists, facilitators, and extension services - Knowledge-sharing platforms (local radio, cooperatives) - Farmers' willingness for self-development and increased production - Access to markets and participation in price regulation through cooperatives	- Limited capital and access to credit - Lack of crop and animal insurance - Weak knowledge of organic manure and traditional pest control - Youth migration to cities seeking jobs	- Potential to strengthen post-harvest handling and infrastructure - Expansion of training workshops and peer learning	gender equality - Risk of reduced youth engagement in agriculture

3.6.5.Priority Action Ranking of AEP

The Priority Action Ranking (table below) translates results into ALLs' priorities perceived by stakeholders, showing where collective effort should focus first.

Table 22. Priority Action Ranking Table (Consolidated Across ALLs)

Proposed Action	Sites Prioritizing	Votes/Validation	Regional Rank
Land tenure security (esp. for women & youth)	Ntui, Bunia, Kabare, Giheta	Ntui (priority), Giheta (9 votes), Bunia (recommendation)	**1**
Agroecological markets & cooperative structuring	Bunia, Kabare, Ntui, Giheta, Kamonyi, Bujumbura	Bunia (cooperatives), Kabare (market regulation), Ntui (market org.), Giheta (solidarity economy)	**2**
Training on composting & soil management	Bunia, Kabare, Ntui, Giheta, kamonyi, bujumbura	Bunia (recommendation), Ntui (training need), Giheta (soil restoration)	**3**
Youth-targeted support (incubators, micrograts)	Giheta, Ntui, Bunia, Kabare	Giheta (10 votes), Ntui (youth inclusion), Bunia (youth migration issue)	**4**
Women-targeted support (land rights, empowerment)	Giheta, Bunia, Kabare, Uvira	Giheta (strong emphasis), Bunia (marginalization noted), Kabare & Uvira (weak empowerment)	**5**
Resilience & climate adaptation (shade trees, irrigation)	Ntui, Bunia, Kabare, Uvira	Ntui (100%), Bunia (shade trees), Uvira (irrigation), Kabare (climate stress)	**6**
Agroecological processing/value addition	Kabare, Giheta, kamonyi, Bujumbura	Giheta (12 votes for processing unit), Kabare and Kamonyi (coffee processing infrastructure)	**7**

The validation workshops held across the six Living Labs (Bunia/Mambasa, Uvira, Kabare, Biega, Ntui, and Giheta) confirmed both notable strengths and persistent gaps in agroecological transitions. To ensure that findings translate into actionable steps, participants collectively identified the following priority areas:

-Land tenure security

a.Farmers stressed the need for reliable and equitable land titles, particularly for women and youth.

b.Secure tenure was recognized as the cornerstone for long-term investment in agroecological practices and resilience.
-Agroecological markets
a.Producers across sites emphasized the importance of structured markets for cocoa, coffee, rice, and diversified crops.
b.Strengthening cooperatives, local food systems, and fair-trade channels was seen as essential to increase added value and stabilize incomes.
-Training in composting and soil management
a.Weak recycling practices and poor soil fertility management emerged as recurrent challenges.
b.Farmers requested hands-on training in composting, biomass recycling, and integrated soil management to enhance productivity and sustainability.
-Support for women and youth
a.Women's empowerment and youth retention were identified as critical social dimensions.
b.Agreed priorities included legal literacy for women's land rights, youth incubators for agroecological entrepreneurship, and tailored training programs to foster inclusive participation.

Chapter 4. DISCUSSION

4.1. Socio-Demographic and Agroecological Determinants of Transition Pathways

4.1.1. Household Structure, Labour Dynamics, and Transition Capacity

The baseline assessment reveals pronounced socio-demographic heterogeneity across the Agroecological Living Labs (ALLs), which fundamentally shapes agroecological transition pathways. Large household sizes combined with high dependency ratios—particularly in Uvira and Biega—create immediate consumption pressures that increase vulnerability, while simultaneously constituting latent labour potential as younger cohorts mature. This structural imbalance helps explain why relatively high agroecological engagement observed under **TAPE Step 1 (CAET)** does not systematically translate into strong economic outcomes under **Step 2**, especially in fragile and conflict-affected contexts of eastern DR Congo.

Household mobility further conditions transition dynamics. In Bunia and Ntui, the temporary or prolonged absence of adult men—linked to insecurity, seasonal migration, or livelihood diversification—reduces available on-farm labour and weakens intergenerational knowledge transmission. At the same time, off-farm income diversification can buffer risk. Uneven CAET scores in governance-related and labour-intensive practices should therefore be interpreted less as reluctance to adopt agroecology and more as a reflection of labour constraints and household reconfiguration.

Across all ALLs, labour remains predominantly family-based, with women and youth playing central roles. While this configuration supports diversification, recycling, and cultural practices (Step 1), it constrains productivity gains (Step 2) due to labour bottlenecks. Moderate reliance on hired labour increases production costs and negatively affects economic performance, reinforcing the structural tension between ecological intensification and labour productivity documented in agroecological systems (Tittonell et al., 2012; Wezel et al., 2016).

4.1.2. Land Use Patterns and Agroecological Practice Portfolios

Land availability and land-use patterns strongly differentiate transition pathways. Small and intensively managed farms in Rwanda and Burundi (Kamonyi, Giheta) contrast sharply with larger, fragmented systems in Kabare, Uvira, and Biega, where resilience, diversification, and risk management take precedence over yield maximization. These differences illustrate that agroecological transition is not a uniform trajectory but a context-adapted process shaped by land pressure, tenure arrangements, and ecological potential.

Tree-based and agroforestry systems are well developed in Kabare, Ntui, and Biega, enhancing biodiversity-based practices and long-term ecological functions. Conversely, Bunia and Bujumbura display limited tree integration, constraining opportunities for ecological intensification and carbon-based resilience strategies. Although non-timber forest products remain marginal overall, their relative importance in Ntui highlights localized innovation niches with scaling potential.

4.1.3. Differentiated Production Systems and Livelihood Strategies

Crop production remains the backbone of all farming systems, confirming its central role in food security and livelihoods. However, the integration of livestock, trees, and diversification niches varies markedly, generating distinct agroecological profiles across ALLs. Livestock emerges as a key differentiator: strong integration in Uvira and Biega supports recycling and nutrient cycling, whereas its near absence in Bunia reflects structural fragility and limited diversification capacity.

Complementary activities such as beekeeping, composting, and small-scale processing remain rare and largely experimental, appearing sporadically in Kamonyi, Ntui, and Uvira. Their limited diffusion indicates that most systems remain in early or intermediate stages of transition, where practice-level adoption has not yet matured into fully integrated agroecological systems.

4.1.4. Market Orientation versus Subsistence Pathways

Production destination further distinguishes livelihood strategies. Bunia, Ntui, and Uvira display stronger market orientation, aligning with commercialization pathways but increasing exposure to price volatility and insecurity. In contrast, Bujumbura, Giheta, Kabare, and Kamonyi remain predominantly subsistence-oriented, prioritizing food security over income generation. Biega stands out for its overwhelming self-consumption orientation, shaped by demographic pressure, isolation, and weak market integration.

These contrasts help explain the divergence between relatively strong CAET scores and modest economic performance outcomes, underscoring that agroecological transition does not automatically translate into income gains without parallel market and institutional support (Duru et al., 2015; HLPE, 2019).

4.1.5. Implications for stakeholders' Validation stage

Taken together, these findings confirm that agroecological transition unfolds within highly heterogeneous production systems embedded in demographically young, labour-constrained, and land-pressured households. High dependency ratios, mobility, and tenure insecurity shape both adoption trajectories (Step 1) and performance outcomes (Step 2). TAPE Step 3 validation results must therefore be explicitly understood as these socio-demographic and agroecological realities to avoid unrealistic expectations and to support differentiated, context-adapted transition pathways.

4.2. Agroecological transition (CAET) in Context

4.2.1. Overall CAET Patterns and Variability

The mean CAET score of 45.6 indicates a moderate level of agroecological transition across the eight ALLs. Substantial variability is observed, with Bunia (53.8) emerging as the highest-performing site, while Giheta (32.9) and Bujumbura (34.3) rank lowest. These differences reflect localized combinations of governance quality, ecological conditions, institutional support, and community engagement (Tittonell, 2014).

High-performing sites—Bunia, Kamonyi, Uvira, and Kabare—demonstrate relatively strong governance, cultural embeddedness, and collective economic mechanisms, making them potential reference points for horizontal learning. Conversely, low-performing sites require targeted interventions to strengthen biodiversity, resilience, and recycling.

4.2.2. Strengths Identified under Step 1 (CAET)

Several dimensions consistently score high across ALLs. It was found that Circular and Solidarity Economy (52.1) reflects the presence of collective mechanisms, mutual aid, and local exchange systems supporting smallholders (Altieri & Nicholls, 2017). Co-creation and Sharing of Knowledge (50.0) indicates functioning spaces for farmer-to-farmer learning and participatory innovation (Vanloqueren & Baret, 2009). Culture and Food Traditions (48.1) highlight the role of traditional diets and practices in sustaining biodiversity and social cohesion (FAO, 2021).

These strengths suggest that social and cultural foundations for agroecological transition are already present, even where economic performance remains limited.

4.2.3. Persistent Weaknesses and Structural Constraints

Despite these strengths, several dimensions remain weak such as Diversity (33.6) reflects continued reliance on simplified cropping systems, limiting ecological resilience (Perfecto et al., 2009); Resilience (39.0) indicates vulnerability to climatic, economic, and biotic shocks (IPCC, 2022) and; Recycling (41.8) reveals underutilization of organic matter and nutrient flows (Pretty et al., 2018).

These weaknesses point to transition bottlenecks common in early agroecological trajectories, where practice adoption precedes systemic integration (Tittonell et al., 2015).

4.2.4. Socio-Economic, Gender, and Environmental Dimensions

Land tenure security varies significantly, influencing long-term investment decisions. While Bunia and Uvira report over 50% secure tenure, Giheta and Ntui remain characterized by insecurity, exacerbating conflict risks (FAO, 2017; O'Connor et al., 2021). Gender disparities are pronounced: only 27.6% of female-headed households fall in the "green" tenure category, compared to 46% for male-headed households, underscoring the need for gender-responsive land governance.

Environmental indicators show contrasting patterns: Uvira and Ntui exhibit relatively good soil conditions, while Giheta and Kamonyi face degradation. Food insecurity remains acute in Biega and Kabare, whereas Bunia displays comparatively favorable outcomes. These results confirm that **high CAET scores in diversification and recycling are structurally feasible**, but labour constraints and institutional gaps limit productivity and food security gains (Steps 1–2).

4.3. Cross-Cutting Relationships Between Practices and Performance

The analysis confirms that agroecological performance is multidimensional and characterized by trade-offs rather than linear gains. No single agroecological dimension significantly explains total productivity, reinforcing evidence that agroecology prioritizes stability, efficiency, and resilience over short-term yield maximization (Tittonell et al., 2012; Ponisio et al., 2015).

Recycling practices are negatively associated with productivity per person, reflecting labour-intensive biomass management (Gliessman, 2015). Circular economy practices show short-term income trade-offs, consistent with transition-phase dynamics (Duru et al., 2015). Responsible governance, however, is positively associated with income, highlighting the mediating role of institutions and markets (FAO, 2018; Anderson et al., 2020).

Women's empowerment is strongly enhanced by co-creation and knowledge-sharing, while cultural norms may simultaneously constrain agency, confirming that agroecological transitions are inherently political and socially embedded (Kabeer, 2012; HLPE, 2019).

4.4. Leverage Points for Agroecological Transition

The baseline identifies multiple leverage points: strengthening extension and learning systems; improving access to finance and water management; reforming policies that favor conventional inputs; investing in agroecological markets and value chains; and reinforcing knowledge-sharing networks. Climate change, insecurity, and weak institutions exacerbate vulnerabilities, underscoring the need for coordinated interventions across policy, training, finance, and markets.

4.5. Evaluation and Adaptation of TAPE as a Baseline Tool

4.5.1. Strengths and Limitations of TAPE

TAPE provides a coherent and participatory framework anchored in FAO's Ten Elements of Agroecology. However, its standardized indicators may underrepresent informal, hybrid, or politically mediated transition pathways, particularly in fragile contexts such as eastern DR Congo. Semi-quantitative scoring introduces subjectivity, and the cross-sectional design limits the capture of long-term dynamics.

4.5.2. Context-Specific Biases and Mitigation Strategies

Sampling bias, social desirability effects, and intercultural interpretation challenges were evident. To strengthen future applications, triangulation with qualitative data, explicit documentation of sampling and scoring protocols, and avoidance of simplistic cross-country rankings are recommended. TAPE should be used as a dialogical and learning-oriented baseline, not as a benchmarking or ranking instrument (FAO, 2019).

4.6. Improving TAPE as a Tool

Fieldwork across the eight ALLs highlighted several indices requiring adjustment, others of lower importance, and the need for new criteria. The following recommendations aim to ensure that TAPE remains both scientifically rigorous and locally relevant.

4.6.1. Indices Requiring Modification

-External inputs (seed quality) ***Challenge:*** Current scoring emphasizes seed origin but overlooks quality, leading to inflated scores even where seed diseases are prevalent. ***Recommendation:*** Integrate a **seed quality sub-indicator** (e.g., germination rate, disease resistance, certification status) alongside origin. This would prevent misleadingly high scores and align with farmers' real production outcomes.

-Crop–livestock integration (livestock roaming)

Challenge: Free roaming of animals is common but unsustainable, yet current scoring rewards livestock presence.

Recommendation: Differentiate between managed integration (stall feeding, rotational grazing, manure recycling) and uncontrolled roaming. Only managed practices should increase scores, while roaming should be neutral or penalized.

-Food self-sufficiency

Challenge: Current scoring inflates self-sufficiency by ignoring reliance on market purchases. ***Recommendation:*** Adjust the indicator to measure dietary diversity and nutritional adequacy, combining farm production with market access. This would reflect the real contribution of agroecology to household food security.

-Local market products and services

Challenge: Existence of local markets alone is not a reliable indicator. ***Recommendation:*** Refocus the indicator on market stability and fairness (e.g., presence of long-term buyers, fair trade channels, price stability). This would better capture whether markets truly support agroecological transition.

4.6.2. Indices of Lower Importance (to be Weighted)

-Waste management ***Challenge:*** Villages generate little waste, yet scores are disproportionately low. ***Recommendation:*** Reduce the weight of this indicator and emphasize organic waste recycling practices (composting, biochar) rather than absolute waste volumes.

-Energy use and renewables

Challenge: Reliance on wood/charcoal is common, but charcoal from waste is not recognized. ***Recommendation:*** Broaden the indicator to include innovative local energy practices (charcoal from waste, small-scale solar, biogas), and weight it moderately.

-Traditional food heritage ***Challenge:*** Practices remain traditional, but globalization influences urban areas. ***Recommendation:*** Keep scores moderate, but add a trend indicator to track erosion or revival of traditional practices over time.

-Local sourcing and circularity ***Challenge:*** Current indicators fail to reflect access to quality inputs. ***Recommendation:*** Refine to measure availability and reliability of inputs (vaccines, seeds, medicines), regardless of origin, with emphasis on quality and accessibility.

4.6.3. Performance Criteria

Challenge: Thresholds in the “traffic light” approach rely on outdated or unavailable national datasets.

Recommendation: Replace national averages with locally validated benchmarks (e.g., community surveys, Living Lab data). Develop context-sensitive thresholds that reflect heterogeneity across ALLs, ensuring accuracy in countries with weak statistical systems.

4.6.4. Addition of New Criteria

-Decent work

Recommendation: Introduce an indicator on working conditions (tools, equipment, labor availability, income security). This aligns TAPE with SDG 8 (Decent Work) and highlights gaps in farm labor sustainability.

-Definition of a "rich" farmer ***Recommendation:*** Establish context-specific socio-economic benchmarks through participatory workshops (e.g., cattle ownership, housing type, land size). This would prevent misclassification and improve comparability across countries.

-Physical access to markets

Recommendation: Add an indicator on **market accessibility** (distance, infrastructure quality, security). This would capture real constraints on farmers' ability to trade, beyond mere market existence.

Chapter 5. CONCLUSIONS

This baseline assessment confirms that agroecological transition across the CANALLS Agroecological Living Labs is real, endogenous, and socially embedded, yet uneven and structurally constrained. Agroecology in the studied territories is not an external model imposed on farmers, but rather a process that builds upon existing practices, knowledge systems, and cultural traditions. However, the extent to which these practices translate into improved ecological, economic, and social performance remains highly dependent on structural conditions.

The TAPE-based analysis reveals that most farming systems are in an intermediate stage of transition, with important strengths in socio-cultural dimensions and knowledge co-creation, but persistent weaknesses in diversity, resilience, and economic outcomes. The consistently low diversity scores across all ALLs represent a fundamental limitation to long-term system stability, while variations in efficiency, recycling, and synergies reflect differences in system integration, labour availability, and institutional support.

A central conclusion of this study is that farm household typology is a stronger determinant of agroecological performance than geographic location alone. Smallholder subsistence-oriented farms face cumulative constraints related to land scarcity, labour pressure, insecure tenure, and limited access to services, placing them at the core of priority transition support. Labour-intensive family farms show promising agroecological engagement but remain vulnerable to demographic and mobility dynamics.

Large land-endowed farms, although rare, illustrate the potential for higher ecological integration when resource constraints are relaxed.

Economic performance results further demonstrate that agroecological transition does not follow a linear path from practice adoption to income gains. In several contexts, short-term productivity is achieved through unsustainable practices, while more ecologically sound systems remain economically constrained due to weak markets, limited value addition, and policy misalignment. This confirms that agroecology cannot succeed through farm-level interventions alone, but requires enabling market, governance, and institutional environments.

Land tenure insecurity—particularly for women—and the widespread lack of decent employment opportunities for youth emerge as cross-cutting barriers that threaten the sustainability of agroecological transitions. The positive experience of Kamonyi illustrates that coherent policies, secure land rights, and effective extension systems can significantly enhance agroecological performance.

This baseline provides a clear and actionable diagnosis for the CANALLS project. It highlights that advancing agroecological transition requires tailored, multi-level, and socially inclusive strategies, addressing not only practices but also land governance, knowledge systems, markets, and social equity. The findings offer a solid foundation for TAPE STEP 3 validation, enabling stakeholders to co-design realistic and differentiated transition pathways that transform existing agroecological potential into durable and equitable outcomes.

Importantly, the field validation also highlighted the need to **improve TAPE as a tool**. Several indices require modification to better capture local realities (e.g., seed quality, managed crop–livestock integration, realistic measures of food self-sufficiency, and market stability). Others should be weighted differently to avoid disproportionate influence (e.g., waste management, energy use, traditional food heritage). Performance thresholds must be recalibrated using locally validated benchmarks rather than outdated national datasets. Finally, new criteria such as decent work, context-specific definitions of wealth, and physical access to markets should be integrated to ensure that TAPE reflects both ecological and socio-economic dimensions of transition. These refinements will make TAPE more robust, context-sensitive, and actionable for guiding agroecological policy and practice.

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APPENDIX

Annex1. Anova2: cluster*ALL

Variable	F_ALL	F_ALL: Cluster	F_Cluster	df_ ALL	df_ALL: Cluster	df_ Cluster	p-value_ ALL	p-value_ ALL:Cluster	p-value_ Cluster
CIRCULAR AND SOLIDARITY ECONOMY	4,98E-14	16,68618	3,902452	7	14	2	1	1,92E-33	0,02084
Co CREATION AND SHARING OF KNOWLEDGE	1,97E-13	5,747377	2,312944	7	14	2	1	2,11E-10	0,100078
CULTURE AND FOOD TRADITIONS	1,67E-13	10,76388	1,390063	7	14	2	1	2,12E-21	0,250067
DIVERSITY	-1,1E-12	5,387294	2,287758	7	14	2	1	1,33E-09	0,102606
EFFICIENCY	4,75E-13	39,83394	17,23935	7	14	2	1	4,37E-71	5,91E-08
HUMANS AND SOCIETAL VALUES	2,4E-13	11,84172	0,754991	7	14	2	1	1,12E-23	0,470576
RECLYCLING	-1,4E-13	9,097275	0,457107	7	14	2	1	8,27E-18	0,633389
RESILIENCE	1,81E-13	6,254541	2,194887	7	14	2	1	1,56E-11	0,112495
RESPONSIBLE GOVERNANCE	-3,5E-14	9,749898	0,950041	7	14	2	1	3,17E-19	0,387456
STEP1résumé	-2,8E-15	16,23698	4,174752	7	14	2	1	1,43E-32	0,015945
SYNERGIES	1,84E-15	7,89495	4,61242	7	14	2	1	3,58E-15	0,010375

Annex 2. **RESULTATS MODELE LINEAIRE MIXTE**

1. Total productivity of the household

```
jv<-
lmer(Tproductivity~DIVERSITY+SYNERGIES+EFFICIENCY+RECLYCLING+RESILIENCE+CULTURE+COCREATION+HUMANS_VALUES+CIRCULAR_ECONOMY+RESPONSIBLE_GOVERNANCE+(1|ALL),data=AI)
Message d'avis :
Dans as_lmerModLT(model, devfun) :
  Model may not have converged with 1 eigenvalue close to zero: 5.5e-13
> summary(jv)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: Tproductivity ~ DIVERSITY + SYNERGIES + EFFICIENCY + RECLYCLING +
    RESILIENCE + CULTURE + COCREATION + HUMANS_VALUES + CIRCULAR_ECONOMY + RESPONSIBLE_GOVERNANCE + (1 | ALL)
   Data: AI

REML criterion at convergence: 18783.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-0.8541 -0.1315 -0.0453  0.0416 16.3376

Random effects:
 Groups   Name        Variance  Std.Dev.
 ALL      (Intercept) 1.879e+14 13707308
 Residual             3.458e+15 58805134
Number of obs: 494, groups:  ALL, 8

Fixed effects:
```

```
                  Estimate Std. Error        df t value Pr(>|t|)
(Intercept)          7.717e+06  1.286e+07  7.393e+01   0.600   0.5503
DIVERSITY            -1.636e+05  2.468e+05  1.019e+04  -0.663   0.5073
SYNERGIES            -2.122e+05  2.297e+05  7.707e+04  -0.924   0.3556
EFFICIENCY           -1.460e+05  1.968e+05  1.575e+02  -0.742   0.4594
RECLYCLING             9.540e+04  1.955e+05  2.322e+03   0.488   0.6257
RESILIENCE           -4.209e+04  2.238e+05  1.588e+04  -0.188   0.8509
CULTURE              -4.568e+04  1.992e+05  1.403e+04  -0.229   0.8186
COCREATION           -8.820e+04  1.650e+05  5.067e+04  -0.535   0.5930
HUMANS_VALUES         3.690e+05  2.147e+05  1.704e+04   1.719   0.0857 .
CIRCULAR_ECONOMY     -1.537e+04  1.937e+05  6.940e+03  -0.079   0.9367
RESPONSIBLE_GOVERNANCE  1.470e+05  1.657e+05  8.390e+03   0.887   0.3752
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) DIVERS SYNERG EFFICI RECLYC RESILI CULTUR COCREA HUMANS CIRCUL
DIVERSITY   -0.179
SYNERGIES    0.033 -0.419
EFFICIENCY  -0.272 -0.129 -0.156
RECLYCLING  -0.123  0.039 -0.126 -0.124
RESILIENCE  -0.007 -0.315 -0.037  0.020 -0.117
CULTURE      0.019  0.107 -0.156 -0.211 -0.179 -0.194
COCREATION  -0.024  0.042 -0.033 -0.056 -0.072 -0.189  0.014
HUMANS_VALU -0.322 -0.071  0.042 -0.073  0.032 -0.055 -0.219 -0.113
CIRCULAR_EC -0.179  0.057 -0.146 -0.068 -0.043 -0.016 -0.139 -0.155 -0.127
RESPONSIBLE -0.042  0.082 -0.123  0.080 -0.120 -0.098 -0.036 -0.313 -0.093 -0.212
```

2.Productivity per person living in a household

```
>summary(jv1)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: proctivity_pers ~ DIVERSITY + SYNERGIES + EFFICIENCY + RECLYCLING +
    RESILIENCE + CULTURE + COCREATION + HUMANS_VALUES +
CIRCULAR_ECONOMY + RESPONSIBLE_GOVERNANCE + (1 | ALL)
   Data: AI

REML criterion at convergence: 31116.3

Scaled residuals:
    Min      1Q  Median      3Q     Max
-0.6679 -0.1763 -0.0430  0.0826 21.1469

Random effects:
```

```
 Groups   Name        Variance  Std.Dev.
 ALL      (Intercept) 0.000e+00 0.00e+00
 Residual             1.274e+27 3.57e+13
Number of obs: 486, groups:  ALL, 8

Fixed effects:
                      Estimate Std. Error        df t value Pr(>|t|)
(Intercept)          3.050e+12  6.351e+12  1.546e+70   0.480  0.63108
DIVERSITY           -1.153e+11  1.453e+11  1.546e+70  -0.794  0.42747
SYNERGIES            9.190e+10  1.398e+11  1.546e+70   0.657  0.51102
EFFICIENCY          -1.262e+11  9.483e+10  1.546e+70  -1.331  0.18318
RECLYCLING          -2.973e+11  1.129e+11  1.546e+70  -2.632  0.00848 **
RESILIENCE           2.583e+11  1.338e+11  1.546e+70   1.931  0.05354 .
CULTURE              2.027e+11  1.185e+11  1.546e+70   1.711  0.08716 .
COCREATION          -1.129e+11  9.902e+10  1.546e+70  -1.140  0.25409
HUMANS_VALUES        1.432e+11  1.277e+11  1.546e+70   1.121  0.26214
CIRCULAR_ECONOMY    -1.351e+09  1.143e+11  1.546e+70  -0.012  0.99057
RESPONSIBLE_GOVERNANCE -6.768e+10  9.686e+10  1.546e+70  -0.699  0.48470
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) DIVERS SYNERG EFFICI RECLYC RESILI CULTUR COCREA HUMANS CIRCUL
DIVERSITY   -0.277
SYNERGIES    0.056 -0.434
EFFICIENCY  -0.160 -0.157 -0.223
RECLYCLING  -0.207  0.091 -0.105 -0.110
RESILIENCE  -0.003 -0.296 -0.017  0.075 -0.131
CULTURE      0.012  0.103 -0.155 -0.193 -0.172 -0.243
COCREATION  -0.055  0.017 -0.030 -0.044 -0.082 -0.178  0.009
HUMANS_VALU -0.336 -0.041  0.045 -0.065  0.037 -0.085 -0.245 -0.104
CIRCULAR_EC -0.102  0.090 -0.171 -0.110 -0.063 -0.029 -0.135 -0.153 -0.180
RESPONSIBLE -0.052  0.081 -0.152  0.145 -0.096 -0.092 -0.017 -0.311 -0.107 -0.237
optimizer (nloptwrap) convergence code: 0 (OK)
boundary (singular) fit: see help('isSingular')
```

3. revenue

```
jv2<-
lmer(revenu~DIVERSITY+SYNERGIES+EFFICIENCY+RECLYCLING+RESILIENCE+CULTURE+COCREATION+HUMANS_VALUES+CIRCULAR_ECONOMY+RESPONSIBLE_GOVERNANCE+(1|ALL),data=AI)
> summary(jv2)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
```

```
Formula: revenu ~ DIVERSITY + SYNERGIES + EFFICIENCY + RECLYCLING + RESILIENCE +
    CULTURE + COCREATION + HUMANS_VALUES + CIRCULAR_ECONOMY +
RESPONSIBLE_GOVERNANCE + (1 | ALL)
   Data: AI

REML criterion at convergence: 11818.8

Scaled residuals: 
    Min      1Q  Median      3Q     Max 
-9.9075 -0.0966  0.0821  0.3087  5.0241 

Random effects:
 Groups   Name        Variance  Std.Dev.
 ALL      (Intercept) 1.382e+09 37169   
 Residual             6.977e+09 83527   
Number of obs: 469, groups:  ALL, 8

Fixed effects:
                       Estimate Std. Error       df t value Pr(>|t|)  
(Intercept)            -7544.23   22776.23    41.40  -0.331   0.7421  
DIVERSITY               -454.30     363.67   456.28  -1.249   0.2122  
SYNERGIES                371.87     333.18   453.94   1.116   0.2650  
EFFICIENCY               -57.67     308.42   345.05  -0.187   0.8518  
RECLYCLING               -52.42     296.60   457.45  -0.177   0.8598  
RESILIENCE               470.72     329.56   455.93   1.428   0.1539  
CULTURE                   56.40     294.08   456.84   0.192   0.8480  
COCREATION              -391.57     238.75   454.34  -1.640   0.1017  
HUMANS_VALUES             71.91     320.59   455.98   0.224   0.8226  
CIRCULAR_ECONOMY        -716.92     287.25   457.84  -2.496   0.0129 *
RESPONSIBLE_GOVERNANCE   455.12     243.00   457.41   1.873   0.0617 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) DIVERS SYNERG EFFICI RECLYC RESILI CULTUR COCREA HUMANS CIRCUL
DIVERSITY   -0.152                                                               
SYNERGIES    0.025 -0.410                                                        
EFFICIENCY  -0.268 -0.140 -0.129                                                 
RECLYCLING  -0.077  0.032 -0.117 -0.149                                          
RESILIENCE  -0.034 -0.297 -0.043  0.007 -0.134                                   
CULTURE      0.033  0.116 -0.176 -0.221 -0.185 -0.188                            
COCREATION  -0.026  0.050 -0.040 -0.054 -0.078 -0.185  0.031                     
HUMANS_VALU -0.290 -0.091  0.053 -0.046  0.016 -0.020 -0.237 -0.109              
```

CIRCULAR_EC -0.188 0.074 -0.138 -0.064 -0.031 -0.006 -0.128 -0.151 -0.127
RESPONSIBLE -0.019 0.070 -0.122 0.067 -0.128 -0.087 -0.031 -0.312 -0.094 -0.220

4.agricultural diversity
summary(jv3)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: diversity_ag ~ DIVERSITY + SYNERGIES + EFFICIENCY + RECLYCLING + RESILIENCE + CULTURE + COCREATION + HUMANS_VALUES + CIRCULAR_ECONOMY + RESPONSIBLE_GOVERNANCE + (1 | ALL)
Data: AI

REML criterion at convergence: 4336.3

Scaled residuals:

Min	1Q	Median	3Q	Max
-2.76737	-0.73088	-0.00629	0.87274	1.98702

Random effects:

Groups	Name	Variance	Std.Dev.
ALL	(Intercept)	46.47	6.817
Residual		356.19	18.873

Number of obs: 493, groups: ALL, 8

Fixed effects:

	Estimate	Std. Error	df	t value	Pr(>|t|)	
(Intercept)	50.310406	4.634676	46.070891	10.855	2.75e-14	***
DIVERSITY	0.162142	0.079748	481.905511	2.033	0.0426	*
SYNERGIES	0.013906	0.073925	478.583952	0.188	0.8509	
EFFICIENCY	-0.104074	0.066805	272.031502	-1.558	0.1204	
RECLYCLING	0.003608	0.063660	475.560249	0.057	0.9548	
RESILIENCE	-0.150352	0.072244	481.465698	-2.081	0.0379	*
CULTURE	0.112212	0.064286	481.657448	1.746	0.0815	.
COCREATION	0.041355	0.053209	479.113208	0.777	0.4374	
HUMANS_VALUES	-0.001732	0.069363	481.438678	-0.025	0.9801	
CIRCULAR_ECONOMY	-0.062742	0.062691	481.784688	-1.001	0.3174	
RESPONSIBLE_GOVERNANCE	0.098724	0.053582	481.994804	1.842	0.0660	.

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
(Intr) DIVERS SYNERG EFFICI RECLYC RESILI CULTUR COCREA HUMANS CIRCUL
DIVERSITY -0.151
SYNERGIES 0.025 -0.417
EFFICIENCY -0.278 -0.124 -0.141

```
RECLYCLING  -0.098  0.030 -0.130 -0.132
RESILIENCE  -0.005 -0.319 -0.038  0.008 -0.111
CULTURE      0.021  0.109 -0.158 -0.217 -0.181 -0.187
COCREATION  -0.016  0.049 -0.034 -0.060 -0.070 -0.193  0.016
HUMANS_VALU -0.297 -0.079  0.044 -0.072  0.031 -0.047 -0.215 -0.118
CIRCULAR_EC -0.182  0.050 -0.142 -0.054 -0.042 -0.014 -0.138 -0.155 -0.116
RESPONSIBLE -0.036  0.083 -0.120  0.066 -0.124 -0.099 -0.038 -0.312 -0.091 -0.206
```

5.Diet score

```
jv4<-
lmer(Dietscore~DIVERSITY+SYNERGIES+EFFICIENCY+RECLYCLING+RESILIENCE+CULTURE+COCREATION+HUMANS_VALUES+CIRCULAR_ECONOMY+RESPONSIBLE_GOVERNANCE+(1|ALL),data=AI)
> summary(jv4)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: Dietscore ~ DIVERSITY + SYNERGIES + EFFICIENCY + RECLYCLING +
    RESILIENCE + CULTURE + COCREATION + HUMANS_VALUES +
CIRCULAR_ECONOMY + RESPONSIBLE_GOVERNANCE + (1 | ALL)
   Data: AI

REML criterion at convergence: 2104

Scaled residuals:
    Min      1Q  Median      3Q     Max 
-2.6856 -0.7279 -0.0080  0.6442  3.2721 

Random effects:
 Groups   Name        Variance Std.Dev.
 ALL      (Intercept) 0.9775   0.9887  
 Residual             3.4053   1.8453  
Number of obs: 494, groups:  ALL, 8

Fixed effects:
                        Estimate Std. Error         df t value Pr(>|t|)    
(Intercept)             3.798208   0.526873  28.573417   7.209 6.73e-08 ***
DIVERSITY               0.005067   0.007820 480.781034   0.648    0.517    
SYNERGIES               0.006387   0.007235 478.146705   0.883    0.378    
EFFICIENCY             -0.011012   0.006729 423.769733  -1.637    0.102    
RECLYCLING              0.008443   0.006265 482.974615   1.348    0.178    
RESILIENCE              0.007635   0.007081 480.161815   1.078    0.281    
CULTURE                -0.004822   0.006304 480.446362  -0.765    0.445    
COCREATION              0.006241   0.005201 478.467294   1.200    0.231    
HUMANS_VALUES           0.006226   0.006791 480.151379   0.917    0.360    
CIRCULAR_ECONOMY        0.005795   0.006156 481.834878   0.941    0.347    
```

```
RESPONSIBLE_GOVERNANCE   0.005321   0.005257 481.050353   1.012    0.312
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) DIVERS SYNERG EFFICI RECLYC RESILI CULTUR COCREA HUMANS CIRCUL
DIVERSITY   -0.126
SYNERGIES    0.019 -0.415
EFFICIENCY  -0.256 -0.120 -0.133
RECLYCLING  -0.079  0.024 -0.131 -0.136
RESILIENCE  -0.003 -0.320 -0.040  0.001 -0.108
CULTURE      0.020  0.110 -0.158 -0.220 -0.182 -0.183
COCREATION  -0.013  0.050 -0.032 -0.060 -0.072 -0.193  0.017
HUMANS_VALU -0.260 -0.081  0.043 -0.074  0.033 -0.045 -0.213 -0.116
CIRCULAR_EC -0.167  0.047 -0.141 -0.047 -0.042 -0.014 -0.137 -0.155 -0.110
RESPONSIBLE -0.031  0.083 -0.118  0.060 -0.126 -0.099 -0.038 -0.313 -0.089 -0.203
```

6. Women empowerment

```
jv5<-
lmer(women_emp~DIVERSITY+SYNERGIES+EFFICIENCY+RECLYCLING+RESILIENCE+C
ULTURE+COCREATION+HUMANS_VALUES+CIRCULAR_ECONOMY+RESPONSIBLE_GO
VERNANCE+(1|ALL),data=AI)
> summary(jv5)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: women_emp ~ DIVERSITY + SYNERGIES + EFFICIENCY + RECLYCLING +
   RESILIENCE + CULTURE + COCREATION + HUMANS_VALUES +
CIRCULAR_ECONOMY +      RESPONSIBLE_GOVERNANCE + (1 | ALL)
  Data: AI

REML criterion at convergence: 4171.2

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.3325 -0.5975  0.1344  0.6847  3.0631

Random effects:
 Groups   Name        Variance Std.Dev.
 ALL      (Intercept)  49.08    7.006
 Residual             247.15   15.721
Number of obs: 494, groups:  ALL, 8

Fixed effects:
                       Estimate Std. Error        df t value Pr(>|t|)
(Intercept)            51.13367    4.15329  37.29292  12.312 1.05e-14 ***
```

```
DIVERSITY              0.03116    0.06654 481.94370   0.468   0.6398
SYNERGIES             -0.01333    0.06161 478.81265  -0.216   0.8288
EFFICIENCY             0.10918    0.05665 366.19077   1.927   0.0547 .
RECLYCLING            -0.05654    0.05323 482.28341  -1.062   0.2887
RESILIENCE             0.04096    0.06026 481.27555   0.680   0.4970
CULTURE               -0.11621    0.05364 481.56963  -2.166   0.0308 *
COCREATION             0.11308    0.04428 479.25115   2.554   0.0110 *
HUMANS_VALUES         -0.02648    0.05780 481.25314  -0.458   0.6470
CIRCULAR_ECONOMY      -0.08393    0.05236 482.77173  -1.603   0.1096
RESPONSIBLE_GOVERNANCE   0.07492    0.04473 482.20649   1.675   0.0946 .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) DIVERS SYNERG EFFICI RECLYC RESILI CULTUR COCREA HUMANS CIRCUL
DIVERSITY   -0.138
SYNERGIES    0.022 -0.415
EFFICIENCY  -0.269 -0.121 -0.137
RECLYCLING  -0.088  0.026 -0.130 -0.134
RESILIENCE  -0.004 -0.320 -0.039  0.003 -0.109
CULTURE      0.021  0.110 -0.158 -0.218 -0.182 -0.185
COCREATION  -0.015  0.049 -0.032 -0.060 -0.072 -0.192  0.017
HUMANS_VALU -0.279 -0.080  0.043 -0.074  0.033 -0.046 -0.214 -0.116
CIRCULAR_EC -0.176  0.049 -0.142 -0.050 -0.042 -0.014 -0.138 -0.155 -0.112
RESPONSIBLE -0.034  0.083 -0.119  0.062 -0.125 -0.099 -0.038 -0.313 -0.089 -0.204
```

7.youth

```
jv6<-
lmer(youth_score~DIVERSITY+SYNERGIES+EFFICIENCY+RECLYCLING+RESILIENCE+CU
LTURE+COCREATION+HUMANS_VALUES+CIRCULAR_ECONOMY+RESPONSIBLE_GOV
ERNANCE+(1|ALL),data=AI)
> summary(jv6)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: youth_score ~ DIVERSITY + SYNERGIES + EFFICIENCY + RECLYCLING +
   RESILIENCE + CULTURE + COCREATION + HUMANS_VALUES +
CIRCULAR_ECONOMY + RESPONSIBLE_GOVERNANCE + (1 | ALL)
  Data: AI

REML criterion at convergence: 4230.9

Scaled residuals:
    Min      1Q  Median      3Q     Max 
-1.7477 -0.5494 -0.2393  0.0956  8.6239 

Random effects:
```

```
 Groups   Name        Variance Std.Dev.
 ALL      (Intercept)  44.24    6.652
 Residual             280.52   16.749
Number of obs: 494, groups:  ALL, 8

Fixed effects:
                        Estimate Std. Error         df t value Pr(>|t|)
(Intercept)             6.722470   4.242849  43.300941   1.584   0.1204
DIVERSITY              -0.136156   0.070814 482.573758  -1.923   0.0551 .
SYNERGIES               0.006061   0.065609 479.301832   0.092   0.9264
EFFICIENCY              0.003012   0.059800 319.542718   0.050   0.9599
RECLYCLING              0.030009   0.056587 480.256049   0.530   0.5961
RESILIENCE              0.115869   0.064145 481.969554   1.806   0.0715 .
CULTURE                 0.094684   0.057099 482.234192   1.658   0.0979 .
COCREATION             -0.088149   0.047156 479.826190  -1.869   0.0622 .
HUMANS_VALUES           0.019874   0.061521 481.938820   0.323   0.7468
CIRCULAR_ECONOMY        0.045224   0.055705 482.999997   0.812   0.4173
RESPONSIBLE_GOVERNANCE -0.035822   0.047598 482.771193  -0.753   0.4521
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) DIVERS SYNERG EFFICI RECLYC RESILI CULTUR COCREA HUMANS CIRCUL
DIVERSITY   -0.145
SYNERGIES    0.024 -0.416
EFFICIENCY  -0.275 -0.122 -0.139
RECLYCLING  -0.094  0.027 -0.130 -0.133
RESILIENCE  -0.004 -0.319 -0.039  0.005 -0.110
CULTURE      0.021  0.109 -0.158 -0.217 -0.181 -0.186
COCREATION  -0.016  0.048 -0.032 -0.059 -0.072 -0.192  0.017
HUMANS_VALU -0.289 -0.079  0.043 -0.073  0.033 -0.047 -0.214 -0.115
CIRCULAR_EC -0.180  0.050 -0.142 -0.052 -0.042 -0.014 -0.138 -0.155 -0.114
RESPONSIBLE -0.035  0.083 -0.119  0.064 -0.125 -0.099 -0.038 -0.313 -0.090 -0.205
```

7.soil condition

```
jv7<-
lmer(soilscore~DIVERSITY+SYNERGIES+EFFICIENCY+RECLYCLING+RESILIENCE+CULT
URE+COCREATION+HUMANS_VALUES+CIRCULAR_ECONOMY+RESPONSIBLE_GOVE
RNANCE+(1|ALL),data=AI)
> summary(jv7)
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: soilscore ~ DIVERSITY + SYNERGIES + EFFICIENCY + RECLYCLING +
   RESILIENCE + CULTURE + COCREATION + HUMANS_VALUES +
CIRCULAR_ECONOMY +  RESPONSIBLE_GOVERNANCE + (1 | ALL)
```

```
Data: AI

REML criterion at convergence: 1073.4

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.8801 -0.5586  0.0025  0.6807  2.4421

Random effects:
 Groups   Name        Variance Std.Dev.
 ALL      (Intercept) 0.08126  0.2851
 Residual             0.40503  0.6364
Number of obs: 494, groups:  ALL, 8

Fixed effects:
                         Estimate Std. Error        df t value Pr(>|t|)
(Intercept)             2.941e+00  1.685e-01  3.675e+01  17.455   <2e-16 ***
DIVERSITY              -5.896e-03  2.694e-03  4.819e+02  -2.189   0.0291 *
SYNERGIES               1.289e-03  2.494e-03  4.788e+02   0.517   0.6055
EFFICIENCY              2.860e-03  2.294e-03  3.674e+02   1.247   0.2133
RECLYCLING              2.623e-03  2.155e-03  4.823e+02   1.217   0.2242
RESILIENCE              1.652e-03  2.439e-03  4.812e+02   0.677   0.4985
CULTURE                 3.371e-03  2.172e-03  4.815e+02   1.552   0.1213
COCREATION             -5.993e-05  1.793e-03  4.792e+02  -0.033   0.9733
HUMANS_VALUES           1.032e-03  2.340e-03  4.812e+02   0.441   0.6593
CIRCULAR_ECONOMY       -1.246e-03  2.120e-03  4.828e+02  -0.588   0.5569
RESPONSIBLE_GOVERNANCE  2.392e-03  1.811e-03  4.822e+02   1.321   0.1871
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr) DIVERS SYNERG EFFICI RECLYC RESILI CULTUR COCREA HUMANS CIRCUL
DIVERSITY   -0.138
SYNERGIES    0.022 -0.415
EFFICIENCY  -0.269 -0.121 -0.136
RECLYCLING  -0.088  0.026 -0.130 -0.134
RESILIENCE  -0.004 -0.320 -0.039  0.003 -0.109
CULTURE      0.021  0.110 -0.158 -0.218 -0.182 -0.185
COCREATION  -0.015  0.049 -0.032 -0.060 -0.072 -0.192  0.017
HUMANS_VALU -0.278 -0.080  0.043 -0.074  0.033 -0.046 -0.214 -0.116
CIRCULAR_EC -0.176  0.048 -0.142 -0.050 -0.042 -0.014 -0.138 -0.155 -0.112
RESPONSIBLE -0.034  0.083 -0.119  0.062 -0.125 -0.099 -0.038 -0.313 -0.089 -0.204
```


APDIK
CANALLS
Atelier de Validation des résultats TAPE dans
le Living Lab BIEGA
Lieu : INERA MULUNGU
Date: Du 23 au 24 Octobre 2025