Co-designing a method to assess agroecosystems undergoing an agroecological transition: results of a case study in Senegal

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Highlights

- *We mobilized prototyping to co-design an assessment method for agroecosystems undergoing an agroecological transition and tested it in a case study.*
- *The case study was a village of nine households, undergoing an agroecological transition supported by a non-governmental organization.*
- *Results revealed a large variability in household performance across social, economic and environmental dimensions.*
- *Results allowed us to identify levers for action at three different levels to accelerate the agroecological transition.*
- *End-users acknowledged the comprehensiveness of the method and its usefulness to steer agroecological transitions.*

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Abstract

Assessing the conditions and performance of agroecosystems undergoing an agroecological transition in different contexts is key to supporting these transitions. However, assessing agroecosystems undergoing an agroecological transition presents methodological challenges, including i) being adaptable to local conditions; ii) consideration of social interactions among stakeholders involved in transitions; iii) clarifying the concept of agroecology; iv) consideration of the temporal dynamics of the transitions to better understand barriers and levers in their development; v) using a participatory bottom-up approach. The objective of this research was to design a method that provided evidence on i) the barriers and levers in the development of agroecological transitions; ii) the performance of agroecosystems achieved following their agroecological transition related to four dimensions: techno-economic issues, agroecosystem health, quality of life, and resilience. To design, test, and adapt such a method while also involving end-users, we adopted a co-design approach based on prototyping. The co-design approach unfolded in nine stages, alternating research work and co-design with end-users.

The prototype was built on the approaches of existing published methods covering the five challenges for assessing agroecosystems undergoing an agroecological transition. It consisted of a four chronological step assessment method. The first three steps consisted of framing the assessment, with the final step being a multidimensional performance assessment using an initial set of 73 indicators to cover the four dimensions. The prototype was then tested and adapted in the village of Sare Boubou, Senegal, which is undergoing an agroecological transition supported by a non-governmental organization. Changes during the testing and adaptation phase affected three steps of the prototype and allowed the initial prototype to adapt to the case study's specificities, related to its scale and context. Context-related changes particularly affected the performance assessment, with a total of 31 indicators changed. The analysis of barriers and levers revealed that the transition began 29 years ago, achieved a fair level of advancement,

and is still ongoing. Results revealed heterogeneity between the nine households of the village in terms of uptake of agroecological practices, household resources, diversification of activities, coverage of food needs through production, and level of sales. This heterogeneity explains the large variability in household multidimensional performances across all dimensions**.** Large disparities were also noticeable at the individual level between men, women, and young men in the village regarding the level of education, empowerment, and participation in knowledge-sharing networks. Despite a method seen as time-consuming and data-intensive, end-user validation acknowledged the comprehensiveness of the method and its usefulness for steering and managing agroecological transitions, making it possible to identify levers for action at different scales.

Introduction

Agroecology is increasingly promoted as an alternative agricultural paradigm to contribute to transforming food systems by applying ecological principles to agriculture while also addressing the need for socially equitable food systems (IAASTD, 2009; De Schutter and Vanloqueren 2011; Altieri and Nicholls, 2012; HLPE, 2019;). Agroecology is a way of redesigning food systems from simplified industrial agroecosystems to complex and diversified agroecological systems to achieve ecological, economic and social sustainability (Hill and MacRae, 1996; Duru *et al*., 2015; Gliessman, 2016). Assessing the conditions and performance of agroecological transitions in different contexts is key to building evidence and supporting agroecological transitions. Evidence on agroecological performance remains fragmented because of heterogeneous methods and data, differing scales and timeframes, knowledge gaps (Mottet *et al.*, 2020) and the polysemous nature of agroecology (Stassart *et al*., 2012). Defined by principles and not by a set of practices (Tittonell, 2020), agroecology is characterized by a diversity of approaches, visions and definitions, adapted to local contexts (Bell and Bellon, 2018). Agroecology's polysemous nature makes it more difficult to define the boundaries of the system to be evaluated, which is one of the first steps in an evaluation process (Lairez *et al*., 2015). To measure the performance of agroecosystems undergoing an agroecological transition, it is essential to introduce benchmarking (Lairez *et al*., 2015) using reference values (Acosta-Alba and Van der Werf, 2011).

Several reports have identified the need to support the development of holistic performance measurements for agroecology and to showcase agroecological success stories (IPES-Food, 2018; HLPE, 2019; Biovision Foundation for Ecological Development and IPES-Food 2020). A recent review from Prost *et al*. (2023) highlighted the need for more holistic assessment frameworks, that consider environment, social and economic dimensions all together. While the environmental dimension is often considered in evaluation methods, the integration of economic and social dimensions is less frequently considered (Affholder *et al*., 2018), and there is still a lack of research on the social (Bellamy and Ioris, 2017) and economic (D'Annolfo *et al*., 2017) contributions of agroecology. Prost *et al.* (2023) further highlighted the need for such assessment frameworks to be flexible to adapt to the diversity of global and local challenges. Such assessment methods are important to steer and manage agroecological transitions and to feed evidence-based advocacy and to support two categories of end-users: i) representatives of non-governmental organizations (NGO), researchers working on agroecological transitions and ii) farmers, designing and implementing agroecological practices.

However, assessing agroecosystems undergoing an agroecological transition is complex and presents methodological challenges. This complexity relates to the diversity of agroecological transitions (Pretty, 2008; De Schutter and Vanloqueren, 2011;Altieri and Nicholls, 2012), their temporal dynamics (Tittonell, 2020), and the diversity of their modalities and starting points (Wezel *et al.*, 2020). Methodological challenges also relate to the need to consider the multidimensionality of the transition towards sustainability (Trabelsi *et al*., 2019; Wiget *et al*., 2020) and the multiple scales of changes (Magrini *et al*., 2019). Assessing agroecosystems undergoing an agroecologial transition raises five methodological challenges identified in the literature. An assessment method first needs to be adaptable to local conditions (Hatt *et al*., 2016; Trabelsi, 2017; Martin *et al.*, 2018; Wiget *et al.*, 2020). This adaptability is essential to capture the context-specificity of the agroecosystem undergoing an agroecologial transition assessed and provide useful and practical knowledge for end-users, such as farmers, NGO representatives and researchers. Second, a method needs to consider the social interactions among stakeholders involved in transitions (Dendoncker *et al*., 2018; Martin *et al*., 2018; Magrini *et al*., 2019; Wiget *et al*., 2020). Third, a method needs to clarify the concept of agroecology (Wezel and Soldat, 2009). Fourth, a method needs to consider the temporal dynamics of transitions to better understand barriers and levers in their development (Magrini *et al*., 2019; Martin *et al*., 2018). Finally, the development of a method needs to mobilize a participatory bottom-up approach (Méndez *et al*., 2013; Martin *et al*., 2018; Wiget *et al*., 2020), which involves stakeholders. This participation provides stakeholders the capacity to shape and adapt the method according to their objectives, needs and to the specificities of their local context (Mackrell *et al*., 2009; Van Meensel *et al.*, 2012). A recent systematic literature review (Darmaun *et al*., 2023) showed that existing published methods assessing the resilience and/or sustainability of agroecosystems could also be used to assess agroecosytems undergoing an agroecological transition, but that none of these methods, covered all five challenges.

Existing assessment methods of agroecosystems are often developed by experts without actively involving end-users or considering their needs (Binder *et al*., 2010; De Olde *et al*., 2016). However, involving end-users in the design of the method allows the method's objectives to align with end-users' objectives, strengthening the "perceived usefulness" of the method (Van Meensel *et al*., 2012). Prost *et al.* (2012) further showed that there was little scientific debate about design methodology and the link with the intended use of the methods being designed. To answer this research gap, Prost *et al.* (2012) recommend developing a participatory methodology design involving end-users in the design of the method. Co-design is an approach that favours the involvement of end-users in the development of a method. Co-design is a participatory approach that includes alternating phases of research work and co-design with end-users (Hatchuel, 2001), while also focusing on the use and operationality of the method. Prototyping is often employed to design sustainable cropping systems (Lançon *et al*., 2007; Sterk *et al*., 2007; Queyrel *et al*., 2023). Prototyping consists of a series of stages of designing, testing, improving and releasing prototypes (Vereijken, 1997; Le Bellec *et al*., 2012), in particular: i) designing a first unfinished version of the prototype with end-users; ii) testing it in different situations of use, allowing end-users to modify parts of the prototype (but not all of it); iii) stabilising the prototype after improvement loops. Within the West African region, Senegal has taken a leading role in starting an agroecological transition through the launch in 2019 of an advocacy platform called DyTAES (Dynamic for an agroecological transition in Senegal) (Boillat *et al*., 2022). The objective of this study was to co-design an assessment method for agroecosystems undergoing an agroecological transition based on prototyping and to test and adapt that assessment method in a case study in Senegal. The aim of this paper is primarily methodological. The results of the use of the prototype, *i.e*., the evaluation of a case study's agroecological transition, are presented to illustrate the usefulness and relevance of the results obtained by using the prototype for the end-users.

Materials and Methods

Project context and case study

This study was conducted within a multistakeholder project (AVACLIM) mobilizing a collaboration between NGO representatives and researchers targeting seven countries (Brazil, Burkina-Faso, Ethiopia, India, Morocco, Senegal, and South Africa). The project also involved farmers from case studies in the seven countries. The prototype was tested in the village of Sare Boubou, located in the Tambacounda region in south-east Senegal's Sudano-Sahelian zone. Situated between the 450 and 800 mm isohyets, Tambacounda is among the wettest regions in the country, with a rainy season lasting between four and five months (ANSD, 2017). Crop production is highly dependent on rainfall (Badji *et al*., 2015) and is characterized by very low productivity (Gueye *et al*., 2008). The region of Tambacounda is considered highly vulnerable, with more than half of its households being in the country's poorest category (WFP, 2011). The village is composed of nine households (154 inhabitants) practicing subsistence family farming. The household is considered as the unit of production and management of activities (Guigou, 1999). The village is embedded in an area historically producing conventional cotton, with the development of the cotton agro-industry led by the Society for Textile Development and Fibres (Sodefitex). The village's main activities comprise food crops (millet, corn and sorghum), cash crops (groundnut and cotton), extensive breeding, fattening and milk collection, and additional non-agricultural activities, such as logging (*i.e*., charcoal production), motorbike transportation service and shopkeeping. Animals roam around the village and graze in collective areas located in the nearby Ouly forest. They are often kept in fields at night to avoid theft and provide organic matter inputs. Similarly to other family farming systems in the country, Sare Boubou's environment is characterized by rapid population growth, liberalization and globalization of the economy, and deteriorating production conditions that limit production (ANSD, 2017). The village has been going through an agroecological transition since 1994, supported by the NGO Enda Pronat.

The co-design approach

The method was designed, tested and adapted between 2020 and 2022 using a co-design approach based on prototyping. Two categories of end-users, distinguished by their use of the prototype, were involved as co-designers to share their experience, provide knowledge and generate ideas for the design of the prototype. The first category was composed of NGO representatives and researchers from the seven AVACLIM countries. They were end-users of both the prototype and its results and were referred to as method-and-results-end-users. They were interested in using the method to assess the agroecological transitions they were supporting or studying. The second category was composed of farmers implementing the agroecological transition. They were interested

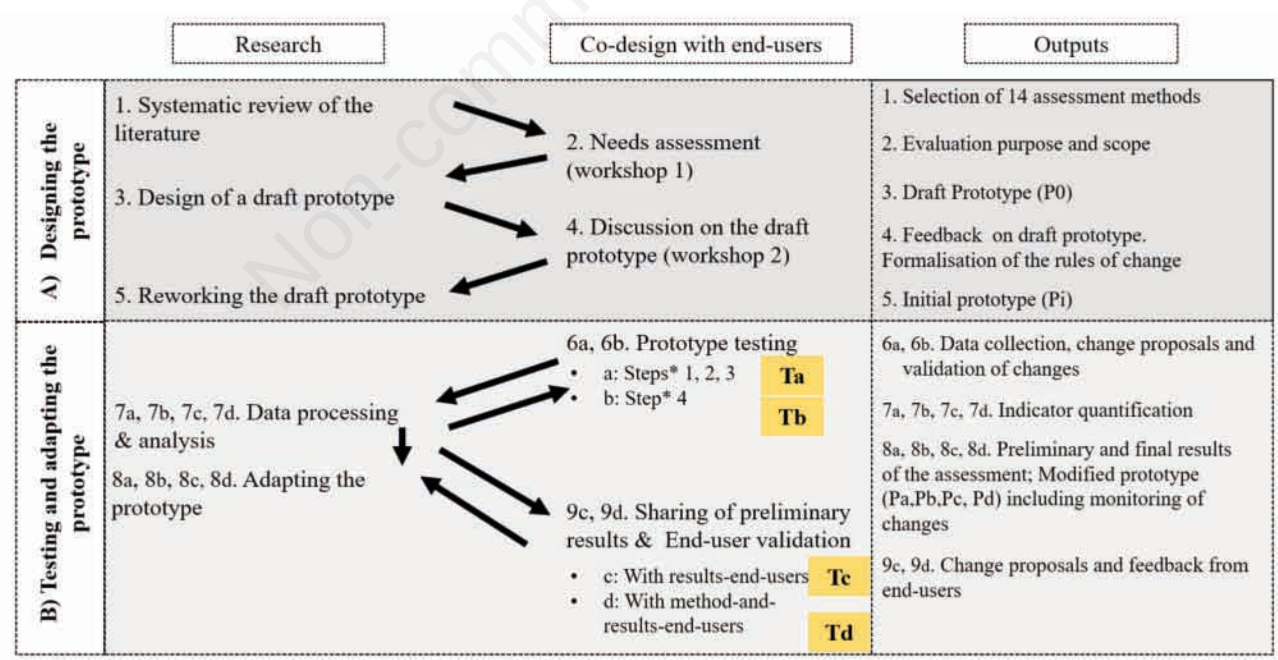

Figure 1. Description of the 2 phases (A and B) and the 9 stages of the co-design approach adopted, based on prototyping. Stage 6 happened two times (6a, and 6b), stages 7 and 8 happened four times. Stage 9 happened once with results-end-users (stage 9c) and a second time with method-and-results-end-users (stage 9d). Ta, Tb, Tc and Td illustrate the four different times of change. Pa, Pb, Pc and Pb illustrate the related four different versions of the initial prototype. a, implementation of the framing steps of the prototype (1 to 3); b, the implementation of step 4 of the prototype; c, the sharing of results with results-end-users; d, the sharing of results with method-and-results-end-users; *correspond to the four chronological steps of the prototype.

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in the results to better manage their farms and were referred to as results-end-users. The co-design approach unfolded in nine successive stages, alternating research and co-design with end-users (Figure 1). Each stage led to methodological decisions (outputs in Figure 1). These decisions were discussed with method-and-results-end-users and agreed upon, building on consensus. The nine stages were grouped in two phases: A) designing the prototype, and B) testing and adapting the prototype to case studies. The two categories of end-users were involved at different times in the co-design approach. Method-and-results-end-users were involved in both A and B phases. In Senegal, method -and-results-end-users were four representatives from the Enda Pronat NGO and three researchers from the Senegalese Institute of Agricultural Research (ISRA). Results-end-users were 32 farmers (men as heads of households, young men and women) from the case study. Young women were not included because there were too few (two) in the village. Results-end-users were involved only in phase B. The following section details both phases.

Phase A: designing the prototype (stages 1-5)

Phase A consisted in designing the initial prototype (Pi). Pi was built after a systematic literature review (stage 1, Figure 1), two co-design workshops with method-and-results-end-users (stages 2 and 4, Figure 1) and research work (stages 3 and 5, Figure 1) focusing on drafting and reworking the prototype following the two co-design workshops. The systematic literature review was conducted to identify methods covering one or more of the five methodological challenges for assessing agroecosystems undergoing an agroecological transition (Darmaun *et al.*, 2023). It led to the identification of 14 published multiscale and multidimensional assessment methods (*Supplementary Material 1*). The first co-design workshop (0.5 day) was organized to collect the needs and expectations of 16 end-users (method-and-results-end-users), using the world café method (Schiele *et al.*, 2022). It led to a shared definition of the prototype's objectives, the assessment's purpose and scope, the system boundaries and the levels of the assessment. The discussions also highlighted relevant criteria and indicators identified by methods-and-result-end-users to suitably assess the agroecosystem's performance. Both the literature review and this workshop allowed us to frame the draft prototype (P0). The draft prototype was framed by looking for relevant approaches in the 14 assessment methods that met each of the method-and-results-end-users' expectations (expressed in stage 2). The draft prototype was designed to cover the five methodological challenges in assessing agroecological transitions identified in the literature (during stage 1). The second co-design workshop (2.5 days) was organized online and involved 36 method-and-results-end-users (16 from stage 2 and 20 additional end-users) to discuss the draft prototype. The discussions provided feedback to improve the draft prototype (P0) and permitted to formalize the rules of change regarding the testing and adaptation of the prototype. Research work: i) framed a draft prototype (P0), and ii) reworked P0 to Pi, presented in the results section (3.1).

Phase B: testing and adapting the prototype in a case study in Senegal (stages 6-9)

Phase B included: i) the testing of the four chronological steps of the initial prototype (stages 6a and 6b, Figure 1); ii) the processing and analysis of the data collected followed by the adaptations of the prototype (stages 7a, 7b, 7c, 7d and 8a, 8b, 8c, 8d, Figure 1); iii) the sharing of the preliminary results with both categories of end-users and the collection of their feedback during the end-user validation (stages 9a and 9b, Figure 1). The initial prototype (Pi) was adapted four times (stages 8a, 8b, 8c and 8d, Figure 1), leading to four successive versions (Pa, Pb, Pc and Pd). The first adaptation of the initial prototype followed the testing of the first three steps of the prototype (Pa, stage 6a), the second followed the testing of the fourth step of the prototype (Pb, stage 6b), the third followed the sharing of preliminary results with results-end-users (Pc, stage 9c) and the fourth followed the presentation of preliminary results with method-and-results-end-users (Pd, stage 9d).

The testing of the four chronological steps of the initial prototype (stages 6a and 6b) included data collection for the assessment and the collection and validation of change proposals to adapt the prototype to the case study. Stepwise data collection was achieved through (Table 1): i) four focus group discussions; ii) a series of individual interviews with results-end-users to understand households' specificities, agricultural practices and individual issues and perceptions; iii) non-participant observation of agricultural practices and living conditions. Change proposals collected by the assessor building on the exchanges with results-end-users were discussed and validated with the seven method-and-results-end-users during two half-day workshops (stages 6a and 6b).

Table 1. Organization of the data collection (techniques, tools mobilized, and the time needed) during the testing of the four chronological steps of the initial prototype (stages 6a and 6b). "a" corresponds to the testing of the three first framing steps of the prototype and "b" to the testing of step 4. See Figure 1 for more detail.

Step-wise data collection of stages 6a and b		Techniques mobilised	Tools mobilized	Time needed
Stage 6a	Step 1	Focus group, non-participant observation of agricultural practices and living conditions	Mapping of the organization and functioning of the case study	2 hours
		Focus group	Mapping of stakeholders	1 hour
	Step 2	Focus group, non-participant observation of agricultural practices and living conditions	Characterization of the Agroecological Transition of the case study	3 hours
	Step 3	Focus group	Timeline of the agroecological transition of the case study	2 hours
Stage 6b	Step 4	Individual interviews, non-participant observation of agricultural practices and living conditions	Interview guide	1 hour (per person interviewed) 2 hours (per household)

The four focus group discussions involved the nine household heads and other available results-end-users (two or three women and two or three youths per discussion session). The four focus groups aimed at collecting data regarding the case study's agroecological transition specificities and functioning, the stakeholders involved, the key historical events of the case study and the level of agroecological transition achieved. The sharing of preliminary results (stages 9a and 9b) had two objectives: to provide feedback on the prototype and its results (end-user validation) and to make final changes in the prototype based on end-users' inputs. The sharing of preliminary results with results-end-users (stage 9a) was achieved through a series of three half-day separate focus group discussions (men, women and young farmers). End-user validation addressed three issues for both categories of end-users: i) ease of understanding of the results; ii) result consistency; iii) result usefulness. Three additional issues were addressed with the method-and-results-end-users: i) level of comprehensiveness of the prototype; ii) its ease of use; iii) eagerness to use it in the future. End-user validation was organized through an open voting system with results-end-users following the focus group discussions, using three coloured paper sets, illustrating the Likert scale levels ranging from low to high. Open comments were also reported. An online questionnaire was sent to method-and-results-end-users, employing a similar Likert scale and in which comments could be added.

Testing and adapting the prototype in phase B led to three types of results both methodological and related to the evaluation of the agroecological transition of the case studies. These were: i) the results of the adaptation of the initial prototype (methodological results); ii) results related to the evaluation of the case study's agroecological transition; iii) feedback from end-users following the end-user validation. These latter results were both methodological (user feedback on the prototype) and evaluation (user feedback on the evaluation results) of results.

Data analysis

The data collected in stages 6a, 6b and 9c, 9d was analysed in stages 7a, b, c, d (Figure 1). This data analysis led to results related to the evaluation of the case study's agroecological transition, through the use of the prototype.

Analysis of the barriers and levers in the development of agroecological transitions

We used an analytical grid that was developed to analyse barriers and levers in the development of agroecological transitions (FAO, 2018; Moraine *et al*., 2018). The grid distinguished three main periods, divided in sub-periods, in an agroecological transition. The first period of change, considered preparatory, relates to the perceived need for change. The second period comprises the implementation of change, with two sub-periods, one relates to decision-making and the implementation of initial actions, the other to the implementation of further actions. The third period comprises the stabilisation of change. The determination of each period was constructed on the historical events identified in the timeline with results-end-users during prototype testing (stage 6a, Figure 1). In each period, events that represented barriers and levers were classified according to four types of resources mobilized during transitions towards agroecology (Moraine *et al*., 2018): material resources (*e.g*., land, water, and local ecosystems), cognitive resources, technical resources, and socio-economic resources (*e.g*., specific marketing channels, subsidies, and social networks). These resources were linked to the 10 elements of agroecology (FAO, 2018). The 10 elements were grouped according to Gliessman's (2016) five levels of food system change, illustrating the level of advancement in the transition over time. The content of the 10 elements was built on the indices of the Characterization of Agroecological Transition of the Tool for Agroecology Performance Evaluation (TAPE) (Mottet *et al*., 2020). Key changes were also identified and categorized.

Analysis of multidimensional performance

Multidimensional performance was constructed on a set of indicators. Quantitative indicators were computed from quantitative variables, and qualitative indicators from qualitative scoring between zero and four (five classes). Quantitative indicators were normalized to attribute a score between zero and four. Different types of reference values were used for the normalization of quantitative indicators: absolute values (based on scientific literature and expert opinion) and relative (comparison of systems in space through averages, medians, minima and maxima) (Van Cauwenbergh *et al*., 2007). These reference values were: i) calculated from regional datasets emerging from the PAPA project – in French, *Projet d'Appui aux Politiques Agricoles* - coordinated by the Senegalese Ministry of Agriculture and Rural Equipment between 2015 and 2019 and from the 2018-2019 household survey led by the National Agency of Statistics; ii) identified in national datasets such as the Food and Agriculture Organisation (FAO) Rural Livelihoods Information System; iii) determined by expert opinion; iv) built on the literature; v) built on a theoretical minimum and maximum. Details on the sources of reference values for each indicator are summarized in the supplementary materials (*Supplementary Material 2*).

Four operating modes were defined for the normalization of indicators, depending on the reference value used. Operating mode 0 did not use any reference value and followed the same scoring system as the method of origin. The other three operating modes employed were: i) relative reference values such as minima and maxima (operating mode 1) following Equation 1 below; ii) relative reference values such as minima, maxima and averages (operating mode 2) following Equation 2 below; iii) absolute reference values for which a qualitative rating was determined (operating mode 3).

Equation 1: normalized indicator score = (x-xmin)/(xmax-xmin), where xmin and xmax are the minimum and maximum values of the indicator respectively.

Equation 2: two options depending on the average value considering the extreme values (distribution law).

Option 1: if average was included in between +/- 20% of (xmax-xmin)/2 then classes of equal amplitude were established. To determine this amplitude (A), we calculated: A=xmax-xmin/five classes.

Option 2: if average had values close to the extreme values (xmin or xmax) the amplitudes of the five classes were not equal but reflected the hypothetical distribution of the values by centring on the average. The amplitudes were determined as follows: i) amplitudes of classes below the average: (average-xmin)/number of classes below the mean (*i.e*., 2.5 as it is half of the five total classes); ii) amplitudes of the classes above the average: (xmax-average)/2.5

Normalized indicators were then aggregated up to the criteria level using an arithmetic average. Following decisions taken in the second workshop with method-and-results-end-users (stage 4, Figure 1), equal weights were given to indicators in the aggregation process and no compensation between indicators was possible. This decision aimed at ensuring a certain level of comparability between different assessments.

Monitoring the changes in testing and adaptation of the prototype

Change proposals were collected and monitored in stages 6a, 6b and 9c, 9d and led to the methodological results of the adaptation of the initial prototype. Four different times of change occurred, corresponding to the four adaptations of the prototype: the first times of change (Ta and Tb) followed the testing of the four chronological steps of the initial prototype (Pa and Pb, outputs 8a and 8b, Figure 1); Tc followed the sharing of preliminary results with results-end-users (Pc, output 8c, Figure 1); and Td followed the sharing of preliminary results with method-and-results-end-users (Pd; output 8d, Figure 1).

Results

Results are fourfold, both methodological (how to assess the case study's agroecological transition) and related to the evaluation of the case study's agroecological transition. The methodological results concern the initial prototype built (Pi, output 5, Figure 1, section 3.1) and its adaptation to the case study (up to Pd, outputs 8a, 8b, 8c and 8d, Figure 1, section 3.2). The results concerning the evaluation of the case study's agroecological transition are the information and data collected by the use of the Pi prototype (section 3.3). The results of the end-user validation (section 3.4) relate both to methodological (feedback on the prototype) and evaluation results (feedback on the results of the evaluation).

The initial prototype

Following the needs assessment (stage 2, Figure 1), the following decisions were taken. The prototype was designed to assess agroecosystems undergoing an agroecological transition covering different scales, such as individual or collective farms, cooperatives, or villages. Prototype Pi considered three levels of assessment: the farm level, the local environment of farms (*e.g.*, village and cooperative) and individuals working on the farms. The prototype consisted of a four-chronological-step assessment method (Figure 2) (DFID, 1999; López-Ridaura *et al*., 2002; López-Ridaura *et al*., 2005; Van Cauwenbergh *et al*., 2007; Duru *et al*., 2015; Ndah *et al*., 2015; Dendoncker *et al*., 2018; Arango *et al*., 2019; Calleros-Islas, 2019; FAO, 2019; Levard *et al*., 2019; Meuwissen *et al*., 2019; Zahm *et al*., 2019; Mottet *et al*., 2020; Petersen *et al*., 2020). The first three steps consisted of framing the perimeter of the assessment, while the fourth focused on a multicriteria assessment of the agroecosystem's multidimensional performance.

Framing the assessment: steps 1, 2 and 3

Three steps were put forward to answer the need of method-and-results-end-users (stage 2, Figure 1) to understand: i) the agroecosystem's specificities and functioning (step 1); ii) its level of advancement in the agroecological transition (step 2); iii) the barriers and levers in the development of the agroecosystem's agroecological transition (step 3). These three steps also made it possible to cover three methodological challenges in assessing agroecological transitions (*Supplementary Material 1*): consideration of social interactions among stakeholders involved in transitions (step 1), clarifying the concept of agroecology (step 2)

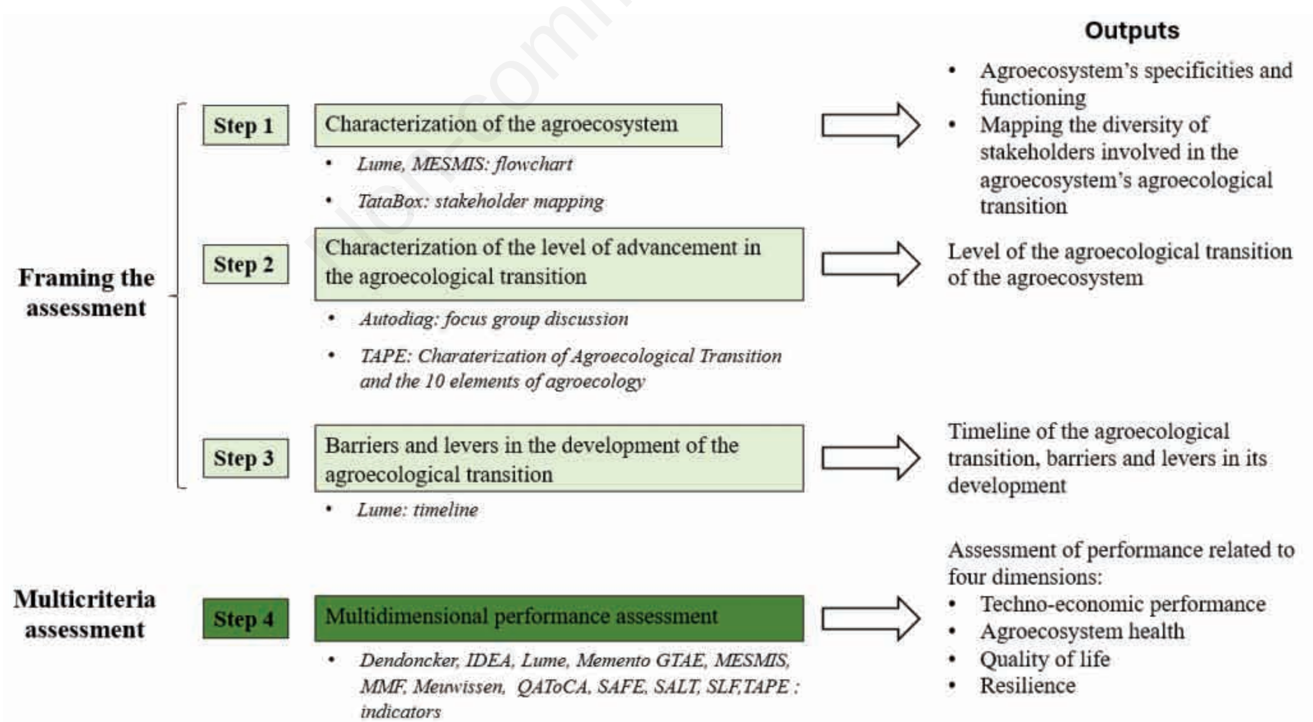

Figure 2. The initial prototype: a four-chronological-step assessment method. In italics are the 14 methods and the way they are used in the initial prototype. After the arrows are the outputs of each of the four steps.

and consideration of the temporal dynamics of transitions to better understand barriers and levers in their development (step 3).

Step 1 included a contextualization phase, employing a flowchart to characterize the the agroecosystem's functioning (as in Lume and MESMIS) and stakeholder mapping to capture the diversity of stakeholders (as in Tata Box), built with results-end-users (Figure 2) (DFID, 1999; López-Ridaura *et al*., 2002; López-Ridaura *et al*., 2005; Van Cauwenbergh *et al*., 2007; Duru *et al*., 2015; Ndah *et al*., 2015; Dendoncker *et al*., 2018; Arango *et al*., 2019; Calleros-Islas, 2019; FAO, 2019; Levard *et al*., 2019; Meuwissen *et al*., 2019; Zahm *et al*., 2019; Mottet *et al*., 2020; Petersen *et al*., 2020). The flowchart was the most resource-efficient approach to i) provide an in-depth description of the functioning of the agroecosystem's assessed; ii) highlight its interactions with internal and external components; iii) identify relevant indicators for the performance assessment. Stakeholder mapping reflected results-end-users' perceptions on the diversity of stakeholders connected with the agroecosystem's and the influential power of each stakeholder on the agroecological transition. Step 2 used the 10 elements of agroecology (Barrios *et al*., 2020; FAO, 2018) through TAPE's Characterization of Agroecological Transitions (CAET) in a guided exercise organized in the form of a focus group discussion (as in Autodiag) with results-end-users (Figure 2) (DFID, 1999; López-Ridaura *et al*., 2002; López-Ridaura *et al*., 2005; Van Cauwenbergh *et al*., 2007; Duru *et al*., 2015; Ndah *et al*., 2015; Dendoncker *et al*., 2018; Arango *et al*., 2019; Calleros-Islas, 2019; FAO, 2019; Levard *et al*., 2019; Meuwissen *et al*., 2019; Zahm *et al*., 2019; Mottet *et al*., 2020; Petersen *et al*., 2020). Step 3 employed a trajectory of change (as in Lume).

Multidimensional performance assessment: step 4

Step 4 built on an initial set of 73 indicators, stemming from the 14 assessment methods (*Supplementary Material 2*) and the two workshops with method-and-results-end-users (stages 2 and 4, Figure 1). Some 33 of the 73 indicators were identified in the workshops and were cross-referenced with existing indicators of the 14 assessment methods. Indicators that were not found in the 14 assessment methods either stemmed from other methods (four indicators) or were further developed (one indicator, *Supplementary Material 2* for more details). The other 40 indicators stemmed from the 14 assessment methods. Indicators were mostly practice-related. Only three were impact-related (*i.e*., carbon stock, infiltration rate and stability of aggregates).

The conceptual framework of step 4 focused on agroecological multifunctionality (as in IDEA and SAFE), structured around four dimensions: techno-economic performance, agroecosystem health, quality of life and resilience (Figure 3). Step 4 took the form of a hierarchical structure, in which dimensions were broken down into criteria and indicators (as in SAFE). The scope of the criteria was determined during the needs assessment (stage 2, Figure 1) and built on the existing literature. Techno-economic performance was built on a combination of five criteria that reflected strategic differences between agroecological and industrial agriculture in the production process (Van der Ploeg *et al*., 2019). Agroecosystem health addressed key natural resources (soil, water, biodiversity and air) and combined six criteria. Quality of life built on the 3-D wellbeing approach (McGregor *et al*., 2009; McGregor and Sumner 2010), considering material, relational and subjective wellbeing and considered five criteria. Finally, resilience was based on Cabell and Oelofse's framework (2012), applied to five criteria.

Results of testing and adaptation of the prototype to the case study

All steps of the initial prototype (Pi) except step 3 were affected by changes. Changes were related to the context and scale of the case study. Scale-related changes were linked to collective and singular issues within the case study and occurred at Ta. Context-related changes led to three types of change: withdrawals, additions or specifications of indicators. Specifications were related to the indicator's content, *i.e*., the variables included in the indicator, or to the indicator's scoring system. Context-related changes occurred at Ta, Tb, Tc and Td. Changes to the prototype were made to i) increase the local relevancy of the assessment (*e.g*., activities existing or not in the case study); ii) address data and resource unavailability; iii) account for key evaluation concerns shared by end-users. We will now detail the two types of adaptations and the way they affected the initial prototype.

Scale-related changes

The village was the case study's scale. This led to changes that distinguished collective features for all households in the village

Table 2. Characterization of the levels of agroecological transition of the nine households in the village of Sare Boubou (result of step 2 of the prototype). The five elements related to Gliessman levels 4 and 5 relate to similar living conditions and collective issues. Therefore they have similar scores for all nine households (figuring in the column 'All'). The individual average scores takes these similar scores into account.

Gliessman levels	Element of agroecology	Households, % 1	2	3	4	5	6	7	8	9	All, %
Level 1	Efficiency	63	63	69	75	56	56	63	69	44	
Level 2	Recycling	56	63	56	63	63	63	63	63	63	
Level 3	Resilience	63	69	56	75	75	69	75	75	69	
	Diversity	56	56	50	69	69	63	81	63	63	
	Synergies	44	38	56	50	38	44	38	38	44	
Level 4	Circular and solidarity economy										75
	Culture and food traditions										75
	Co-creation and sharing of knowledge										75
Level 5	Human and social values										60
	Responsible governance										58
Average score		62	63	63	67	64	64	66	65	62	

from specific issues related to each household. These changes affected the initial way the flowchart in step 1 and the 10 elements of agroecology in step 2 of the prototype were used. Regarding the flowchart (step 1), key features and characteristics of the village of Sare Boubou were represented at two levels (Figure 4): one focusing on collective issues at the village level, the other revealing household specificities. Finally, the nine households were distinguished and numbered according to their gross production and level of sales, which were the most discriminant criteria between the households determined using a principal component analysis (PCA) (data not shown). Sales were related to cash crops, fattening and charcoal production. Among the 10 elements of agroecology in step 2 we distinguished those that were related to similar living conditions and collective issues from those that related to each household, *i.e.*, related to practices (Table 2).

Context-related changes

Context-related changes affected the steps employing descriptive scales or indicators (steps 2 and 4). Changes in step 2 were related to the scoring system. Changes consisted of clarifying the descriptive scales, by: 1) adding issues to make them more accurate to assign the scores more objectively, or 2) changing the descriptive scale to make it more relevant to the case study's context. These changes affected four elements of agroecology (diversity, synergies, efficiency and recycling) and six criteria (*Supplementary Material 3*). For example, the number of crops and the share of the main crop were added in the descriptive scales of the cultures criteria in the diversity element.

Changes in step 4 focused exclusively on indicators, as per the rules of change (stage 4, Figure 1). A total of 32 changes occurred (31 indicators), affecting all dimensions (Figure 3). One indicator was affected by two types of changes, specified for relevance in Ta and then withdrawn in Tb because of the absence of a reference value (indicator 41, *Supplementary Material 4*). From the initial set of 73 indicators, testing and adaptation led to a set of 68 indicators specific to the case study (Figures 3 and 5). Most of the changes happened following the testing of step 4 of the prototype in Tb (23 of 32 changes) (Figure 5 and *Supplementary Material 4*). In Ta, only relevance-related changes happened and were mostly withdrawals (six out of seven). Data-related changes happened exclusively in Tb and were mostly withdrawals (eight out of 10). In Tc and Td, only additions occurred. All nine indicators added were related to end-users' inputs and all added information to dimensions related to (*Supplementary Material 5*): i) efficiency of the production process (cow lactation duration); ii) wellbeing (level of education); iii) decent employment (difficulty of the work); iv) practices favouring soil health (surface area receiving organic matter); v) economic viability (share of agricultural activities); vi) biodiversity and social cohesion (commitment to territorial environmental initiatives). Indicators withdrawn due to lack of relevance affected information related to biodiversity, soil health (*e.g.*, infiltration rate) and water use (volumes of water withdrawn), affecting agroecosystem health and resilience. Indicators withdrawn for data reduced the level of information on the efficiency of the production process (*e.g.*, added-value per working unit) and local development (youth employment opportunities), affecting mostly the techno-economic performance. Specifications preserved nine indicators, modifying information

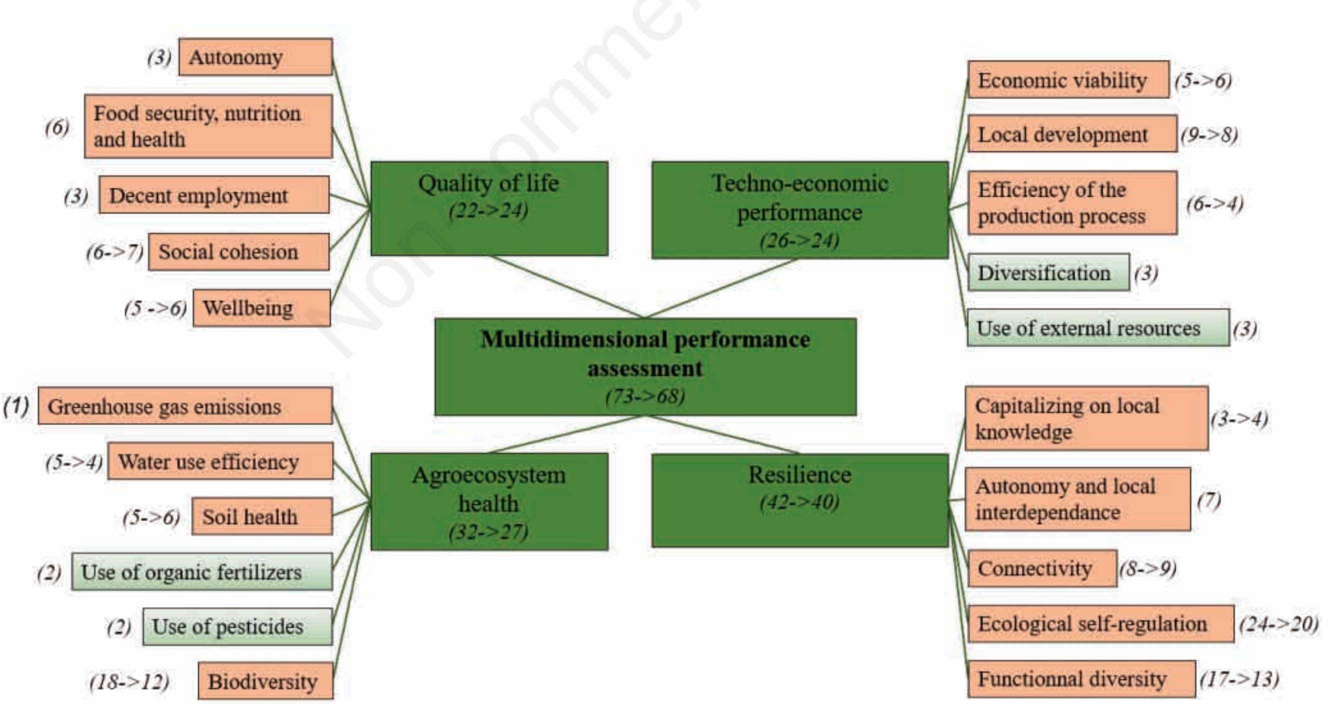

Figure 3. Structure of the multidimensional performance assessment of the case study (step 4 of the prototype). Dimensions are presented in dark green, and criteria in light green or pink. Pink criteria are those that have been affected by the testing and adaptation phase and green criteria are those which did not change. The number of indicators is indicated in brackets. The evolution of the number of indicators through the testing and adaptation phase is illustrated by an arrow (*e.g.*, for social cohesion: 6 indicators were in the initial prototype, while testing and adaptation led to a total of 7 criteria).

related to i) biodiversity (*e.g.*, diversity of agroecological infrastructures) and wellbeing (*e.g.*, non-monetary economic wealth) to contextualize the indicator content; ii) greenhouse gas emissions and local development (reciprocal trade) to overcome data unavailability; iii) autonomy (general perceived autonomy) and food security (dietary diversity) to align with results-end-users' way of judging performance. Specifications affected all dimensions.

Results of the assessment

The use of the Pi prototype led to the assessment of the case study's agroecological transition. The following sections present the results of the four chronological steps of the prototype: i) the framing steps (1, 2 and 3); ii) the assessment of the multidimensional performance.

Results of the framing steps

Step 1: specificities and functioning of the case study

The village was characterized by social initiatives (*e.g.*, self-managed solidarity funds), mutual support in agricultural activities, regular exchanges of agricultural material and seeds between households, and collective mobilization for land restoration and land management, with collective grazing areas (Figure 4). The results revealed a heterogeneity in household resources, diversification of activities, coverage of food needs by production and level of sales (Figure 4 and *Supplementary Material 6*). The enabling environment for the agroecological transition in the village was weak, with support being provided exclusively by national and international NGOs (*Supplementary Material 7*).

Step 2: characterization of the level of advancement of the agroecological transition

Average scores on all 10 elements of agroecology illustrated a similar average level of agroecological transition among the village's nine households (Table 2). Elements of agroecology corresponding to level 4 of food system change were all at 75%, illustrating strengthened connections between farmers and consumers *via* direct marketing arrangements. Levels regarding human and social issues (60%) and responsible governance (58%), which related to level 5 of food system change, highlighted the average levels of empowerment of farmers and revealed the limited global changes in the food system. Variability between households affected mostly efficiency (with a minimum of 44% and a maximum of 75%) and diversity (with a minimum of 56% and a maximum of 81%). This variability illustrated differences between households in strategies regarding the management of pests and diseases (*e.g.*, pesticide use), levels of external expenses on agricultural inputs, food self-sufficiency and activity diversification. Variability between households affected mostly levels 1 and 3 of food system change, illustrating a heterogeneous uptake of agroecological practices in the village.

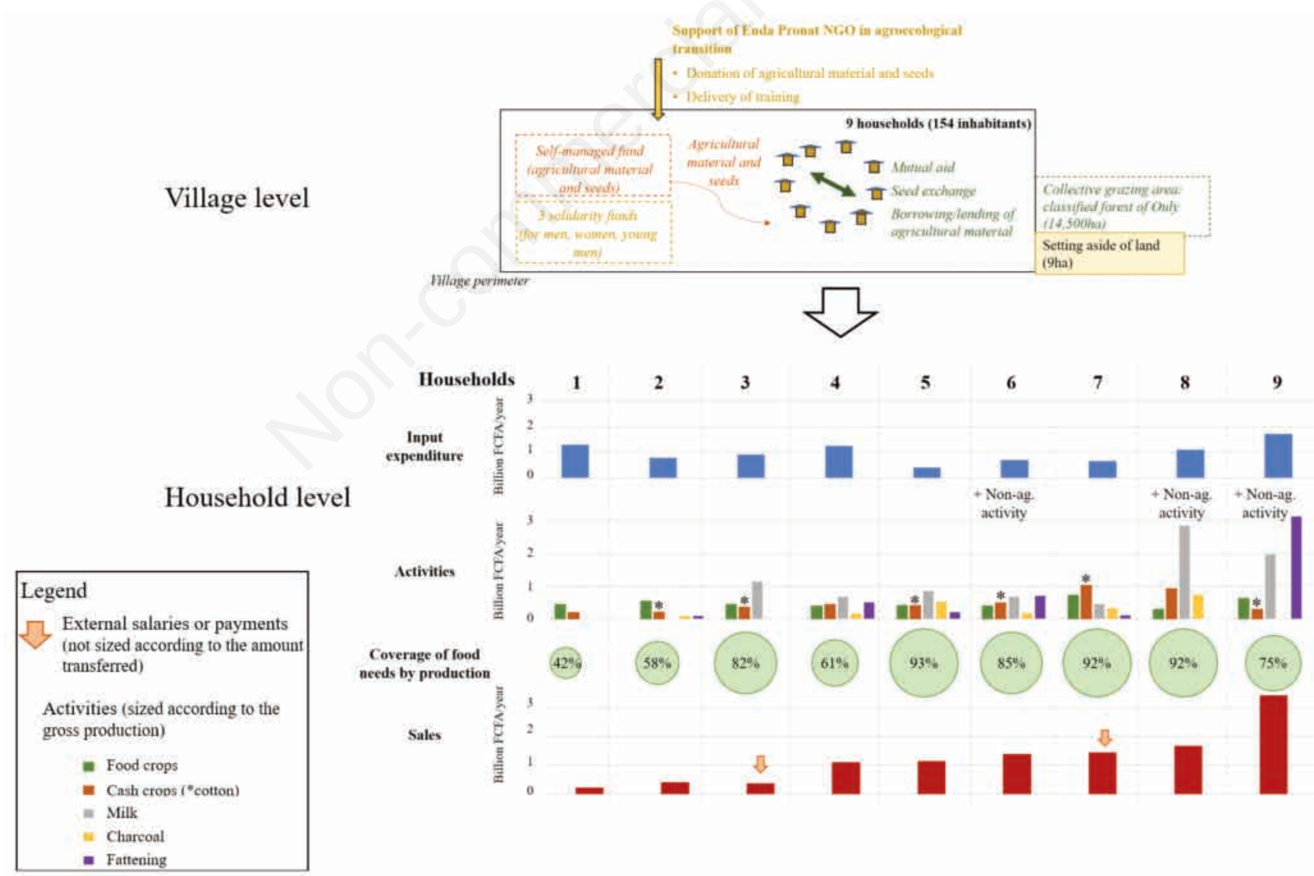

Figure 4. Key features and characteristics of the village of Sare Boubou, at the village and household levels (results of step 1 of the prototype). Note that the activity of extensive livestock rearing does not feature, as it is practiced by all households. FCFA, local money in Senegal; Non-ag. Activity, non-agricultural activity; NGO, non-governmental organizations.

Step 3: barriers and levers in the development of the agroecological transition

The agroecological transition in the village was built around two periods (Figure 6). No period of stabilisation of change had until now occurred, illustrating the ongoing implementation of changes. The transition began in a village characterized by low levels of self-sufficiency among the households and the cultivation of conventional cotton as the main cash crop, in addition to groundnut. The transition was triggered by farmers' endogenous willingness to reduce the use of phytosanitary products, hindered by the lack of cognitive resources (Period 1, Figure 6). Farmers requested the NGO Enda Pronat's support in changing practices. Enda Pronat being at that time the main NGO working in the field of organic cotton production in the region.

The temporal dynamics illustrated the transition's NGO-driven nature, marked by two successive external support strategies provided by Enda Pronat (Period 2, Figure 6). The first support strategy provided cognitive, technical and socio-economic resources to initiate the transition in the village and focused on technical and economic issues. It focused on elements of agroecology related to levels 4 and 5 of the transition (Gliessman, 2016), in particular circular and solidarity economy and responsible governance. Actions led to the establishment of an organic and Fairtrade cotton production chain and a farmers' organisation**,** leading to the abandonment of the cultivation of conventional cotton and an increase in the number of farmers producing organic cotton as a cash crop in addition to groundnut. Changes were also related to the reduction of pesticide use and an increase in the adoption of agroecological practices, such as crop rotations and crop associations (in particular cowpea and corn). Two crises disrupted the dynamic's progress in 2012-2013: the dissolution of the farmers' organisation and a crisis in organic cotton production related to selling prices aligning with conventional cotton and delays in payment by the Sodefitex company (Kleene, 2014; Sane, 2021). This crisis led to a decrease in organic cotton production as a cash crop, replaced by the production of groundnut.

The second support strategy focused on strengthening the village's internal social and cognitive dynamics and made available all four essential resources (material, cognitive, technical and socio-economic) for the transition. It focused particularly on elements of agroecology related to Gliessman's (2016) 1, 2 and 3 levels of transition, such as efficiency, recycling, diversity and synergies (Period 2, Figure 6). The following of practices and technical results in the longer run favoured the development of knowledge and practice-sharing dynamic in the village, leading to an increase in farmer interest in implementing agroecological practices that were not only focused on organic cotton production. Improved access to seeds and agricultural material made possible by the self-managed solidarity fund supported by Enda Pronat provided a technical resource for the transition. Internal socio-economic resources were strengthened through the establishment of additional committees and three solidarity funds by farmers. Key changes in this period were related to the cultivation of groundnut as the main cash crop and the recovery of the cultivation of conventional cotton for some households, an increase in herd size and in the adoption of agroecological practices, such as assisted natural regeneration practices, keeping animals in fields at nighttime to provide organic matter inputs, crop rotations and crop associations. This period was also characterized by the improvement of household levels of food self-sufficiency. Today, access to land represents a major challenge,

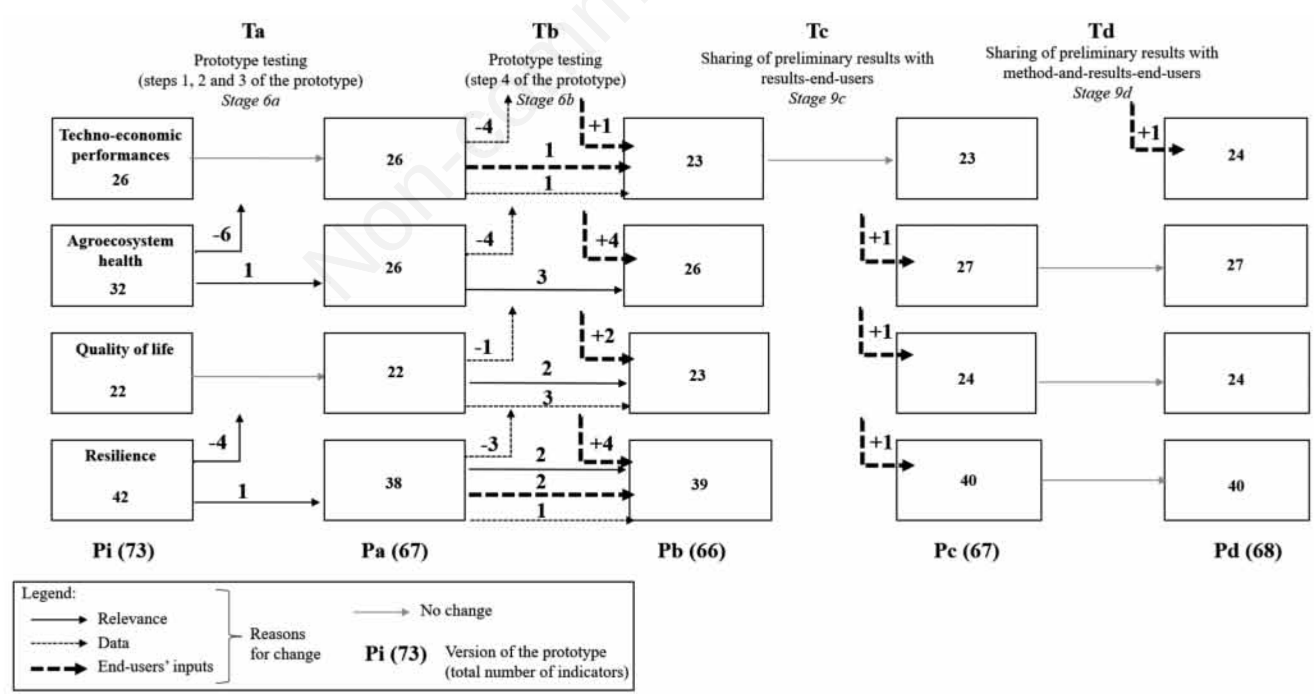

Figure 5. Changes during the testing and adaptation of the prototype in the case study in Senegal. Specified are time of change (Ta to Td), stage of the co-design, reason for change (relevance, data and end-user inputs) and type of change (additions: +, withdrawals: - and specifications: straight black arrow). Numbers represent the indicators.

in particular given the village's growing population. The intensification of agroecological practices is a strong objective of farmers to increase production and reduce the land access issue.

Cognitive resources were provided through the delivery of training throughout period 2. The focus of training broadened in time, from a focus on organic cotton production to issues related to biodiversity, seeds and the governance of natural resources. Over time, this training led to the establishment of internal and horizontal exchanges of practices between farmers.

Multidimensional performance assessment (step 4)

Village level

Results revealed a large variability in household performance across all dimensions (Figure 7), especially regarding techno-economic performance. Variability in techno-economic performance depended on the household's economic diversification, economic viability and efficiency in the production process (Figure 7). This illustrated different levels of activity diversification leading to differences in the number of products sold (*Supplementary Material 8*). Households were also characterized at the indicator level by different income levels and were dependent on subsidies to different degrees. Not all households managed to live from farming. Production-related aspects such as yields, fertilisation rate, the quantity of milk collected and the duration of lactation of cows varied between households (*Supplementary Material 8*).

Variability in performances concerning quality of life depended on the household's level of wellbeing, decent work and food security, health and nutrition (Figure 7). Differences in wellbeing related to variability in property ownership (*i.e.*, non-monetary economic wealth), income and the education level of the head of household. Only five heads of households had access to education until primary school. The variability in scores regarding food security, health and nutrition was linked to pesticide use and the

proportion of land dedicated to food production, which were both related to the production of conventional cotton (Figure 4). Food self-sufficiency also varied significantly between households and was related to production capacity (*i.e.*, agricultural land, herd size and number of activities) as well as food needs (household size). Differences in decent employment were linked to income and the average perception of the level of work drudgery within the household. Variability in household performance regarding agroecosystem health depended on pesticide use and soil management practices, such as levels of organic matter inputs (Figure 7). Some performances were similar among households, corresponding to similar resource use and marketing conditions (Figure 7). These similarities corresponded to a limited use of external resources (synthetic fertilizers and agricultural inputs), a good level of local development, through the use of local resources mainly and the mainly selling through local channels. The importance of collective work in the village also characterized the good level of local development. Other household performances corresponded to similar living conditions, such as the good level of social cohesion and autonomy. Finally, some similar household performances corresponded to similar practices, such as good levels of planned biodiversity given their diversified cropping, diversity in animal species and ecological management of agroecological infrastructure. These similar performances revealed a limited development of agroecological infrastructure, with a low implementation of assisted natural regeneration practices and access to a limited number of crop varieties. The low level of greenhouse gas emissions related to the balance between emissions and sequestration. No household achieved high performance levels for all four dimensions (Figure 7). Three households (1, 4 and 8)

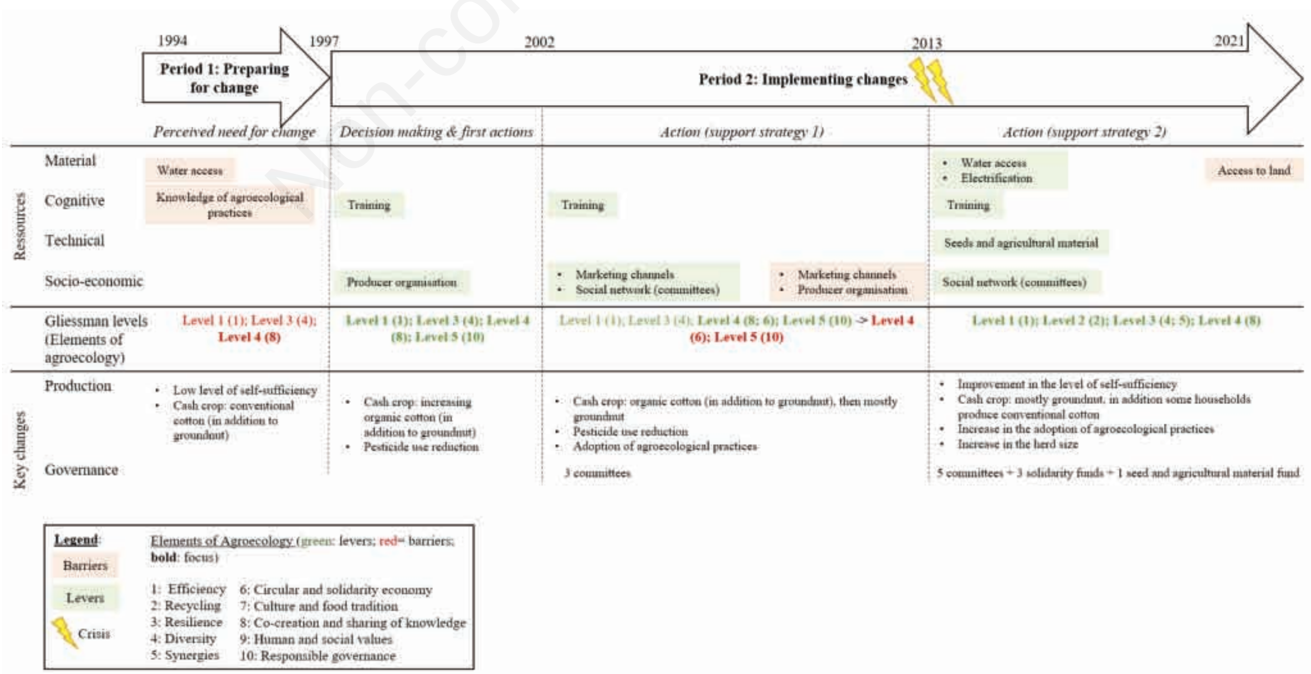

Figure 6. Barriers and levers in the development of the agroecological transition in the village of Sare Boubou (result of step 3 of the prototype).

presented the highest performance levels regarding agroecosystem health and were the only households in the village not using pesticides (Figure 4).

Household level

To better illustrate how results at the household level could provide an explanation on household performance, we focused on two highly contrasting households, households 1 and 8. Household 8 had lower trade-offs between the four dimensions, with the highest performance levels regarding quality of life and techno-economic performance. This household also presented the third highest performance level for agroecosystem health, after households 4 and 1. Household 8 managed to make a living from farming activities, with a share of agricultural income of around 80% (*Supplementary Material 8*). It was characterized by diversified activities (among the highest number of activities in the village) and low degree of specialisation (among the lowest in the village) (*Supplementary Material 8*). Household 8 was characterized by the presence of non-agricultural activity (off-farm income), representing a certain security and higher income (*Supplementary Material 8*). Household 8 also presented one of the highest levels of food self-sufficiency in the village (92%), related to the household's large number of activities and gross production and its limited household size (Figure 4). Furthermore, Household 8's production was steered towards selling, with sales outstripping input expenditure (Figure 4). Household 8's higher levels of wellbeing and decent employment related to a higher income, lower perceived drudgery of work, more decent work, access to education and higher property ownership (non-monetary economic wealth) (*Supplementary Material 8*). Household 1 presented the village's highest performance levels regarding agroecosystem health, with a particularly high performance for soil health. This was related to i) areas dedicated to fallow (8% of land) and to crop rotation (59% of land under rotation); ii) high levels of soil carbon stocks (14.8 tonnes/ha at a depth of 0-30 cm); iii) high organic matter inputs per ha per year (9.321 kg/ha), and 4) the large share of area of land covered with vegetation (50%) (*Supplementary Material 8*). However, household 1 presented the village's lowest techno-economic performance, which was related to its low diversification level and low production process efficiency (Figure 7). Household 1's performance regarding quality of life was part of the lowest in the village, in particular because of very low income, low agricultural wealth, low property ownership and a high perceived drudgery of work (*Supplementary Material 8*).

Individual level

Results related to quality of life at the individual level revealed large disparities between the village's men, women and young men (*Supplementary Material 9*), reflecting the "weight of cultural issues" (feedback from results of end-users in stage 9). Heads of households had higher scores regarding education level, empowerment and participation in knowledge sharing networks. Young men, followed by women, were the individuals that found the work the most difficult. Young men were those most frequently applying pesticides, with little or non-existent protective clothing. Only one indicator presented similar low scores for all three groups of individuals (involvement in professional structures), highlighting a generalized low social involvement with entities from beyond the village.

Results of the end-user validation

The ease of understanding the results was high in the majority of cases but presented some variability for both end-user categories

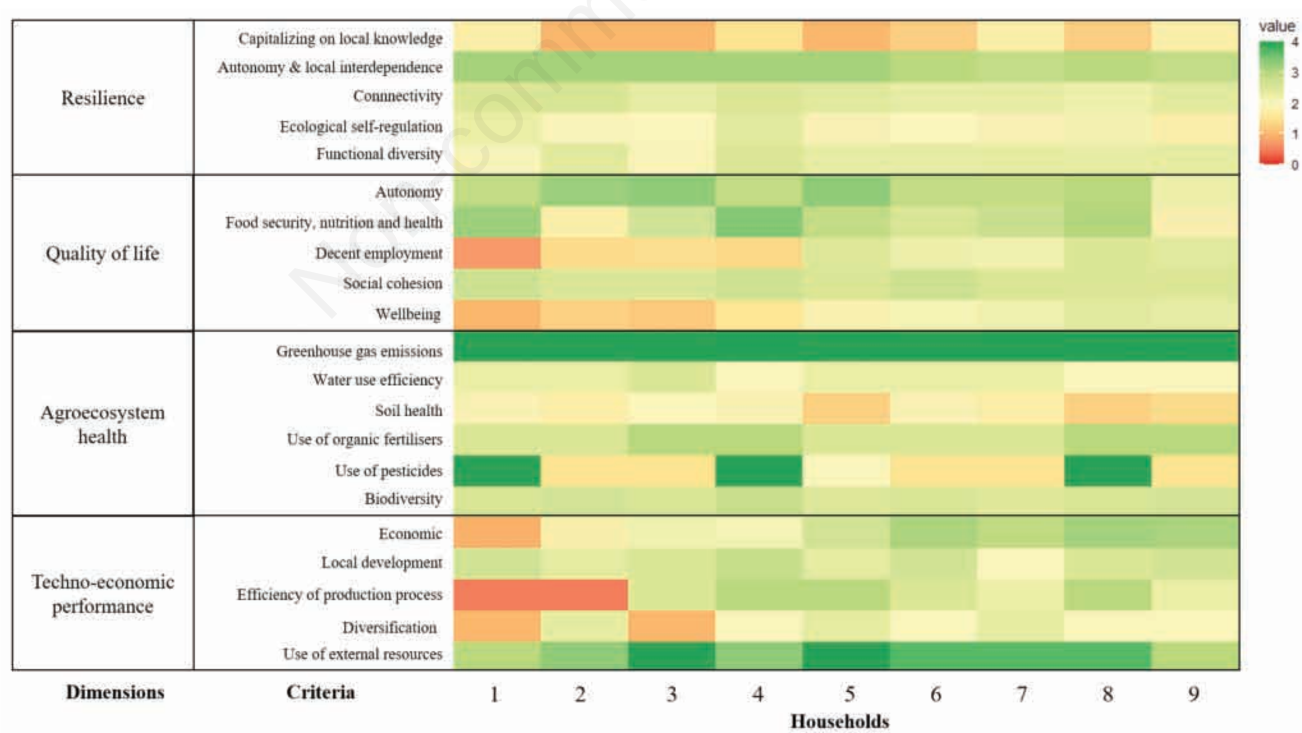

Figure 7. Heat map comparing the performances of the nine households of the village at the criteria level. The colours represent the average values of scores for each criteria for the corresponding household. Shades of green denote the highest scores (best possible value), amber are medium scores and red are the lowest scores (worst possible value). See *Supplementary Material 8* for raw values taken by indicators.

(Table 3). These results highlighted the importance of sharing and discussing the results to increase the level of understanding and raised the need to improve visuals in result presentations. Both categories of end-users provided positive feedback on the method's results, which they considered "relevant" and "useful". Results-end-users highlighted the results' capacity to "understand the diversity in the village" and "highlight weaknesses and draw actions accordingly". Results-end-users further acknowledged that the results could "help NGOs to target priority aspects to be addressed in relation to agroecology". Method-and-results-end-users provided more mixed feedback, questioning in particular the capacity of the results to feed advocacy. These results revealed the usefulness of the prototype to steer and manage the agroecological transition in the village, but its limited capacity to feed advocacy. Feedback on the ease of use of the prototype and regarding the eagerness to use it in the future were timorous. The prototype was seen as "time-consuming" and "data intensive", weaknesses perceived by the method-and-results-end-users as the "counterparts to its comprehensive and holistic nature". A posteriori searches for relevant reference values were seen as "difficult". Method-and-results-end-users mentioned the need to simplify the last version of the prototype to scale out its use. Both categories of end-users shared their wish to include a diachronic analysis to reveal the evolution of results over time. Direct exchanges between both end-user categories made it possible to identify levers for action at different scales. These concerned in particular, at the household level, improving: i) the management of organic matter; ii) assisted natural regeneration practices. Levers for action at the village and individual levels were particularly related to gender issues and concerned i) women and youth empowerment: the need to include them in the village's decision-making processes because although women and youth were able to give their opinion, they were never involved in decision-making; ii) women's empowerment: the need for NGOs to foster women's inclusion in knowledge sharing networks. Women highlighted how they sometimes felt left out of knowledge-sharing activities and emphasized their wish to be more involved.

Discussion

Using prototyping to build an assessment method and to assess a case study's agroecological transition

In our study we used prototyping (Lançon *et al.*, 2007; Sterk *et al.*, 2007; Perinelle, 2021). To our knowledge, prototyping has never been used to design an assessment method. Generally, designers of assessment methods adopt a more traditional approach: first designing the assessment method and then implementing it, before modifying it and building on end-user feedback.

The approach used in this study has several advantages. First, it saves time compared to the more traditional approach, by simultaneously adapting the prototype and providing evaluation results by the use of the prototype during the testing. Second, this approach makes it possible to implement a more participatory design methodology compared to the more traditional approach, where end-users, and not only designers, drive the evolution of the prototype. This differs from the traditional approach where designers ensure the method evolves building on end-user feedback, without involving them in the change proposals nor in the evolution of the prototype. In contrast, our approach is inspired by innovative design approaches, refusing to separate designers and end-users by arguing that the design continues through its use (Béguin and Rabardel, 2001; Cerf *et al.*, 2012). The involvement of end-users has multiple effects that we present in 4.2. Third, changes allowed the initial prototype to adapt to the case study's scale and context specificities. Prototyping therefore made it possible to introduce adaptability in the approach. Finally, this approach permits us to obtain both methodological results and results related to the evaluation of the case study's agroecological transition. Results of the testing and adaptation of the prototype revealed: i) end-users' visions of what was important and relevant to assess in the agroecological transition; ii) the difficulties in assessing the

Table 3. Results of the end-user validation with both categories of end-users. Percentages illustrate the share of end-users choosing 'low', 'medium' or 'high' for each question. Three questions were common for both categories of end-users: ease of understanding, results consistency and results usefulness. Three additional questions were addressed to method-and-results end-users: level of comprehensiveness, ease of use of the prototype and eagerness to use the prototype in the future.

Evaluation criteria	Results-end-users' validation Group	Low, %	Medium, %	High, %
Ease of understanding	Men	0	38	63
	Women	0	0	100
	Youth	0	44	56
Results consistency	Men	0	0	100
	Women	0	9	91
	Youth	0	0	100
Results usefulness	Men	0	12	88
	Women	0	0	100
	Youth	0	0	100

Evaluation criteria	Method-and-results-end-user's validation Low, %	Medium, %	High, %
Ease of understanding	0	40	60
Results consistency	0	20	80
Results usefulness	0	40	60
Level of comprehensiveness	0	0	100
Ease of use of the prototype	20	30	50
Eagerness to use the prototype in the future	40	40	20

agroecological transition (*e.g.*, lack of data or measurement capacity), but also the means to overcome these difficulties (*e.g.*, change of indicator). The classical evaluation approach only provides results related to the evaluation, as it does not detail the design of the method. Results of the use of the prototype provided a comprehensive diagnosis of the agroecological transition taking place in the village. Results of the assessment made it possible to "understand the diversity in the village", "highlight weaknesses and draw actions accordingly" and "help NGOs to target priority aspects to be addressed in relation to agroecology" (verbatim from results-end-users). Levers for action to foster the transition and improve performance were identified at the village, household and individual levels. Levers for action provided the basis for an action plan with concrete changes to undertake. As an example, the agroecological transition's history and characterization of the level of advancement illustrated the need to revive the previously existing farmers' organization to improve farmers' empowerment and increase the uptake of agroecological practices in the village. Furthermore, households identified as high performers, such as household 8, could be considered as sources of inspiration for other farmers and stimulate exchange of practices between farmers to accelerate the agroecological transition (Nicholls and Altieri, 2018).

This approach also has its drawbacks. The high level of involvement of end-users requires time. Our results showed that the prototype was seen as "time-consuming" and "data intensive", weaknesses perceived by the method-and-results-end-users as the "counterparts to its comprehensive and holistic nature". These weaknesses further led to the low level of eagerness to use the prototype in the future. This questions the potential to scale-out the prototype following this study. A similar judgement was shared by designers of the sustainable livelihood framework (DFID, 1999), though this is a frequently used framework today. This suggests that achieving relevant, useful and comprehensive results does not come without a cost: the cost of time and resources. It further reveals the existing tension between the level of comprehensiveness and the difficulty of implementation, highlighted by De Olde *et al.* (2018) and Marchand *et al.* (2014). Furthermore, adapting the prototype to each situation increases its local relevance, fulfilling one of the evaluation's purposes, *i.e.*, to steer and manage agroecological transitions. However, the adaptation also leads to case studies and context-specific results, that do not allow us to compare different situations and thus reduce the genericity of the results. This aligns with Binder *et al.* (2010) and Reed *et al.* (2006)'s view that an assessment specific to the context is relevant for localized steering assessments but not for benchmarking. Reconciling these two evaluation purposes therefore seems contradictory.

The participatory approach used for the design of the prototype

The participatory approach suggested by the use of prototyping is in line with the participatory and action-oriented agroecological perspective highlighted by Méndez *et al.* (2013) and Gliessman (2016). Using such a participatory approach has several effects. This approach ensures a degree of co-ownership and increases the legitimacy of the assessment method (De Olde *et al.*, 2018). It further ensures a high level of understanding and relevance of the prototype, as shown by our results. Such a participatory approach leads to a use-relevant prototype, by making it possible to incorporate the perspective of the end-users involved in the evaluation. This leads to a more meaningful assessment for end-users (López-Ridaura *et al.*, 2005; Gasparatos, 2010) but also to rethink performance indicators (Charue-Duboc *et al.*, 2010). Our results highlighted how the initial indicator list of step 4 of the prototype evolved through end-users' inputs. Their involvement allowed us to add information they deemed relevant and useful that was missing in the initial indicator set, related to livestock productivity, working conditions and practices favouring soil health. Other indicators were specified, such as general perceived autonomy and dietary diversity. A participatory approach finally leads to collective learning (Berthet *et al.*, 2016). This happened in our study through the creation of "learning environments" (Cerf *et al.*, 2012) among the co-designers that took place during the debriefing sessions (stages 2, 4, 9a and 9b). These sessions are essential to discuss and account for discrepancies between different interpretations (Garcia Parrilla *et al.*, 2016). These learning environments allowed us to discuss results of the evaluation following the use of the prototype, raising awareness on the strengths and weaknesses of the ongoing agroecological transition and permitting to identify levers for action to accelerate the transition. For example, Results-end-users realized the existing variability among the households in the village and learned why some households performed better. Thus, results-end-users realized the importance of managing better organic matter or the need to improve assisted natural regeneration practices, observing the higher performance levels for soil health in the households implementing such practices. Results-end-users also acknowledged the existing inequality between men, youth and women. Women raised the need for the supporting NGOs to involve them more in their activities to foster the transition.

The participatory approach adopted in this study also presents some limitations. First, the two different categories of co-designers were involved at different times and through different techniques, relating to their role in the design of the prototype. This revealed an asymmetry in the participation level between the different end-users involved, related to the adopted hybrid approach (co-design). Method-and-results end-users were involved in both phases and could share their experiences, provide knowledge and generate ideas for the design of the prototype during two workshops (stages 2 and 4, Figure 1). They were able to frame the prototype according to their needs (stage 2) as they were to use the prototype thereafter to support or study agroecological transitions. Results-end-users were involved at a later stage, in testing and adaptation, during data collection, through individual interviews and focus group discussions. They could also give their views following the sharing of preliminary results (stage 9a, Figure 1). Their role was to provide local knowledge, information, share elements of concern to adapt the prototype to their needs and help to make sense of the results following the preliminary result presentations (stage 9a, Figure 1). Although they had the opportunity to provide inputs to adapt the prototype, their capacity to shape the prototype was more limited than method-and-results-end-users.

Second, we mobilized different participatory methods in this study, particularly: i) group work during workshops; ii) surveys; iii) dialogue. These methods granted a flexible and open exchange of ideas and opinions among the end-users involved and permitted us to make decisions on the dimensions, criteria and indicators used in the evaluation of performance. These methods were chosen because they were commonly mobilized in the end-users' context of work and enabled them to feel more at ease to share their ideas. Other participatory methods could have been used, such as the Parsimonious Analytical Hierarchy Process (P-AHP). P-AHP would have added more structure and replicability to the decision-making in our work. AHP is a convenient approach to prioritize and rank preferences of stakeholders (Saaty, 1977; Mendoza and Prabhu, 2009). P-AHP allows consideration of a high number of elements in the prioritization (Abastante *et al.*, 2019). The four dimensions of step 4 of the prototype were broken down into criteria and indicators, following method-and-results-end-users proposals in stages 2 and 4 (Figure 1), without any prioritization. However, the initial list of criteria and indicators would have benefitted from a ranking and prioritization, mobilizing a diversity of viewpoints in both phases A and B of the co-design approach, when using P-AHP. This could, for example, have reduced the number of criteria and indicators in the initial prototype. In phase B, it could have permitted results-end-users to have a more in-depth understanding of the initial content of the evaluation grid and take part more in shaping the assessment according to their views. Regarding aggregation, we assumed equal weights for the indicators, as decided with method-and-results-end-users. Mobilizing P-AHP would have further permitted us to compute weights and therefore set priorities, by taking into account the local stakeholder viewpoints, as in other research works (Abastante *et al.*, 2019; Fattoruso *et al.*, 2022). This would have shed light to the most important indicators and thus would have shaped even more the evaluation according to end-users' views. Yet, such a structured participatory method is time and resource consuming (Kwatra *et al.*, 2021) and would have called for additional time for both categories of end-users. P-AHP also presents another limitation, as it is based on the prioritisation of the existing but does not allow for additions. Yet results in our study revealed the importance of the additions to include end-users' views and concerns, and thus permit them to participate in the evolution of the prototype.

Conclusions

Assessing conditions and performances of agroecosystems undergoing an agroecological transition in different contexts is key to building evidence on and supporting agroecological transitions. In this paper, we have presented the results of the design, testing and adaptation of a method assessing agroecosystems undergoing an agroecological transition. Results were fourfold, both methodological and related to the evaluation of the case study's agroecological transition. The methodological results concerned the design of the initial prototype and its adaptation to the case study. The results of the evaluation of the case study's agroecological transition followed the use of the prototype. The results of the end-user validation were both methodological (feedback on the prototype) and evaluation results (feedback on the results of the evaluation). We detailed the adopted co-design approach based on prototyping and involving end-users. The initial prototype was framed according to the literature and the needs assessment and aimed at covering five methodological challenges in assessing agroecosystems undergoing an agroecological transition. The prototype testing in a village in Senegal made it possible to adapt the initial prototype to the village's scale and context specificities. The results of the evaluation of the case study's agroecological transition provided a diagnosis of the ongoing agroecological transition and permitted us to identify levers for action at three different scales (village, household and individual) to accelerate the agroecological transition. Despite a method seen as time-consuming and data intensive, end-users acknowledged the comprehensiveness of the method and its usefulness for steering and managing agroecological transitions. The serious tooling of end-users to support agroecological transitions strengthens advocacy for agroecology. Still in an evolutionary trajectory, the prototype would benefit from additional testing at other scales and in other contexts to check its adaptability and usefulness for supporting a diversity of agroecological transitions.

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Online Supplementary Material:

Supplementary Material 1. Approaches of the 14 selected assessment methods covering the five challenges in assessing agroecosystems undergoing an agroecological transition (evaluation criteria) and used to build the prototype.

Supplementary Material 2. Initial set of 73 indicators stemming from the 14 selected assessment methods. Some of the indicators were identified in the first or second workshop with method-and-results-end-users (stages 2 or 4 of the co-design approach). Lines in grey represent indicators withdrawn following the testing and adaptation phase in the case study in Senegal. No scoring system is indicated for these indicators. Details are provided regarding the indicators' scale of assessment (V: Village; H: Household; I: Individual), sources of references values, operating mode for their normalization in the case study, and scoring system. Note: in italics are the three impact-related indicators.

Supplementary Material 3. Elements of agroecology and related criteria affected in step 2 by changes during the testing and adaptation phase. Types of changes and details of the changes made.

Supplementary Material 4. Changes during the testing and adaptation of the prototype in the case study in Senegal. Specified are time of change (Ta to Td), reason (R: relevance; D: data; E: end-user inputs), type of change (addition: A; withdrawal: W; Specification: S) and justification for change.

Supplementary Material 5. Set of indicators added to the initial indicator set following the testing and adaptation to the case study. All these indicators stem from end-user inputs. Details are provided regarding the indicators' scale of assessment (V: Village; H: Household; I: Individual), operating mode for their normalization in the case study, sources of references values and scoring system.

Supplementary Material 6. Key features of the nine households of the village of Sare Boubou.

Supplementary Material 7. Stakeholder mapping reflecting results-end-user views (result of step 1 of the prototype).

Supplementary Material 8. Data for village (V) and household (H) level indicators (in grey: indicators withdrawn following the testing and adaptation phase in the case study in Senegal). Village level indicators present the same data for all nine households. In grey, indicators withdrawn. In bold, indicators that have been specified.

Supplementary Material 9. Heat map comparing individual level indicators regarding the quality of life dimension. The colours on the heat map represent the average values of scores for each indicator for each individual of the corresponding gender group (men, women and youth). Shades of green denote the highest scores (best possible value), amber are medium scores and are red the lowest scores (worst possible value).