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What future for banana-based farming systems in Uganda? A participatory scenario analysis

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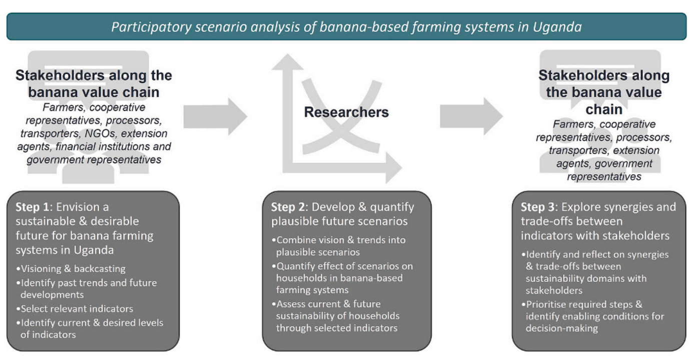
HIGHLIGHTS

- Economic performance of banana farming systems in Uganda has improved, but at the expense of other sustainability domains.
- Transition pathways towards a sustainable future were envisioned with stakeholders, quantified, and trade-offs explored.
- Enhanced food self-sufficiency and farm gross margins are feasible; trade-offs are increased labour and investment costs.
- Participatory scenario analysis led to stakeholder consensus on sustainability priorities and entry points for improvement.
- Higher-level support and advocacy is required in decision-making on more complex, long-term challenges.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Population pressure, land scarcity and encroachment of nature reserves are challenging sustainable intensification of agriculture in Uganda. One of the main staple crops in Uganda is East African Highland banana. Area expansion and improved management have enhanced the economic performance of banana, yet at the expense of food security, environmental and social sustainability. While a transition of banana-based farming systems to a more sustainable future seems necessary, the desired future state and pathways of getting there may differ among actors involved.
OBJECTIVES: Our study aimed to co-design potential transition pathways with stakeholders along the banana value chain in Uganda, and to assess the effects of these pathways on sustainability indicators at the household level.

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METHODS: We conducted a participatory scenario analysis consisting of: 1) stakeholders envisioning and backcasting a sustainable future for two banana-based farming systems in Uganda; 2) researchers developing and quantifying plausible future scenarios to assess their effects on locally-relevant sustainability indicators at the household level; 3) stakeholders reflecting on the results, including synergies and trade-offs between sustainability indicators.

RESULTS AND CONCLUSIONS: Stakeholders' envisioned future combined with main trends influencing banana-based farming systems resulted in four contrasting scenarios: *Marginalisation* (stagnation compared with the reference baseline); *Business as usual* (extrapolation of historic trends); *Intensification* (including Integrated Soil Fertility Management and collective marketing of banana); and *Transformation* (irrigation in banana, balanced crop nutrient management, cooperatives, and increased farm sizes for some as other households leave agriculture).

Compared with the current baseline situation, selected sustainability indicators food self-sufficiency and farm gross margins decreased in *Marginalisation*, but improved in all other scenarios. Soil nutrient balances were unfavourable in all scenarios, except with balanced crop nutrition in *Transformation*. Stakeholders recognised labour as a main trade-off for desired improvements in other sustainability domains. Stakeholders also reflected on benefits and risks of a continued specialisation in banana, and fiercely debated the desirability of mineral fertilizer use.

The active involvement of stakeholders in providing the building blocks for the scenarios, identifying relevant indicators and reflecting on the results, aimed to guide stakeholders on concrete entry points for improving sustainability of the system.

SIGNFICANCE: Indications of stakeholder commitment towards a more sustainable future included a convergence of ideas on the need for Integrated Soil Fertility Management, collaboration in cooperatives and the need for savings to overcome risks of specialising in banana. Meanwhile, higher-level advocacy and support is required in decision-making on more complex, long-term challenges.

1. Introduction

Food insecurity and poverty remain major challenges in Sub-Saharan Africa (FAO, IFAD, UNICEF, WFP and WHO, 2020). At the same time, climate change effects threaten food production (FAO, 2015; IPCC, 2022), while increases in production are needed given the expected doubling of the population by 2050 (Godfray et al., 2010; Van Ittersum et al., 2016; United Nations, 2022). The options for expansion of agriculture into uncultivated areas are limited and often undesirable in already densely populated areas, which implies that, largely, intensification of agriculture is needed on land currently under production (Pretty et al., 2011; Vanlauwe et al., 2014; Van Ittersum et al., 2016). There is consensus, however, that this intensification needs to happen in a sustainable way, with minimal negative environmental impact and with due attention for social and human wellbeing (Godfray, 2015; Smith et al., 2017; Reich et al., 2021).

One of the countries facing ongoing population pressure, land scarcity and encroachment of nature reserves is Uganda (Adonia and Kakurungu, 2014; Mwesigye et al., 2017). In Uganda, 80% of the population are smallholder farmers (UBOS, 2020). One of the most widely grown staple crops in Uganda is East African Highland banana (*Musa* spp., hereafter referred to as banana), grown by >75% of all farmers in the country (Promusa, 2020). Major growing areas are concentrated in the south and southwest of the country (UBOS, 2020; Ochola et al., 2022).

Especially in the southwest of Uganda, banana cultivation has expanded over the past decades (Ochola et al., 2022). The area under banana has increased and its management has improved, resulting in marked increases in production volumes and incomes (Gold et al., 1999; Rietveld et al., 2021). However, while the increases have generally improved the economic performance of the farming system, this has largely been at the expense of other dimensions of sustainability: the banana area increase has been at the expense of other (food) crop, livestock and forest areas (Rietveld et al., 2021; Ochola et al., 2022), with implications for food and nutrition security and environmental services (Wairegi and van Asten, 2010; Den Braber et al., 2021; Rietveld et al., 2021). Moreover, the expansion of banana and changes in its agronomic management have resulted in social implications with respect to gender relations and labour division (Rietveld et al., 2021; Rietveld and van der Burg, 2021).

In western Uganda, banana is part of a more diverse farming system (FEWS NET, 2013; Ochola et al., 2022). This diversity favours the farming system's sustainability attributes with respect to food security, environmental services and resistance to shocks. However, population increase has led to expansion of agricultural land into the original primary forest (GFW, 2021), and improved market integration is driving this system towards intensified banana production and expansion as well. Besides, in the farming systems of both southwestern and western Uganda, the use of fertilizer and manure remains highly limited, resulting in soil fertility depletion (Wairegi and van Asten, 2010; Den Braber et al., 2021; Rietveld et al., 2021). Hence, looking towards the future of the systems in both regions, increased vulnerability to climatic and market shocks as a result of the increased dominance of banana, soil fertility loss, deforestation, and changing social relations are important sustainability concerns.

While a transition of these systems towards a more sustainable future seems necessary, the perceived need for this transition, the desired state of the future system and the preferred pathways of getting there may differ among actors involved. Envisioning future transition pathways therefore requires involvement of a wide range of stakeholders, to elicit their perspectives on the most important local needs and priorities, and to create the necessary ownership, commitment and joint social learning to foster the transition towards the desirable future (Walz et al., 2007; Reed et al., 2013; Schneider et al., 2019). To facilitate such a process, participatory visioning and backcasting can be employed to guide discussion and convergence of views of different actors through imagining a successful outcome in the future, and identifying the steps needed to reach that outcome (Quist and Vergragt, 2006; Robinson et al., 2011; Kanter et al., 2016).

Transition pathways need to be planned under uncertainty about the future (Quist and Vergragt, 2006; Larkin et al., 2020), which can be catered for by combining backcasting with the use of exploratory scenarios (Kok et al., 2011; Robinson et al., 2011; Vervoort et al., 2014). In participatory scenario planning, stakeholders imagine plausible futures in the form of scenarios – defined here as "plausible descriptions of what the future *might* hold" (Reed et al., 2013) – often ranging between the worst and best imagined futures; identify the most relevant issues to be considered in the scenarios; and define uncertainties around planning for the future (Williams et al., 2023). The qualitative development of scenarios is sometimes followed by a quantitative scenario analysis, in which future uncertainties are simulated, impacts of the identified scenarios quantified and emerging trade-offs between different sustainability domains reconciled (Walz et al., 2007; Soste et al., 2015; Williams et al., 2023).

Only a minority of backcasting and participatory scenario planning studies took place in Africa (Oteros-Rozas et al., 2015; Bourgeois and Sette, 2017; Thorn et al., 2020), where data scarcity, limited digital skills and limited experience with the concept of scenarios pose challenges. Even fewer studies focus on a local, smallholder farming setting (with Vervoort et al., 2014 as an exception), while this level comprises the actors most directly affected (Giller et al., 2021b; Ortiz-Miranda et al., 2022). Moreover, while the choice of indicators to quantify in scenario analyses is often guided by the models used (cf. Walz et al., 2007; Starkl et al., 2013; Soste et al., 2015; Chopin et al., 2021; Homann-Kee Tui et al., 2021), explicit involvement of stakeholders in the identification of locally relevant criteria and indicators for assessment happens less frequently (exceptions are e.g. Reed et al., 2013; Starkl et al., 2013; Vervoort et al., 2014).

The objective of our study was therefore to combine participatory visioning and backcasting with the use of exploratory scenarios, to co-design potential transition pathways for banana-based farming systems in Uganda, and to assess the effects of these pathways for farm households on different sustainability indicators co-identified by stakeholders. Specific objectives were to: 1) identify the steps needed to reach an envisioned desirable future for two banana-based farming systems in Uganda; 2) develop plausible scenarios to unpack uncertainties in future developments and quantify the effects of the scenarios on sustainability indicators at the household level; and 3) explore synergies and trade-offs between indicators in different sustainability domains with stakeholders to inform their future decision-making. We refer to the entire process as a participatory scenario analysis, and also reflect on the methodological aspects of conducting such participatory scenario analysis in a smallholder farmer setting.

2. Methodology

2.1. Study regions

Southwestern and western Uganda were selected for their importance as banana producing areas within Uganda, and for their contrasting soil, climatic and farming systems conditions. Within southwestern Uganda, the study took place in Birere and Rugaaga sub-counties in Isingiro district; and in western Uganda in Rwimi sub-county in Bunyangabu district. All sub-counties had been involved in previous interventions around banana and were considered as representative study sites for the region.

The sites in the southwest are located at an altitude of 1350–1500 m above sea level (masl) and have moderately fertile loamy soils. The southwest receives rainfall of 800–1100 mm year^{-1}, which is marginal for banana production. The expected increased drought incidence due to climate change will make production more vulnerable in future (Wichern et al., 2019). Banana production in the region is dominated by the cooking type, and as much as 70% of the rural population in this region indicates that the production of cooking banana is their sole source of income (ACORD Uganda, 2010). Monocultures and the increased dependence on income solely from banana make the system increasingly vulnerable to outbreaks of pests and diseases (Blomme et al., 2013; Blomme et al., 2019; Fan et al., 2022), and to market or climatic shocks (Rietveld et al., 2021).

The sites in western Uganda are located at an altitude of 1100–1200 masl and receive moderate to good rainfall (1200–1500 mm year^{-1}). The region has fertile, black, volcanic ash soils. The west has a shorter history of banana cultivation than the southwest (Gold et al., 1999; Ochola et al., 2022), yet the continued cultivation without external nutrient inputs is threatening soil fertility in the longer term.

2.2. General approach

The participatory scenario analysis consisted of three steps, directly related to the three objectives (Fig. 1). Step 1 focused on the visioning of a sustainable and desirable future for the two different farming systems by stakeholders, and the identification of the steps needed to reach that vision through backcasting. In step 2, researchers used the results from step 1 to develop plausible future scenarios, and quantified these scenarios to assess the effects on sustainability indicators at the household level. In step 3, synergies and trade-offs between sustainability domains were identified and reflected on with stakeholders.

2.3. Step 1: Envisioning a sustainable and desirable future

In both regions, workshops were held with stakeholders along the two regional banana value chains. These stakeholders had been identified in a preceding Net-Map exercise (Schiffer and Hauck, 2010; Uckert et al., 2022), and consisted of representatives of farmer groups, co-operatives, processors, transporters, NGOs, extension agents, researchers, financial institutions and the local government. One to two representatives (and three in the case of farmer groups) of each stakeholder category were invited. A detailed overview of participants per workshop is given in Table S1.1. A team of researchers and implementing project partners facilitated the workshops.

A first two-day workshop late 2019 focused on visioning and backcasting, to develop a shared vision for sustainable farming systems and banana value chains in the "near future": 10 to 20 years from now. This is a period that can be foreseen, yet allows participants to dream big and not feel restricted by a short time frame, in line with e.g. Vervoort et al. (2014) and Kanter et al. (2016). Four sustainability domains were selected beforehand by the project partners: the food security, economic, social and environmental domain. These domains were verified with stakeholders, which led to no changes in the southwest, and a combination of the economic and food security domain in the west, as stakeholders argued that these should be considered together.

After an introduction to participatory visioning, stakeholders discussed the question: "What will farming in this region look like in a sustainable future?". The participants were divided randomly into groups per sustainability domain. The smaller groups served to allow all stakeholders to give their view and to minimize the dominance of certain (powerful) actors (cf. Reed et al., 2013). Each group addressed the question by writing down their 'hopes and wishes' for the future on post-its and placed these on a sheet per sustainability domain. The groups then selected their top-five hopes and wishes, which we refer to as 'elements of a sustainable future' in the remainder of this study. A second round focused on the banana value chain in the same way. Next, backcasting was introduced as the steps needed to reach the vision. Backcasting started by the identification of obstacles that could arise when aiming to reach the vision for the elements of a sustainable future per domain. This exercise was done for the banana value chain only.

On the second workshop day, stakeholders identified opportunities to overcome the obstacles. As there were similar, cross-cutting obstacles across sustainability domains, the obstacles were regrouped into obstacles related to production, processing/ value addition and marketing. New groups were formed around these three categories, and each group picked out the three main obstacles in their view. The groups listed opportunities that would help to overcome the obstacles, and possible project interventions. Then, the groups rotated twice and added to the findings of the first group. The process aimed to go from the collection of different perspectives in the visioning part, to consensus among stakeholders on the most important topics to focus on.

In a second two-day workshop early 2020, stakeholders from both regions were invited together. In this workshop, four potential project interventions from the first workshop, gauged as most feasible by the project partners, were presented to the participants. Through pairwise ranking (by each individual stakeholder), two project interventions

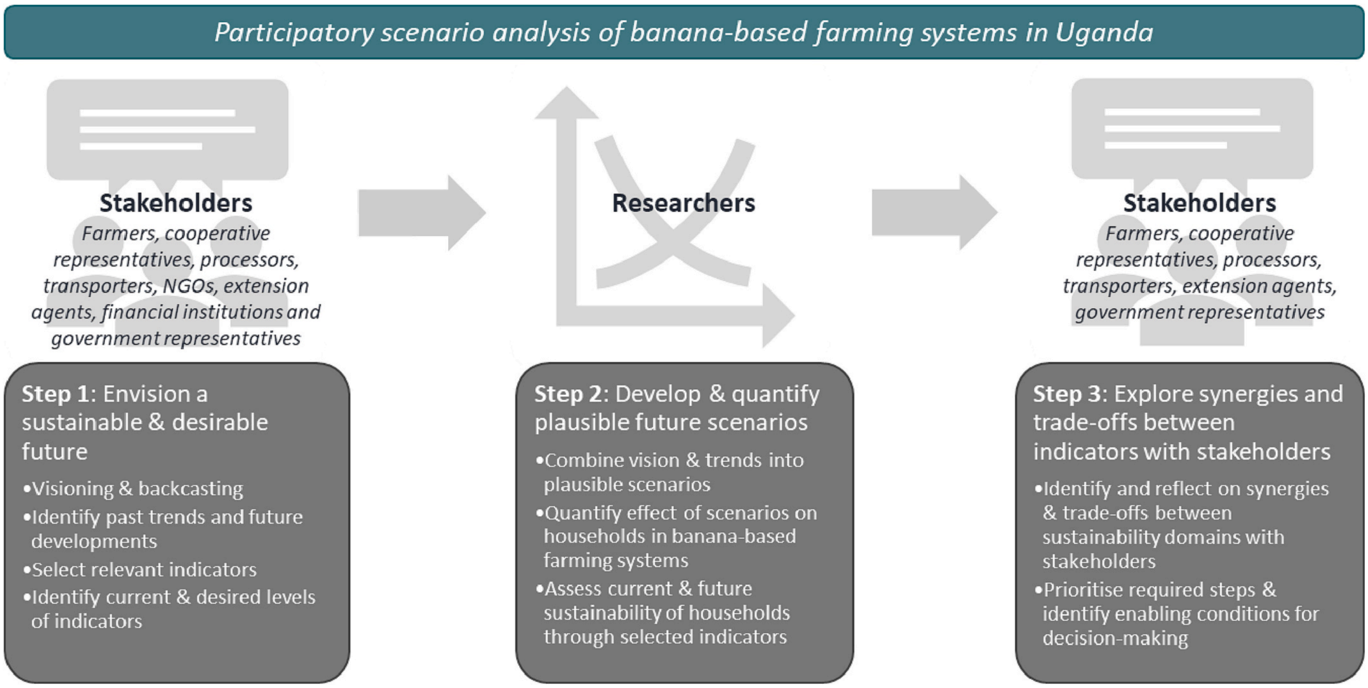

Fig. 1. The participatory scenario analysis, consisting of three steps and conducted in two banana-based farming systems in southwestern and western Uganda.

were selected per region. For the two selected interventions, groups per region identified a set of locally relevant indicators, to monitor anticipated effects of the interventions. Finally, a number of past trends and changes, gathered from literature and reports, was presented to the participants. The participants reflected on the applicability of these trends and their effect on people's livelihoods in their respective regions. This was done in a qualitative way. The magnitude and potential effects of the trends were quantified as part of Step 2.

2.4. Step 2: Developing and quantifying plausible future scenarios

2.4.1. Developing future scenarios

In Step 2, researchers reviewed the results of Step 1 for the two regions, and identified elements of a sustainable future (workshop 1) and trends influencing people's livelihoods (workshop 2) that were listed and prioritised by stakeholders in both regions. Researchers then combined these trends and elements to develop distinct, plausible future scenarios which are detailed in Section 3.1. Scenarios were the same for both regions to reduce complexity, and as warranted by the overlap in trends and elements in the two regions.

2.4.2. Quantification of the baseline situation

The scenarios were compared with the current, baseline situation of farm households in the two study regions. The baseline situation was based on data from several farm surveys conducted between 2017 and 2020. These surveys included a general socio-economic and bio-physical survey describing farming systems and banana production practices, and additional surveys on specific topics including banana bunch weights, market prices and input use (Table S1.2). The sampling strategy allowed for representing the farming population in the study sites, and resulted in a complete dataset of 114 households in southwestern and 54 households in western Uganda.

Variables quantified to assess the baseline situation were: available farm land, crop production, input use and costs, market prices, labour available and required, and nutrient offtake and input. Currently available farm land was based on farmers' estimates in the socio-economic baseline survey. The production of banana (t farm^{-1} year^{-1}) was derived from the biophysical baseline survey, based on allometric relations (Wairegi et al., 2009; more detail in S3.1). Banana yields were farm specific, as also reflected in varying input use between farms. The production of other crops was based on farmers' estimates from the socio-economic baseline survey. For these crops, mean yields were calculated per crop per region and allocated to all farms growing this crop, assuming no differences in input use between farms.

Input use per crop was derived from the socio-economic baseline survey based on a yes/no indication of the use of improved seed, manure, mulch, mineral fertilizer and pest control measures. For banana, inputs were considered per farm. For other crops, inputs were allocated to all farms when the majority of farmers used this input in a particular crop. This was only the case for use of improved maize varieties in western Uganda. Input quantities and prices were estimated from different sources (Table S1.3). Market prices for crops were based on the average farmer-reported market price per crop per region from the socio-economic baseline (Table S1.4). All financial data were converted to 2017 price levels and expressed in 2017 US dollar Purchasing Power Parity ($PPP) (World Bank, 2020b).

Family labour available was estimated from the indicated full time (365 days per year) or part-time (56 days, equalling 8 weeks of school holidays) availability of each household member in farming, and their estimated labour productivity (adults $>$ 16 years old $=$ 1; kids 4–16 years old $=$ 0.5). Labour use data per crop per farm was collected in the socio-economic baseline survey. Nutrient offtake from banana fields as N, P and K was calculated by multiplying banana yields by their dry matter fraction of 0.15 g/g (Taulya, 2015), and the NPK content of banana bunches (Table S1.5). Nutrient inputs were assumed from manure, mineral fertilizer, banana peels and indigenous soil supply (details in S3.2). Mulch was not assumed to contribute any nutrient inputs (G. Taulya, personal communication).

2.4.3. Quantification of scenarios

The same variables were used for the quantification of scenarios, based on the survey data and literature. The time horizon of the scenario analysis was set to 2040, in line with the stakeholder workshops.

Available farm land in future was assumed to change as a result of a population growth of 3.0% per year and an urbanisation rate of 5.2% per year (World Bank, 2020a). Additionally, in one of the scenarios we assumed that a number of farmers would leave agriculture. This was based on farmers' attitude towards farming gauged in the socio-economic baseline through the extent of (dis)agreement with statements such as “I would prefer if my children do not end up working as farmers”, “If I had a choice I would not be a full time farmer” and “There is no better investment than farming” (more detail in S3.3).

Crop production in the scenarios was assumed to be affected in two ways: through climate change, and through the application of good agronomic practices. Climate change in Uganda is predicted to result in an increase in temperature of 1 to 3 °C by mid-century, and a concentration of rainfall in heavier and less frequent events (McSweeney et al., 2010). This results in a larger evaporative demand and an increased occurrence of droughts, combined with heat stress and increased pest, disease and weed pressure (Adhikari et al., 2015). Crop-specific assumptions about the effects of these changes were based on average values from existing literature, based on the range of projected crop yield changes under different models and scenarios (see details of values found in different studies in Table S1.6).

The effects of the application of good agronomic practices on banana yields were specific for the study sites, and are explained in detail in Section 3.3.2 and further. For other crops, more general trends in Uganda and/or Sub-Saharan Africa were considered with no differences between the sites. For these other crops, expected changes in yield were based on IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (IFPRI, 2019). This model simulates changes in crop yields in Sub-Saharan Africa up to 2050, combining projected effects of climate change, investments in agricultural research and other developments compared with a reference scenario (IFPRI, 2019). IMPACT data points were only available for 2030 and 2050; expected changes in crop yields for 2040 were obtained through linear interpolation.

The scenario-specific changes in input use, market prices, labour, and nutrient offtake and input are described in Section 3.3.

2.4.4. *Assessing sustainability indicators*

To assess the current and future sustainability under the different scenarios for farm households in the two regions, researchers selected one indicator in each sustainability domain, derived from the larger set of indicators defined by stakeholders in Step 1. The selection was needed to match the availability of data in the baseline surveys and to ensure relevance of the indicators in relation to the scenarios. Also, some indicators selected by stakeholders related more narrowly to the project interventions and therefore focused on banana production alone instead of the farm level, and did not cover all four sustainability domains. The selected indicators were: food self-sufficiency (food security), gross margin from crop farming (economic), labour sufficiency (social) and nutrient balances of banana fields (environmental).

Food self-sufficiency was calculated as the percentage fulfilment of a household's energy needs by on-farm production of calories (Falconnier et al., 2018). The crop produce per farm was converted to calories, based on a food composition table for Uganda (Hotz et al., 2012). We assumed an average requirement of 2250 kcal per day for adults, and 1850 kcal per day for children <18 years (FAO, WHO, and United Nations University, 2001). Farm gross margin resulted from the value of the total crop produce (crop produce multiplied by market prices) minus the total input costs per farm. Farm gross margins were compared to the poverty line of 1.90 USD (2.07 $PPP) per adult equivalent per day, and to the living income – the minimum amount of money required for a “decent living” – of 3.82 $PPP in (south)western Uganda (Van de Ven et al., 2020). To get an indication of the relative effect of labour on farm gross margins, annual labour costs were also added to farm input costs. All labour, both family and hired, was costed at 5.51 $PPP per day equivalent to the price paid for rural casual labour. Labour was expressed as a sufficiency ratio between the family labour available and the labour required. All labour data was collected in hours ha^{-1}, but converted to 8-hour working days for ease of reference. A partial nutrient balance was composed for individual banana fields on each farm, resulting from NPK inputs minus offtake. Nutrient balances were also converted to nutrient use efficiencies (nutrient input/ nutrient offtake) for ease of interpretation based on the EU Nitrogen Expert Panel (2015). To assess synergies and trade-offs between the indicators measured in different units, indicators were translated into standardised scores of either −1, 0 or 1 (Table 1).

We also conducted a sensitivity analysis, in which we varied the main variables by 50% (in line with variations in e.g. climate change predictions and market prices), and assessed the effect of this variation on the four sustainability indicators.

2.5. *Step 3: Exploring synergies and trade-offs between indicators with stakeholders*

In a one-day feedback workshop early 2021, researchers presented the baseline and quantitative scenario analysis to stakeholders, after which the results were discussed and verified. Initially, a mid-term workshop was planned to reflect on the scenarios developed by researchers. However, due to the COVID-19 pandemic this was not possible. Therefore, only the effects of the scenarios on the different sustainability indicators were discussed, with a focus on banana. After a brief recap of the process followed in Step 1, a simplified explanation of the scenarios was given as: “How will [the selected indicators] change in future if we were to achieve [the prioritised elements of a sustainable future], taking into account the effects of [the identified trends]”. Or as an example: how will *banana yields* change in future, if we had *irrigation*, taking into account the effects of *climate change*.

Stakeholders first reflected on the representativeness of the baseline values for the selected sustainability indicators, and then on the indicator values under each of the scenarios. Some indicators were presented as opportunities, for instance: will *irrigation* (future element) allow us to achieve desirable *banana yields* (indicator); others as prerequisites or trade-offs, for instance: “we may reach an increased *banana yield*, but it also means we will have to hire additional *labour*. How feasible and desirable is this?”. The reflection on the synergies and trade-offs allowed to identify priorities for decision-making for farmers, policy makers and other stakeholders: what opportunities and challenges arise in the different scenarios to reach the desired future, and which trade-offs should be avoided/ minimized?

3. Results

3.1. *Step 1: Envisioning a sustainable and desirable future*

Step 1 started with the participatory visioning exercise. In the southwest, the visions for agriculture in general and the banana value chain had a large overlap, as participants argued that banana played such an important role that in a vision for agriculture they automatically pictured banana. Despite the division of groups around the four sustainability principles, a number of topics were cross-cutting (Table S1.7): the wish for processing of and value addition to banana

Table 1
Conversion of sustainability indicators into standardised scores of either −1, 0 or 1.

Indicator	Score		
	−1	0	1
Food self-sufficiency	<90%	90–110%	>110%
Farm gross margin	<poverty line	>poverty line & < living income	living income
Labour ratio	<1	>1 & < 2	>2
Nutrient use efficiency	<0.70 or > 1.30	0.70–0.90 or 1.10–1.30	0.90–1.10

and by-products like banana peels; the need to apply good agricultural practices to improve production and productivity, including access to water for irrigation to reduce vulnerability to drought; and well-functioning cooperatives. In the west, stakeholders agreed that in a desirable future, banana would be the main enterprise and other crops would be grown in support and contributing as food crops. The topics mentioned above were also considered important in the west, as well as diversified income sources and job opportunities outside farming (Table S1.7).

In the backcasting exercise, the main obstacles to reach the desired future in both the southwest and the west related to a lack of knowledge, skills, technologies and investment capacity for production, processing/ value addition and marketing; and a lack of well-functioning cooperatives (Table S1.7). Opportunities to overcome these common obstacles included trainings on good agricultural practices, processing/ value addition and the re-use of banana waste. Opportunities for improved marketing included collective marketing and trainings to improve the functioning of cooperatives. A detailed report of the entire visioning and backcasting process is available in Ronner et al. (2019a) and Ronner et al. (2019b).

In the second workshop of Step 1, stakeholders voted for two concrete interventions from a shortlist of four, judged by project partners as the most feasible among the opportunities: 1) training and exchange visits on an identified training need, 2) packaging of banana for improved marketing, 3) improved access to knowledge on Integrated Soil Fertility Management (ISFM) and mineral fertilizer in banana and 4) training on banana-beverage making with improved access to planting material for these banana varieties. Interventions 3 and 4 were selected in both regions. For each of the selected interventions, stakeholders identified locally relevant sustainability indicators and discussed baseline values and desired future levels.

The main trends identified were population growth & urbanisation, climate change, agricultural technology development (new varieties, use of inputs, pest and disease management, water management) and value chain development (improved access to information, contracts with buyers, cooperation in farmer groups/ cooperatives, access to finance), and were largely similar between the two regions. Detailed results of the second workshop are available in Ronner et al. (2020).

3.2. Step 2: Developing plausible future scenarios

Researchers selected the future elements for a sustainable banana value chain that were roughly similar in both regions:

- Food security: focus on banana as main crop for food and cash; other crops contribute
- Economic: application of good agronomic practices in banana cultivation including ISFM and irrigation; improved market linkages and collective marketing
- Social: equal participation of men and women in banana value chain (labour division); opportunities outside farming

Table 2
Main trends and elements of a desirable future in the different sustainability domains, identified in the participatory visioning workshops, and their translation into four plausible scenarios. Text in bold represents the response to trends and the elements of the future that were used as main differences between scenarios (corresponding to bold text in Fig. 2).

	Trends		Elements of a sustainable future					
	Population growth & urbanisation	Climate change	Food security	Economic		Social		Environmental
			Banana is main crop	Application of good agronomic practices	Marketing (output & input prices)	Labour division between men and women	Opportunities outside farming	Enough water for production through irrigation
Marginalisation	**None of rural migrants sell their land**; ongoing land fragmentation due to population growth	No response to climate change, negative effect on crop yields	Banana remains dominant in the southwest, and part of a diverse system in the west	No change	No change	Labour required for cropping activities, for men & women	No change	No change
Business as usual	**Half of rural migrants sell their land**; farm land per capita slightly increases despite population growth	Farmers respond to climate change by using **improved varieties** (drought & disease tolerant) and intensified **pest & disease management**	Banana dominant in southwest; diverse system in west	**Mineral fertilizer** use increases following historic trends	Improved access to market **price information** and **collection centres** increases output prices	Labour required for men & women	No change	No change
Intensification	**All rural migrants sell their land**; farm land per capita increases	**Improved varieties** and intensified **pest & disease management**	Banana dominant in southwest; diverse system in west	All farmers apply **ISFM*** **(manure, mineral fertilizer, mulch)** in banana; 50% of recommended **mineral fertilizer** rates in other crops	Farmer groups **collectively market** their produce and negotiate **reduced input prices**	Labour required for men & women	No change	No change
Transformation	**All migrants sell their land**; farm land per capita increases	**Improved varieties** and intensified **pest & disease management**	Banana dominant in southwest; diverse system in west	All farmers apply balanced crop nutrition **(manure, mineral fertilizer) and irrigation** in banana; 100% of recommended mineral fertilizer rates in other crops	**Cooperatives market their produce directly** to output buyers and negotiate reduced input prices	Labour required for men & women	**Additional farmers** leave agriculture and **sell their land** to remaining farmers	All farmers apply **irrigation** in banana

* ISFM = Integrated Soil Fertility Management.

– Environment: re-use of waste products from banana; enough water for production

These elements served as focus for the development of contrasting future scenarios (Table 2). The elements that were not suitable to apply or quantify at the household level were adjusted, e.g. 'enough water for production' was considered as on-farm irrigation; 'equal participation of men and women in the banana value chain' was translated into the labour division between men and women in banana production. Some elements were not incorporated as explicit differences between scenarios; only their effects at household level were assessed, such as the effects of continued specialisation in banana in the southwest. Researchers combined the elements to form coherent story lines, for instance assuming that production intensification also requires improved marketing, or that agricultural intensification is enabled by increased per capita land availability for some households through the creation of opportunities outside farming for others.

From the main trends identified by stakeholders, researchers considered population growth & urbanisation and climate change as external trends in the scenarios: they were assumed to happen in all scenarios. However, researchers let the responses of households to these trends vary between scenarios (Table 2): because of population growth & urbanisation, an increasing proportion of the people migrating to the city was assumed to sell the remaining land, resulting in differences in available farm land between scenarios (see Section 3.3.1). The response to climate change differed in the use and adaptation of agricultural practices to deal with the effects of climate change, resulting in differences in crop yields (see Section 3.3.2). Researchers combined the trend "agricultural technology development" with the future element of "application of good agronomic practices", resulting in varying degrees of application of good practices between the scenarios. We also combined the trend "value chain development" with the "improved marketing" element, with various degrees of collaboration and collective marketing between the scenarios.

The combination of elements and trends resulted in four scenarios (Table 2): *Marginalisation*, in which we assumed a stagnation compared with the baseline situation; *Business as usual*, in which we extrapolated historic trends in agricultural development (e.g. with respect to the use of good agronomic practices) and value chain development (establishment of collection centres for banana, better access to price information). In *Intensification*, we included elements of a sustainable future and assumed that all households apply ISFM in banana and market their banana produce collectively. In *Transformation*, we assumed that all households apply irrigation in banana, further improve crop nutrient management, market their banana produce through cooperatives, and some households abandon agriculture as a result of improved opportunities outside farming.

3.3. Step 2: Quantifying scenarios

The scenarios were quantified to assess their effects on farm households in the study regions. The quantification is schematically represented in Fig. 2, in which the elements in bold correspond to Table 2 and allude to the main differences between scenarios. In the following paragraphs we describe how the variables depicted in Fig. 2 were assumed to be affected by the different scenarios.

3.3.1. Available farm land

Available farm land in future was assumed to change as a result of the trend population growth & urbanisation. At the moment, few people moving to the city sell their land, implying ongoing land fragmentation despite people leaving rural areas. However, it was assumed that the selling rate will increase in future as a result of increased land pressure and land prices. In the scenarios (except in *Transformation*, see below), we translated this into the assumption that the total farm land for a household remained the same in future (reflecting the notion that

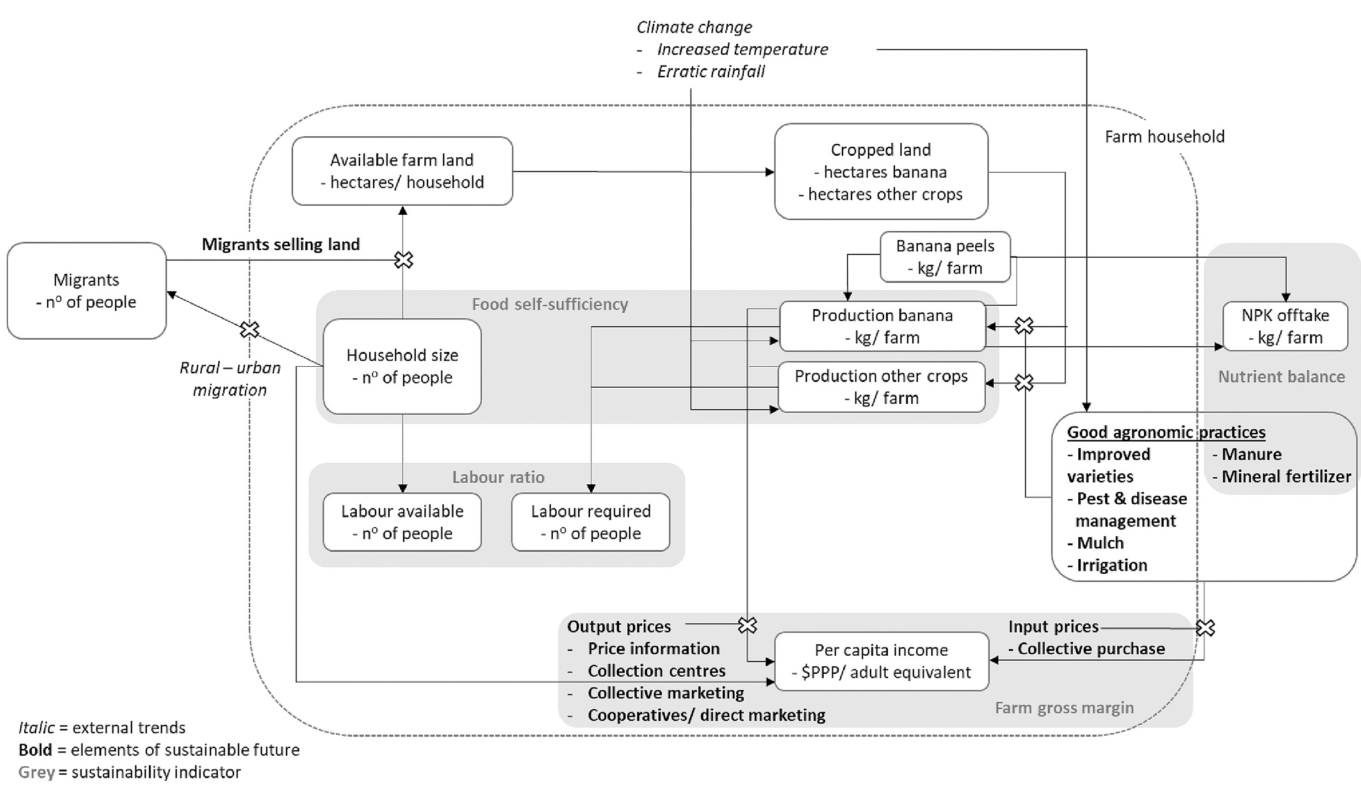

Fig. 2. Schematic representation of the quantification of changes in different scenarios and their effects on different household variables in southwestern and western Uganda. Variables in bold correspond to the bold elements in Table 2, comprising the main differences between scenarios. X indicates that the combination of the two intersecting lines influences a certain variable.

household members generally do not sell their land at present as confirmed by stakeholders), and divided this land equally among all future household members (reflecting land inheritance within the household), who double based on the 3.0% annual growth rate. From the household members migrating to the city, based on the 5.2% annual urbanisation rate, none would sell their land in *Marginalisation*, resulting in ongoing land fragmentation (Fig. 3). In *Business as usual*, half of the migrating household members would sell their land to the household members staying behind, reflecting expected trend of an increasing number of people selling their land. In *Intensification* all migrating household members would sell their land, assuming an increased value of the land.

In *Transformation*, we assumed that in addition to urbanisation, a number of rural households would find opportunities outside farming and sell all their land. The households leaving farming were selected based on their attitude towards farming (details in S3.3). The land of farmers with a negative attitude (30%) was redistributed among farmers with a positive attitude (21%), proportional to the size of their current land in their attitude group. A neutral group (49%) kept the same farm size as in the baseline. This resulted in a total of 74 and 34 households remaining in agriculture in *Transformation* (and hence used in the analyses), in the southwest and west respectively. All the acquired land was assumed to be devoted to banana farming in southwestern Uganda, and proportionally to banana and other crops in western Uganda based on current land use.

3.3.2. Crop production

Future crop production was assumed to be affected through climate change and through the application of good agronomic practices. In *Marginalisation*, we only applied crop-specific climate change effects to the baseline crop production. No further change in the application of good agronomic practices was assumed (Table 2). This resulted in negative effects on yields (Table 3).

In *Business as usual*, *Intensification* and *Transformation*, climate change effects were combined with the application of good agronomic practices, resulting in a joint effect on crop yields. For banana, under *Business as usual*, this combination was expected to result in an increased use of improved drought and disease tolerant varieties and increased investments in pest and disease management as a response to climate change. Fertilizer use was expected to increase following historic trends (*Africa Fertilizer*, 2018; more detail in Section 3.3.3). These changes were assumed to increase banana yields up to the 75th percentile baseline yields in both regions, which is a relative increase of a factor 1.14 compared to the baseline (Table 3). In *Intensification*, the additional application of ISFM practices (mulch, manure and mineral fertilizer) resulted in an expected increase in banana yield to the 90th percentile baseline yields (in line with Den Braber et al., 2021), a relative increase of a factor 1.41 compared to the baseline. In *Transformation*, an additional increase in banana yield was expected as a result of the use of drip irrigation (see S3.4); a relative increase of a factor 1.72 compared to the baseline. The change in yield for other crops was based on the IMPACT reference scenario for *Business as usual*, the “high R&D scenario” for *Intensification* and the “comprehensive investment scenario” for *Transformation* (Rosegrant et al., 2017; Fig. S2.1).

3.3.3. Input use and costs

Input use changed under the scenarios as described in Section 3.3.2 and Table S1.8: no changes in input use compared with the baseline in *Marginalisation*, and additional input costs from the purchase of improved seeds, increased mineral fertilizer application and intensified pest and disease management under *Business as Usual*. In *Intensification* and *Transformation* all farmers applied mulch and manure. The average quantity of manure applied decreased to 50% of the baseline value as a result of increased scarcity. This was compensated by the use of mineral fertilizer at recommended rates. In *Transformation*, all farmers applied drip irrigation in banana, with a relatively larger water demand in the southwest than in the west (details in S3.4). Besides, we assumed that mineral fertilizer application balanced crop requirements: instead of applying the recommended rate of an existing fertilizer blend in *Intensification*, increased soil testing would indicate the nutrients required to top up the supply through manure to arrive at a neutral soil nutrient balance. In practice, this meant that only potassium (K) had to be applied, as bananas contain a relatively large amount of K and replenishing this nutrient in relatively large quantities is needed to avoid K-deficiencies.

Price levels of inputs were kept the same as in the baseline (Table S1.3), except for an assumed 10% discount in *Intensification* and a 20% discount in *Transformation* on seed, mineral fertilizer and pest and disease management as a result of collective purchase of inputs in farmer groups or cooperatives.

3.3.4. Market prices

In *Marginalisation*, prices for banana were kept the same as in the baseline. As a result of assumed value chain development with improved

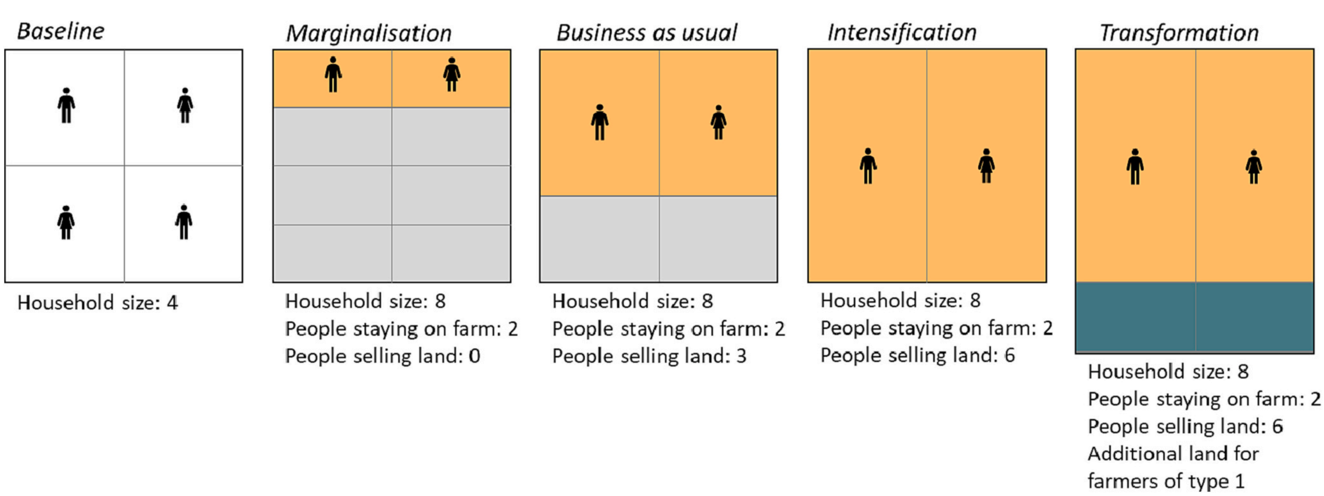

Fig. 3. Schematic representation of the change in available farm land per capita in 2040 under the different scenarios, for a sample household with four members in the baseline situation and eight in 2040 (3% annual growth rate). In all scenarios, two household members remain on the farm and six (based on the annual urbanisation rate of 5.2%) migrate to the city. From the six migrants, a varying proportion (0% in *Marginalisation*, 50% in *Business as Usual* and 100% in *Intensification* and *Transformation*) sells land to the remaining household members. In *Transformation*, an additional number of households in the region abandons agriculture and sells their land to remaining households.

Table 3
Crop yields (kg ha^{-1}) in the baseline, and change in crop yields (as factor compared with the baseline situation) in 2040 for different crops in the four scenarios. Changes in *Marginalisation* were assumed to be the result of climate change only; the other scenarios combine climate change effects with application of good agronomic practices.

Crop	Baseline (kg ha^{-1})		Scenarios (change in yield compared with baseline)			
	Southwestern	Western	*Marginalisation*	*Business as usual*	*Intensification*	*Transformation*
Banana	37,000	43,000	0.85	1.14	1.41	1.72
Maize	2,709	2,244	0.90	1.28	1.65	1.96
Millet	1,254	622	0.90	1.42	1.69	1.87
Rice	–	1,277	0.90	1.80	2.29	2.62
Irish potato	850	1,275	0.93	0.98	1.10	1.21
Sweet potato	4,429	2,593	0.93	1.73	1.94	2.10
Common bean	637	617	0.95	1.32	1.52	1.68
Groundnut	1,051	1,270	0.85	1.07	1.25	1.36
Coffee	1,588	876	0.85	1.48	1.50	1.56

access to market information and use of collection centres, prices in *Business as usual* increased by 20% (Svensson and Yanagizawa, 2009; Courtois and Subervie, 2015); in *Intensification* by 50% through collective marketing (Ngambeki et al., 2010) and in *Transformation* by 100% through the use of cooperatives for direct marketing (Ngambeki et al., 2010). Prices of other crops were assumed to follow trends in world market prices as predicted in the IMPACT scenarios (Table S1.4).

3.3.5. Labour available and required

In all scenarios, family labour availability decreased as a result of urbanisation. The labour required changed as a result of changes in the use of inputs and practices (details in S3.5).

3.3.6. Nutrient offtake and input

Nutrient offtake in the scenarios varied with changes in banana yields. Nutrient inputs varied with changes in the application of manure and mineral fertilizer as described in Section 3.3.3.

3.4. Step 2: Current and future sustainability of farm households

3.4.1. Food self-sufficiency

The quantification of the baseline situation and scenarios showed that the combined production of banana and other crops led to food self-sufficiency for 78% of the households in southwestern and 89% of the households in western Uganda in the baseline. Banana contributed up to 90% of total calories in the southwest, and at least half in the west (Fig. 4). In *Marginalisation*, the percentage of households being food self-sufficient dropped to 49% in the southwest and 63% in the west as a result of reduced crop yields under climate change as well as a reduction in the available farm land per household member. In *Business as usual*, the increased yields combined with farm land per household member similar to the baseline resulted in food self-sufficiency for about 95% of households. In *Intensification* and *Transformation* these percentages increased to about 98% and 99% respectively in both regions, and all households produced large surpluses of food. The only two households (one in each region) that were not food self-sufficient in *Transformation*

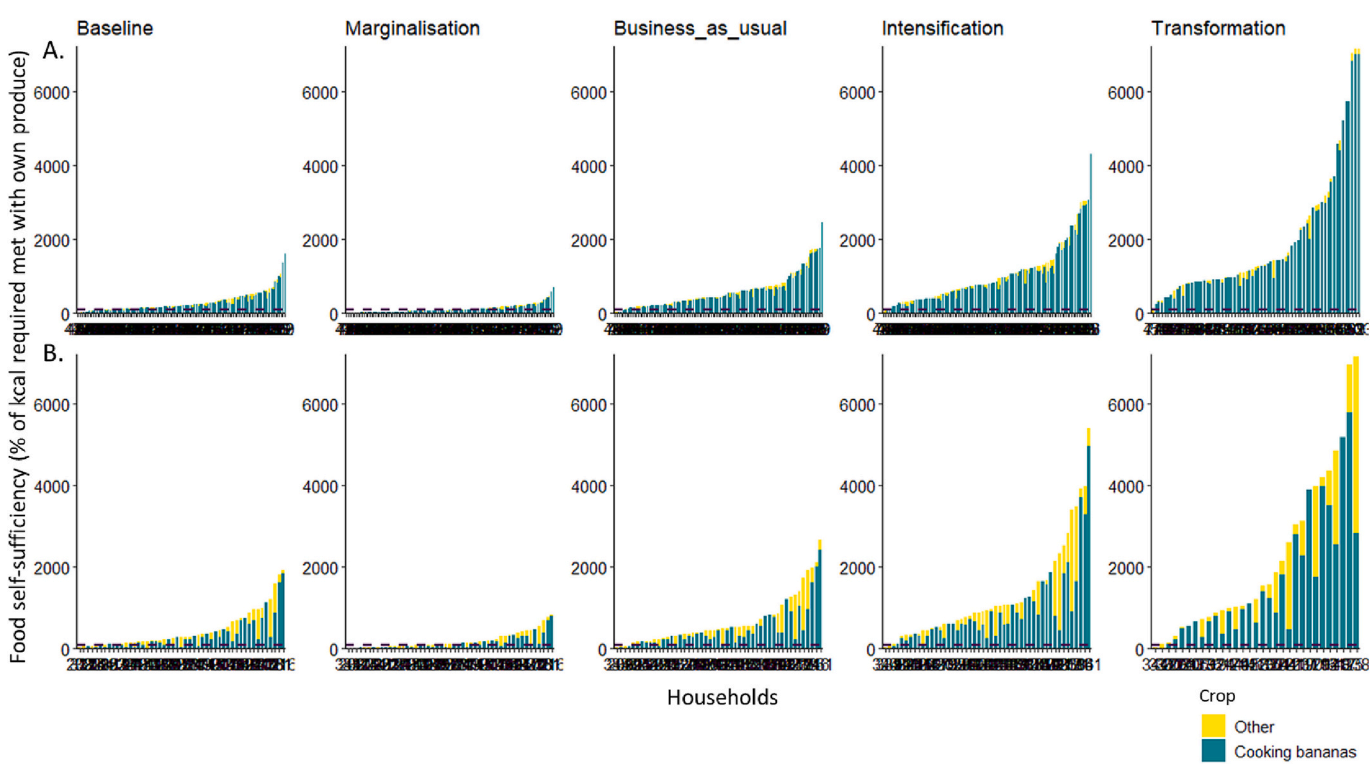

Fig. 4. Households' food self-sufficiency (% of household's calorific needs met with own produce) in the different scenarios in southwestern (A) and western (B) Uganda. Dashed line indicates 100% of household's calorific needs is met with own produce.
Data from 7 households removed (> 7500% food self-sufficient) to improve visibility.

did not grow banana.

3.4.2. Farm gross margin

All farms had a positive gross margin from crop farming in the baseline, with a median of 690 $PPP and minor differences between the southwest and west. On average, 45% of households in the two regions had a gross margin above the poverty line, and 29% above the living income threshold. Adding off-farm income to these gross margins changed these percentages to 59% and 39% respectively, hence off-farm income only played a moderate role (data not presented). Farm gross margin showed a pattern similar to food self-sufficiency (Fig. S2.2): banana contributed a large share to the total gross margin, and gross margins increased in all scenarios compared with the baseline, except in *Marginalisation*. In the latter scenario, median gross margins reduced to 290 $PPP, and only 20% of households had a gross margin above the poverty line, 4% above the living income threshold.

In *Intensification* and *Transformation* the larger investments in inputs and irrigation were compensated by higher yields and higher market prices for banana, resulting in about 95% of households with a gross margin above the poverty line and >85% above the living income threshold.

However, when labour costs at a median of 750 $PPP per adult equivalent per year were included, farm gross margins in the baseline became negative for most households and only 10% instead of 28% would earn a living income (Fig. 5A). Median gross margins improved over the scenarios, although some households had a slightly more negative gross margin in *Transformation* than in *Intensification*: the households that did not acquire any additional land in *Transformation*. For them, the additional labour costs for irrigation outweighed the income gain. The households with very negative gross margins were generally the same in each scenario, and were households that had indicated high labour use in the baseline already, combined with a limited application of practices such as mulch and manure or pest and disease control. For them, the additional labour for the application of these practices in the respective scenarios was unfavourable, whereas gross margins without labour costs increased for all of these households.

3.4.3. Labour sufficiency ratio

In the baseline situation, family labour available was generally larger than labour required for crop production (Fig. 5B). In *Marginalisation*, the reduced farm land per household member resulted in a more positive labour ratio. In the other scenarios, labour ratios decreased due to the increased application of inputs combined with the increase in farm land per household member. In *Transformation*, half of the farms had insufficient family labour to cover labour needs. The family labour available represented a maximum. Almost 45% of households hired labour in banana cultivation, accounting for about 30–44% of the total labour days in banana in southwestern and western Uganda respectively. Men and women spent a similar number of labour days in banana production, and on the different types of activities (data not presented).

3.4.4. Nutrient balance for banana fields

Nutrient balances for banana fields in the baseline were positive for nitrogen (N) and phosphorus (P), but largely negative for K, especially in western Uganda (Fig. 6). Only households with relatively low yields or who applied manure attained a positive K balance. In *Marginalisation*, all nutrient balances became slightly more positive as a result of the reduced offtake. In *Business as usual* the increased banana yields with limited additional mineral fertilizer use resulted in a considerably more negative K balance, averaging -110 kg K ha^{-1} year^{-1}. In *Intensification*, the combined application of manure and mineral fertilizer positively affected the K balance in southwestern Uganda, although the balance was still negative.

In the west, banana yields were larger than in the southwest and K supplied was still by far not sufficient to compensate K offtake, resulting in a deficiency of 193 kg K ha^{-1} year^{-1}. The positive N and P balances persisted in this scenario. In *Transformation*, K requirements were assumed to be exactly compensated by the application of Muriate of Potash (MOP). The combined inputs from manure and banana peels were roughly sufficient to compensate the offtake of N and P, and no further mineral fertilizer input was considered. Only in the west a slightly negative balance for these two nutrients existed, and in the longer term modest addition of N and P would be required.

3.4.5. Sensitivity analysis

A 50% variation in available farm land, crop yields or market prices had very little influence on food self-sufficiency, but a relatively large effect on farm gross margins (Fig. S2.3). With a 50% increase in any of

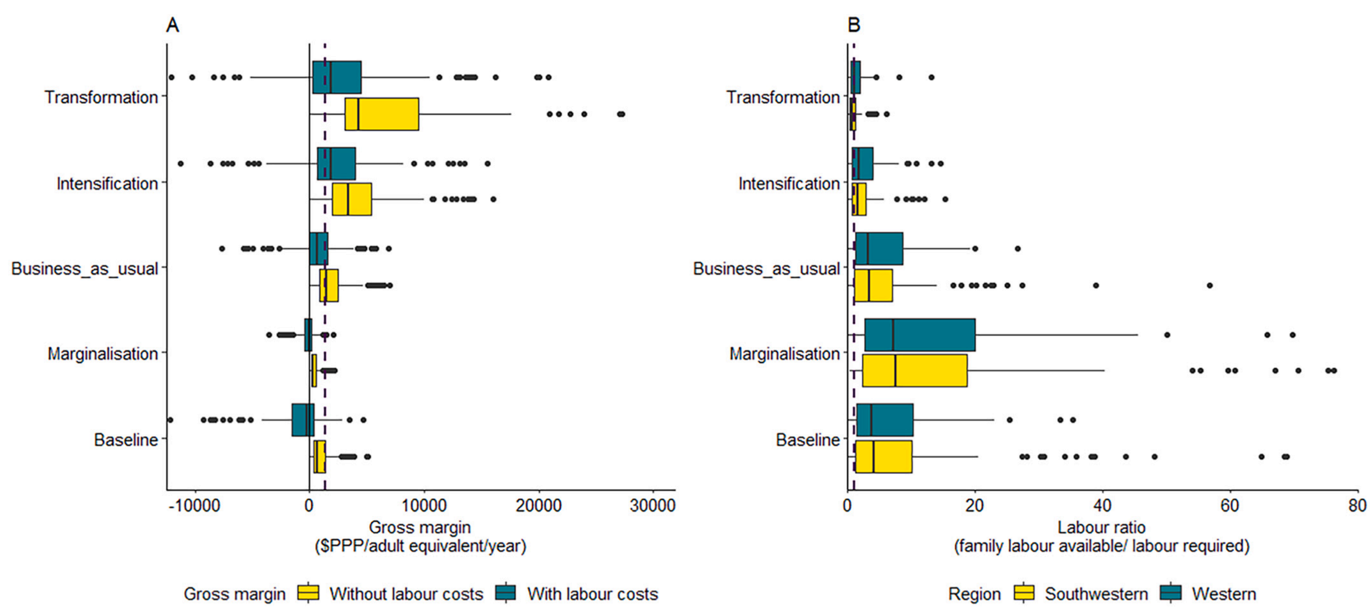

Fig. 5. A & B: Gross margin from crop farming (US$PPP/ adult equivalent/ year) with and without labour costs (A) and labour sufficiency ratio (family labour available / labour required) for banana and other crops (B) in southwestern and western Uganda in the different scenarios. Dashed line in Fig. A represents a living income of 1394 $PPP/ adult equivalent/ year. Dashed line in Fig. B represents a labour ratio of 1 (labour available = labour required).
Data from 8 households removed (< −12,500 or >30,000 $PPP) (A) and from 6 households removed (labour ratio > 80× labour required) (B) to improve visibility.

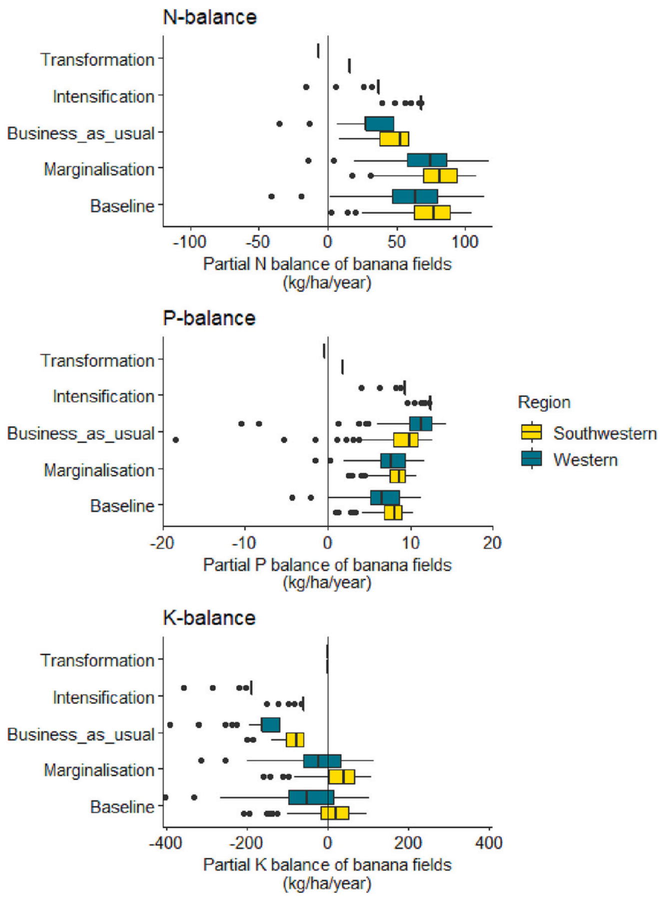

Fig. 6. Partial nutrient balances for N, P and K of banana fields in southwestern and western Uganda in the different scenarios.

these variables, about 95% of households reached a living income in *Intensification* and *Transformation*, instead of 85%. The labour ratio was relatively insensitive to the above changes. Nutrient balances were most sensitive to the variation in crop yields, indigenous soil supply of nutrients and the NPK content of banana. Despite the relative sensitivity, the findings of a generally positive N-balance and negative K-balance remained valid across the range of parameter values.

3.5. Step 3: Exploring synergies and trade-offs between indicators with stakeholders

3.5.1. Synergies and trade-offs

Co-benefits rather than synergies existed between food self-sufficiency and farm gross margins (Fig. 7). Compared with the baseline, both indicators decreased considerably in *Marginalisation*, and increased in the other scenarios with the same trend in both regions. However, whereas the large majority of households was food self-sufficient, most did not have a gross margin above the living income threshold. In reality, a trade-off exists between food that is consumed or sold, further reducing actual gross margins. Only in *Intensification* and *Transformation* the majority of households in both regions had a living income, and large surpluses of food. A trade-off existed between food self-sufficiency and gross margins on the one hand, and labour use on the other: labour ratios decreased over the scenarios as a result of out-migration and increased demand due to the application of e.g. ISFM or irrigation. Although not presented in Fig. 7, investment costs also exposed a trade-off: median annual input costs were 0 in the baseline and *Marginalisation*, but increased to 790 and 890 $PPP in *Intensification* and *Transformation*. Nutrient use efficiencies were unfavourable in most of the scenarios, except in *Transformation* where nutrient inputs balanced soil and crop requirements. In all, *Transformation* showed the most positive scores on all indicators in both regions, but the most negative score for labour and investment costs (not presented).

3.5.2. Stakeholders' feedback on the scenarios

Stakeholders reflected on the results of the scenario analysis, including the emerging synergies and trade-offs. Food self-sufficiency was discussed through the amount and diversity of food produced. Related to the latter, stakeholders in the southwest reiterated their wish for continued specialisation in banana production as both food and cash crop. Farmers would still keep small patches of other food crops. In addition, food production at the larger, regional level was considered sufficiently diverse not to jeopardise food security. In the west, stakeholders considered the production of other crops essential for food self-sufficiency and income, the latter also because prices for banana were lower than in the southwest. Related to the amount of food, banana yields in the different scenarios were discussed. Current banana yields were larger in the west than in the southwest (Table 3). Stakeholders in both regions had envisaged in Step 1 that current yields could increase to about 1.5 times current levels, based on an increase in the number of bunches harvested as well as bunch weights. This desired increase was almost achieved in *Intensification*, and fully in *Transformation*.

In the economic domain, the increase in income from banana in *Intensification* and *Transformation* was considered attractive, as stakeholders argued that the combination of increased bunch weights with higher prices per bunch, obtained through collective or direct marketing in farmer groups or cooperatives, were desirable. Cooperation was considered important in both regions: in the southwest, a strong cooperative already existed in one of the sites, which set an example for farmers in other parts of the region. In the west, banana bunch prices were generally lower than in the southwest, and no cooperative for banana existed yet so stakeholders were keen to learn from the example in the southwest.

Stakeholders in both regions acknowledged that a focus of resources in one crop would enhance financial benefits. However, trade-offs associated with specialisation such as drought, pests or diseases wiping out banana were discussed and acknowledged, as such incidents had already happened in the past (see Rietveld et al., 2021). Savings and other insurance mechanisms were mentioned to help overcome temporary shocks, and more information and training on such topics were desired. Another trade-off coming from the desired increase in income were increased investment costs. Stakeholders found the average production costs for banana as calculated from the baseline low. These costs reflect the current absence of the use of inputs. Double or triple the current costs were therefore considered affordable, provided this would result in increased production volumes and therefore revenue. However, stakeholders in the southwest also mentioned that despite the good incomes one could get from banana, re-investments in the farm were generally difficult given other household expenses. In both regions, stakeholders agreed among themselves that the additional costs required to implement ISFM in *Intensification* were affordable, also in relation to the additional income gains. Costs for drip irrigation under *Transformation* were considered too high, and unlikely to be implemented without any further support.

Like production costs, the average labour use calculated from the baseline survey was considered low in both regions. Stakeholders argued that some farmers visit their banana fields every day, whereas the average includes farmers who visit their plantations less frequently. In both regions, stakeholders indicated that additional labour requirements were undesirable, as this would have to be hired. Family labour was already fully engaged in other farm and non-farm activities. Consequently, the doubling of the amount of labour required in *Intensification* was considered impossible. The implementation of ISFM therefore appears to be largely labour constrained.

In the environmental domain the focus was on the use of nutrient inputs in banana, which was very limited in the baseline. The

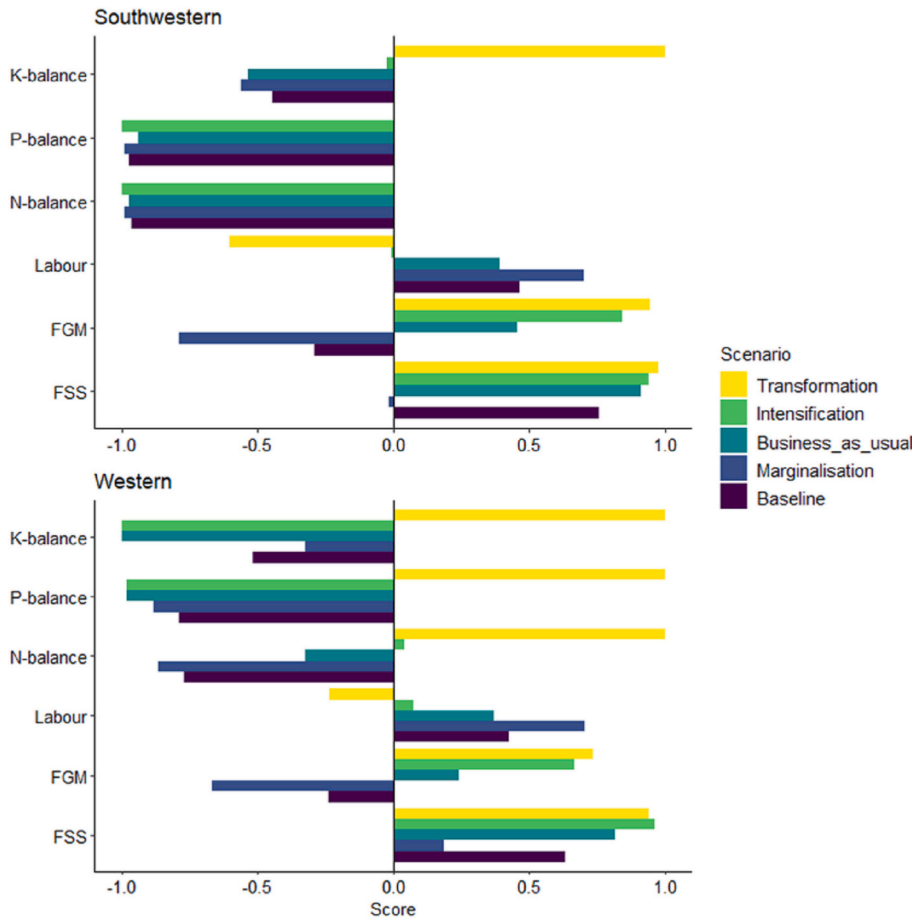

Fig. 7. Average performance for each indicator translated into a standardised score, to compare indicators measured in different units across the scenarios in southwestern and western Uganda. -1 represents the worst performance of an indicator, 1 the best.

desirability of future use of mineral fertilizer was fiercely debated, with strong opinions favouring and resenting mineral fertilizer use. Stakeholders in the southwest were generally more open to mineral fertilizer than in the west, though in both regions many preferred 'organic farming', with nutrient inputs limited to the use of manure and crop residues. Given the hesitation on mineral fertilizer use already expressed in Step 1, we discussed in Step 3 that 25 to 50 cattle ha^{-1} would be needed to supply manure to replace the required K in *Intensification* or *Transformation* (Den Braber et al., 2021). All stakeholders agreed that such numbers were impossible to integrate at the farm or village level. The stakeholders present in the meeting therefore started to appreciate the need for mineral fertilizer in addition to manure. Also, as one of the selected interventions in Step 1 was improved access to knowledge on ISFM and mineral fertilizer use in banana, demonstrations with different combinations of mineral fertilizer and manure had been set up and links with a private sector input supplier of a banana-specific mineral fertilizer blend had been made. As part of these efforts, we registered the number of farmers buying fertilizer to try out on banana in the two sub-counties that we worked in in the southwest, and one sub-county in the west. Compared with 4 farmers using fertilizer use in the baseline, 16 farmers bought mineral fertilizer in the southwest in season 2020B, 13 in 2021A and 25 in 2021B. In west, farmers did not buy fertilizer in season 2020B, but in 2021A we registered 55 farmers and in 2021B 23 farmers. Despite these changes among a limited group of farmers, stakeholders emphasized that the majority of farmers still had negative perceptions of mineral fertilizer and hence, reaching more farmers with knowledge and evidence was considered much needed in both regions. As a follow-up, therefore, an interactive radio campaign was initiated on the use of fertilizer in banana (see Ronner et al., 2022 for details).

4. Discussion

4.1. Current and future sustainability of banana-based farming systems in Uganda

In current banana-based farming systems in (south)west Uganda, the large majority of households was food self-sufficient. However, $<$50% had an income above the poverty line. Low income levels translated into limited investment in external inputs for agriculture, which in turn resulted in negative K balances. For these poorer households, a negative spiral of soil fertility depletion, yield decrease and declining income is a real risk (cf. Tittonell and Giller, 2013). At the other end of the spectrum, however, almost 30% of households were able to achieve a living income with crop farming, or even banana cultivation alone. This distinction is in line with Rietveld et al. (2021), who indicates that some farmers have accumulated wealth from the sale of bananas, whereas at the same time inequity has increased.

Potential future pathways showed that inequity further increased, with farmers with favourable gross margins – and generally large farm sizes – in the baseline expanding their wealth relatively more than farmers with small gross margins and small farm sizes (cf. Thuijsman et al., 2022). Equity is a dimension often overlooked in sustainability analyses (Chopin et al., 2021), but would be important to consider to cope with arising social friction (Rietveld et al., 2021). Overall however, the percentage of households earning a living income increased (except in *Marginalisation*), and every individual household was better off in *Intensification* and *Transformation* than in the baseline. The diversified farming systems in western Uganda had advantages in terms of food self-sufficiency, but households in the southwest were able to generate larger incomes from their specialisation in banana production. In this context, it is worth noting that some of the households achieving the largest food self-sufficiency and gross margins were selected to leave farming in *Transformation* because of their negative outlook on farming. Hence, even farmers who seem to do well do not see a future in farming for themselves or their children. The relatively large farms that they would leave behind would free up a considerable amount of land for other farmers to expand their business. Such trends are currently not yet visible in densely populated countries such as Uganda (Jayne et al., 2019), but could contribute to an actual transformation of agriculture and would require sufficient, attractive opportunities outside agriculture. If not, the continued land fragmentation under *Marginalisation* remains more plausible, clearly presenting an undesirable situation in which the majority of farmers would be left with insufficient food and income from agriculture (Giller et al., 2021b; Giller et al., 2021a).

Although the labour balance was relatively favourable in the baseline, including labour costs largely resulted in negative gross margins. Hence, opportunities like ISFM should translate into increased income to be worth the additional investments. It should be noted, however, that estimates of labour use are often difficult without detailed logs (also given seasonal peaks), and hence the labour balance should be seen as an approximation of labour availability and demand. Nevertheless, labour requirements presented a clear trade-off, as found in many other studies of agricultural intensification options (Tittonell et al., 2007; Komarek et al., 2018; Ronner et al., 2018).

The scenario analysis further pinpointed that nutrient balances are a sustainability concern. The predominantly negative K-balances warn for future depletion, as represented in *Business as usual*. Only when an increase in banana yields goes hand in hand with a balanced supply of all required nutrients this trade-off can be avoided. Whereas the presented nutrient balances were static, a consideration of changes in nutrient stocks over time would even exacerbate the negative K balance, and the N and P surpluses. Hence, more detailed assessments of such dynamics, the resulting balance of nutrients required and the optimal ratio between organic and inorganic fertilizer (as reflected on in e.g. Gram et al., 2020; Den Braber et al., 2021) are required.

The scenarios themselves meant to sketch alternatives under an uncertain future (Walz et al., 2007; Palazzo et al., 2017; Williams et al., 2023), such as varying degrees of value chain or agricultural development, continued land fragmentation or not, etc. While the analyses hinge on assumptions and potential inaccuracies in data, the sensitivity analysis showed that the overall picture did not change much for food self-sufficiency, gross margins or labour. Soil nutrient balances were relatively most sensitive to variations in data, but this did not alter the overall conclusions with respect to the negative K-balance.

4.2. Participatory scenario analysis in a smallholder farming setting

Conducting a participatory scenario analysis in a smallholder farming setting had its benefits and challenges. Benefits relate to the combination of quantitative and qualitative information that allowed for the integration of knowledge, data and topics of local relevance (Klapwijk et al., 2014; Palazzo et al., 2017; Homann-Kee Tui et al., 2021). Moreover, the qualitative discussions brought up aspects that would not have been observed in a purely quantitative analysis: the need to hire labour despite the apparent labour surplus in the baseline, or the strong sentiments around the use of mineral fertilizer. The other way around, the quantitative analyses, trade-off analysis and future explorations were aspects that stakeholders could not have evaluated by themselves (Walz et al., 2007; Klapwijk et al., 2014; Vervoort et al., 2014), and therefore provide complementary knowledge for their decision making.

We also showed the feasibility and usefulness of a participatory visioning and backcasting process in a smallholder setting. In this setting, it is important to keep in mind the 'decision space' that represented stakeholders have, so that expectations about what can be achieved in such a process are tied to what local stakeholders can contribute (Kok et al., 2011; Vervoort et al., 2014; Johnson and Karlberg, 2017). These processes do not necessarily lead to actual decision-making, but have an inspirational aim of imagining fundamentally different futures, raising awareness and provoking debate (Carlsson-Kanyama et al., 2008; Bourgeois and Sette, 2017; Larkin et al., 2020). However, through the active involvement of stakeholders in providing the building blocks for the scenarios, identifying relevant indicators and reflecting on the results, we aimed to support stakeholders as much as possible to translate the results of the analyses into concrete entry points to improve the sustainability of the system (cf. Coteur et al., 2020). While no formal assessment of the effects of the process on the stakeholders was conducted, achievements that indicate success in this respect were the increased purchases of mineral fertilizer, a keen expression of interest in working through cooperatives, and the recognition of the need for savings to overcome shocks when specialising in banana. The process also led to a convergence of ideas among stakeholders from different backgrounds (Kok et al., 2011), including agreement on the selected priorities and interventions, consensus that ISFM and improved cooperation among farmers are desirable and feasible, but that the application of irrigation in banana is a step too far.

Challenges in the participatory process related to finding a common ground for discussions between researchers and stakeholders (cf. Marinus et al., 2021). For example, the selection of sustainability indicators required a lot of explanation, and was almost impossible without giving examples that then steered the discussion in a certain direction. And still, the chosen indicators could not be directly used in our analyses. Moreover, stakeholders that were invited to the workshop were often selected for their dual role as farmer and trader, government officer or representative from a cooperative. In that sense they did not represent the 'average' farmer and, consequently, found the reported averages from the baseline survey not always representative for their case. Hence, despite our efforts to invite a wide diversity of stakeholders, especially in Step 3 the group included relatively fewer farmer representatives than during the first workshop. The stakeholders therefore also called for a wider dissemination of the findings, which was partly addressed through a radio campaign.

In the process from visioning to scenario-building we also had to make some simplifications, as not all elements of a desirable future identified by stakeholders were suitable to apply or quantify at the household level. The quantification of the scenarios required a large amount of data, and led to results that were relatively complex to interpret for the stakeholders given the interactions and combinations of future elements in the different scenarios. We therefore also chose to simplify the presentation of results to the stakeholders. Vervoort et al. (2014) call this "scenario development in intervention-style processes", in which the scenarios – like in our case – relate more to concrete interventions instead of tackling multi-dimensional challenges. For future studies in this setting, a deliberate choice to limit the amount of variables to quantify and discuss could be considered (cf. Walz et al., 2007).

5. Conclusion

Our study highlights that a sustainable future for banana-based farming systems in (south)western Uganda whereby the large majority of farmers is food self-sufficient and earns a living income from farming on sustainably managed soils is feasible. The main challenges to achieve this future lie in the increased labour and investment costs required – also to combat negative effects of climate change on crop yields – and warrant support to farmers in upfront financing of such investments. Prerequisites therefore include the need for proper assessments of costs and benefits of agricultural innovations, as farmers need to be sure such investments pay off, and insurance of risks to cushion farmers that move into specialised production. Another prerequisite is institutional support to facilitate land transactions among farmers who want to leave agriculture to those who want to expand, and to ensure sufficiently attractive alternative employment outside agriculture. With respect to environmental sustainability, more detailed assessments of long-term soil fertility dynamics and response to fertilizer in banana systems are needed to enhance recommendations that extension officers and private sector could use.

The participatory scenario analysis conducted in a smallholder farming context, considering multiple sustainability domains and with locally relevant indicators, contributed to a convergence of ideas among the participating stakeholders on concrete, short-term steps that could be taken to improve the sustainability of banana-based farming systems. While we aimed for a representation of stakeholders all along the banana value chain, future studies may benefit from more deliberate efforts to discuss and disseminate findings among different types of farmers. Finally, we conclude that higher-level advocacy and support is required in decision-making on the more complex, long-term challenges.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2023.103669.

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