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LETTER

Embedding stakeholders' priorities into the low-emission development of the East African dairy sector

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Supplementary material for this article is available online

Abstract

A growing body of evidence shows that more intensive dairy systems can be good for both nature and people. Little research considers whether such systems correspond with local priorities and preferences. Using a mixed methods approach, this study examined the effects of three intensification scenarios on milk yield and emission intensities in Kenya and Tanzania. Scenarios included (a) an incremental change to feed management; (b) adaptive change by replacing poor quality grass with nutrient-rich fodder crops; and (c) multiple change involving concurrent improvements to breeds, feeds and concentrate supplementation. These scenarios were co-constructed with diverse stakeholder groups to ensure these resonate with local preferences and priorities. Modelling these scenarios showed that milk yield could increase by 2%–15% with incremental changes to over 200% with multiple changes. Greenhouse gas emission intensities are lowest under the multiple change scenario, reducing by an estimated 44%. While raising yields, incremental change conversely raises emission intensities by 9%. Our results suggest that while future interventions that account for local priorities and preferences can enhance productivity and increase the uptake of practices, far-reaching shifts in practices are needed to reduce the climatic footprint of the dairy sector. Since top-down interventions does not align with local priorities and preferences in many situations, future low-emission development initiatives should place more emphasis on geographic and stakeholder heterogeneity when designing targeting and implementation strategies. This suggests that in low-income countries, bottom-up approaches may be more likely to improve dairy productivity and align with mitigation targets than one-size-fits-all approaches.

1. Introduction

Dairy production is a source of smallholder revenue, nutrition, and can function as a safety net particularly for women (Herrero *et al* 2013). Some studies suggest that increasing dairy productivity can positively influence smallholder dairy farm (SHDF) income and help overcome market access constraints (Westermann *et al* 2018). In many developing countries, smallholders fail to realize yield potentials, and are often confronted by adoption barriers arising from lack of capacity, resources, and incentives (Orr *et al* 2018). In particular, the agricultural sector in Sub-Saharan Africa (SSA) continues to be disproportionally affected by climate change, which discourages investment in better dairy practices and technologies (Vermeulen *et al* 2012, Taylor *et al* 2017). Compared to more industrialized regions, the dairy sector in SSA accounts for a particularly high proportion of total greenhouse gas (GHG) production (Valin *et al* 2013, FAO and GDP 2018). Recognizing this, many donors and development agencies in SSA now actively promote low emission development (LED), also because of the dairy sector's significance to food and nutritional security and rural incomes.

It is widely claimed that delivering on dairy sector mitigation targets demands a reduction of GHG emissions intensities. This is generally achievable through milk yield-oriented interventions (Gerber *et al* 2011, Forabosco *et al* 2017). However, this often necessitates significant capital and labour investments into more sustainable management practices (Odhong' *et al* 2019). With enteric methane accounting for approximately 60% of sectoral emissions in East Africa (Mottet *et al* 2017), much mitigation can be achieved through improvements in feed quality (Caro *et al* 2016). Doing so, could also increase milk yield (by approximately 51%–96%) and smallholder dairy income (Ortiz-Gonzalo *et al* 2017, Brandt *et al* 2020). To achieve this, a large-scale food system transition is needed (Rufino *et al* 2013), but is hindered by smallholder capacity, resource constraints, and pervasive feed availability issues. Interventions more responsive to what are often highly variegated, addressing feed adoption barriers are therefore sorely needed.

The success of LED interventions in dairy is contingent on local buy-in and responsiveness. This demands more participatory and bottom-up strategies that depart from technologist one-size-fits-all approaches (Schoneveld *et al* 2019). Multi-stakeholder planning is increasingly regarded as an essential first step to designing locally appropriate solutions sensitive to context and group-specific adoption challenges (Dunnett *et al* 2018). Smallholders prioritizing milk outputs in land scarce areas, for example, may prefer adopting nutrient-rich feedstuffs (Cameron *et al* 2018) or introducing higher yielding grasses (e.g. *Pennisetum purpureum*) (Maleko *et al* 2018), while more subsistence-oriented farmers are likely to be more receptive to practices and technologies that help manage seasonal water and feed shortages (Campbell *et al* 2014, Gebremeskel-Haile *et al* 2019). Complex land management decisions typically underpin smallholder adoption dilemmas, which may range from preserving native grasslands under increasing cattle densities to food-feed crop production trade-offs within small production units (Herrero *et al* 2014). In some cases, adopting improved feeding practices may be achievable through incremental changes that seek to minimize disruptions on dairy farms (Garnett *et al* 2013). Other dairy farms may require highly integrated and more radical approaches involving multiple concurrent changes to several aspects of farm management (e.g. introducing exotic cattle breeds alongside nutrient-rich diets and improved health care) (Notenbaert *et al* 2018).

Given the complexity of designing LED interventions that account for complex SHDF decision-making patterns, this study explored how future LED strategies can be better grounded in stakeholder priorities whilst not losing sight of mitigation targets. We did this by positioning LED within diverse decision-making spaces. Specifically, through multi-stakeholder workshops held in Kenya and Tanzania, we co-constructed LED scenarios that resonate with diverse stakeholder priorities and preferences. Three scenarios were constructed, which included an incremental change scenario (ICS), an adaptive change scenario (ACS) and a multiple change scenario (MCS). By means of a mixed-methods analytical strategy that draws on large-scale survey data, we subsequently analysed how these three scenarios were likely to impact milk output, land use and GHG emissions. In doing so, we showed that stakeholders' priorities varied across the study area and demonstrated how more locally appropriate and evidence-based LED interventions could be designed.

2. Methods

2.1. Study area

The study covered important dairy production areas in the highlands of Kenya and Tanzania, covering approximately 70 000 km^2 (dark grey, figure 1). Dairy households were surveyed in three dairy counties in Kenya (Bomet, Nandi and Murang'a) and four dairy districts in Tanzania (Njombe, Rungwe, Mvomero and Mufindi). Drawing on survey results, stakeholders' workshops were held in Bomet, Nandi, Njombe and Rungwe. These areas were selected because of the significance of dairy in local livelihoods and economies. Scenario models were then implemented at the administrative unit and the regional level.

2.2. The baseline and household surveys

A baseline scenario was constructed using data collected through a household survey conducted under the IFAD-funded greening livestock project in 2018–2019. A total of 2250 SHDFs were randomly sampled across the study areas in Kenya and Tanzania (details included in appendix 1). The survey instrument captured data on, amongst other things, on-farm feed production, feed purchases and seasonal feed shortages (details in table S1). Feed shortage periods (i.e. seasonality) was used to model feed available from native grasslands in the baseline and three scenarios (figure S1, tables S2 and S3 (available online at stacks.iop.org/ERL/16/064032/mmedia))

2.3. Mapping stakeholders' priorities

To understand the adoption potential for improved management practices, we organized and facilitated four multi-stakeholder workshops in 2019. These workshops involved a total of 55 participants in Tanzania and 38 in Kenya. Participants were selected based on their direct engagement in the dairy sector (i.e. dairy farmers, farmer organisations, developmental organisations, milk buyers and processors)

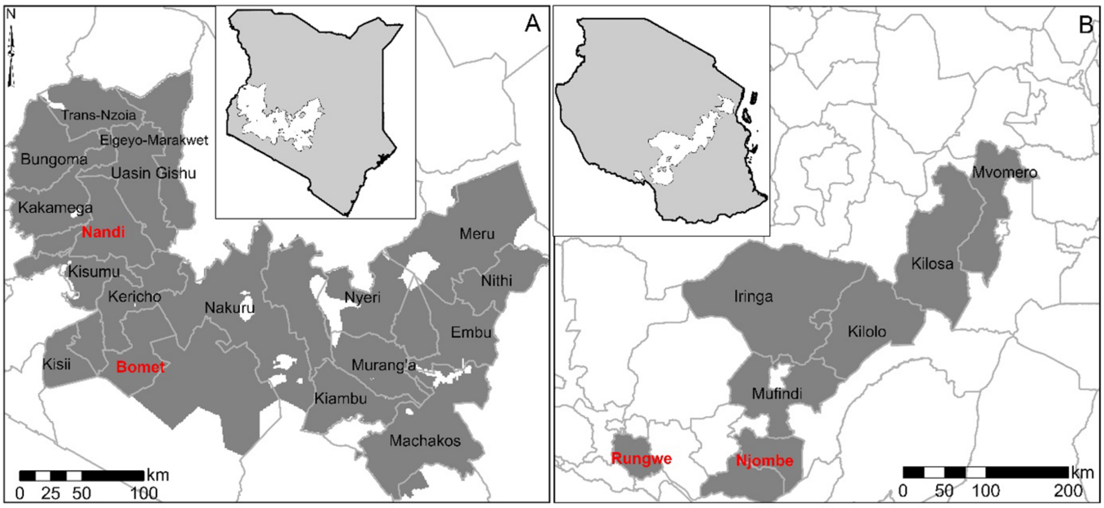

Figure 1. Spatial extent of the highland dairy production regions in Kenya (A) and Tanzania (B) overlaid on administrative maps. Red labels indicate the locations where stakeholders' workshops were conducted. Insets show the locations of the dairy regions in each country.

Table 1. Representation of stakeholders categorized by sector who participated in the assessment workshops in the counties and districts of Kenya and Tanzania.

	Kenya		Tanzania	
	Bomet	Nandi	Njombe	Rungwe
Dairy farmers (%)	29	29.4	33.3	22.6
Farmer organisations (%)	5	5.9	—	16.1
Buyers (%)	9.5	5.9	4.2	6.5
Processors (%)	14	11.7	25	9.7
Local government officials (%)	33	35.3	25	38.7
NGOs (%)	9.5	11.7	12.5	6.4

or their regulatory functions (see table 1 for an overview).

Prior to the workshops, a literature review of global and SSA case studies was conducted to identify best dairy practices and their impact on farm output (figure 2, appendix 2). This review guided the framing of questions on management practices and promising LED strategies. Stakeholders' priorities and preferences were identified through a questionnaire on various feed and dairy management practices. Participants were specifically asked about the importance of selected practices to SHDF milk output on a five-point Likert scale (i.e. priorities), as well as preferred intervention strategies (i.e. preferences) on a seven-point Likert scale (see appendix 3 for details).

Analysis of the farm management practices revealed three priority areas: adoption of improved cows, better diets, and improved health (figure 2). Three priority areas related to feed management were also identified: zero-grazing (cattle confined all the time), grazing on native grasslands and supplementation with concentrates (figure 2). To analyse the data on stakeholders' preferences for future interventions, we employed the 'top-two box' and 'Z-score to percentile rank' approaches (Nielsen and Levy 1994). The analysis revealed a distinct preference for interventions that increase feeds purchased, the cultivation of nutrient-rich pasture on-farm, the allocation of land for grazing and the replacement of commercial feeds with on-farm feeds, and also involve market-oriented actions that raise milk prices (figure 2). Because this analysis revealed no significant differences between the different stakeholder groups, we then pooled these results on priorities and preferences at counties and districts level.

2.4. Modelling future dairy production under different scenarios

The results from the workshops were used to design three scenarios (table 2) that align with stakeholder priorities and preferences. These scenarios are summarized:

2.4.1. Incremental change scenario

Aligns with priorities on minimizing SHDF investment burden. It therefore quantifies the impact of implementing change to improve feeds only on milk yield and emission intensities (table 2). Under this scenario, there is no adoption of improved cows because of the high cost and lack of access to artificial insemination services (Murage and Ilatsia 2011). ICS therefore involves a retention of crossbred cows

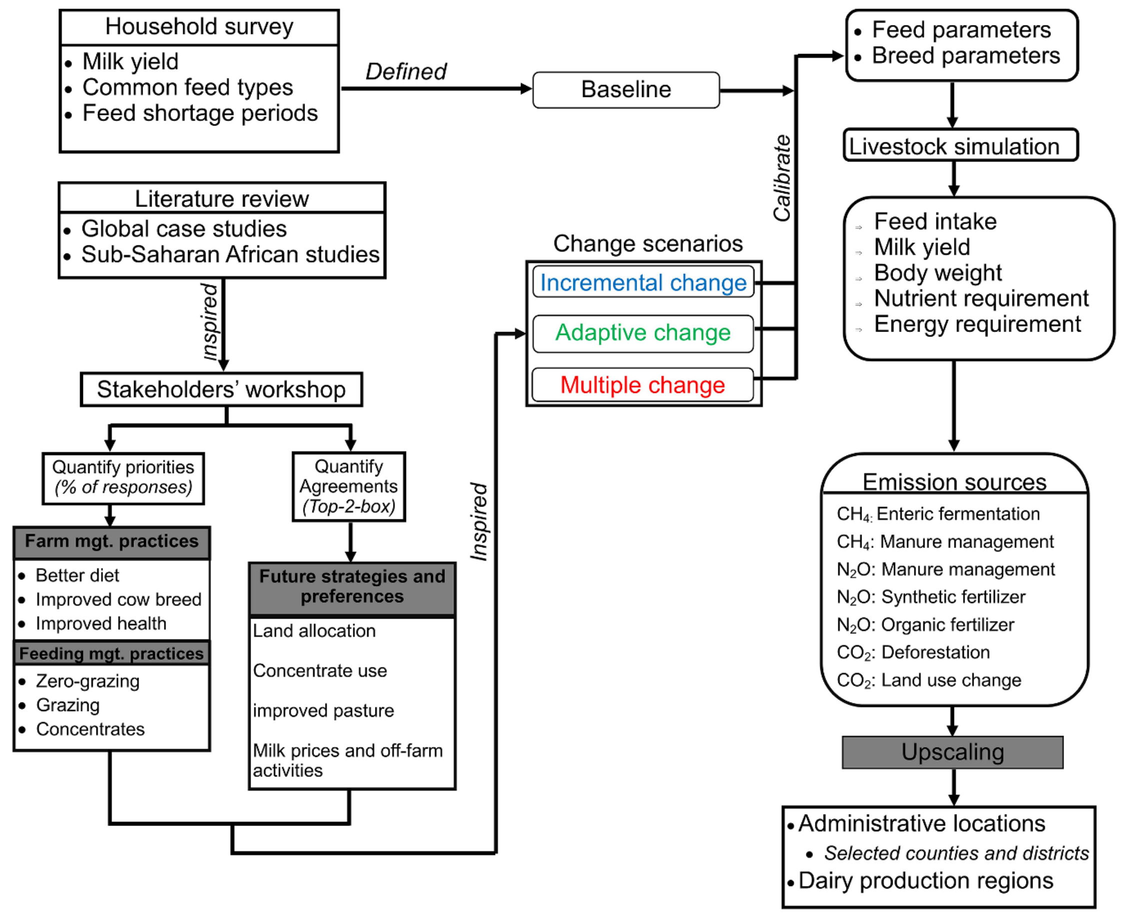

Figure 2. Workflow illustrating main steps used to integrate data collected during stakeholders' workshops and household survey data into an assessment framework that quantifies the impacts of different management strategies on smallholder dairy farm output.

with low-genetic merit and changes to SHDF feeding strategies through the introduction of Napier grass (tables S2 and S3) and supplementation with 1 kg of concentrate per cow per day during early lactation.

2.4.2. Adaptive change scenario

Quantifies the impact of transitioning to crossbred cows with higher genetic merit (i.e. improved cows) and better diets. It also considers the replacement of low-quality native grass with a diverse mix of nutrient-rich pasture and the introduction of modest amounts of concentrate (1.5 kg per cow per day) (tables 2, S2 and S3). ACS promotes a reliance on locally cultivated and more nutritious feed resources to insulate farmers from market fluctuations. Furthermore, there is the assumption that intercropping with herbaceous legumes is more likely to be associated with improved feed management practices which may also improve the quality and yield of commonly used feeds under ACS (e.g., Napier grass) (Orodho 2006, Lukuyu *et al* 2009).

2.4.3. Multiple change scenario

Quantifies the effects of simultaneously improving cows, diets and concentrate use, as per best practices. Under MCS, SHDF are more exposed to input and output price fluctuations due to high amounts of concentrate fed (3 kg per cow per day).

2.5. Scenario modelling

The effect of each scenario on milk productivity was quantified using the dynamic livestock simulation (LIVSIM) model (Rufino *et al* 2009). LIVSIM quantifies the impact of farm resource allocation on lifetime productivity by simulating milk yield and faecal and urine excretion. It also quantifies energy and nutrient requirements for the maintenance of dairy cow as a function of mature body weights (appendix 5). For each scenario, 1000 simulations were run, with the mean of relevant parameters (e.g. milk yield) used to calculate GHG emissions.

GHG emission associated with milk production for a dairy cow were quantified using the IPCC Tier 2 approach (IPCC 2006). We used the Python programming language as a shell to incorporate LIVSIM outputs with several functions written for the calculation of emission factors from the different sources (appendix 6). These emission sources are methane (CH_4) due to enteric fermentation and manure management and direct and indirect nitrous oxide (N_2O) from manure management, synthetic fertiliser

Table 2. Stakeholders' priorities and preferences for dairy management practices included in three future scenarios. Data collected during stakeholders' assessment workshops in counties and districts of Kenya and Tanzania.

	Farm management			Feed management					
Scenario	Improve cow breeds	Better diet	Improve health	Native grass	Zero-grazing	Concentrate use	Management priority	Preferences for future intervention(s)	Modelling actions
Incremental change	NI	P	NI	P	NI	NI	Increase reliance on crop residues, maintain low-genetic merit crossbred cows.	More nutrient-rich pasture.	Increased quantity of maize stover, introduce Napier grass and supplement 1 kg of concentrates per day during early lactation.
Adaptive change	P	P	P	P	NI	NI	Replace low-genetic merit cows with improved cows, reduce reliance on crop residues.	More nutrient-rich pasture, no allocation of more land for grazing, less concentrate supplements.	Improved cow breeds, reduce quantities of low-quality feeds, introduce Napier grass, add clover (*Trifolium repens*), *Stylosanthes* spp to diet, and up to 1.5 kg concentrates per day during early lactation.
Multiple change	P	P	P	P	P	P	Replace low genetic merit cows with improve cow breeds, reduce reliance on crop residue and intensify zero-grazing practices.	More nutrient-rich pasture, no allocation of more land for grazing, more concentrate supplements.	Improved cow breeds, reduce the quantity of low-quality feeds, introduce Napier grass, add clover (*Trifolium repens*) to diet and 3 kg concentrates per day during early lactation.

NI = Not important; P = Prioritised.

Table 3. Perceived importance of farm and feed management practices to milk yield expressed as percentage of stakeholders prioritising a practice.

	Stakeholders prioritising a practice (%)				
Farm practices	Bomet	Nandi	Njombe	Rungwe	Average prioritized
Better diet	67	93	92	76	85
Improved cows	62	100	63	45	68
Improved health	100	73	88	93	89
Feeding practices					
Zero-grazing	100	94	100	100	99
Native grass	73	71	100	100	86
Concentrates	100	88	100	96	96

applications, manure on grasslands and crop residues arising from conversions of grasslands for feed cultivation (i.e. land use change (LUC)). Carbon dioxide (CO_2) emissions from feed cultivation were also quantified (table S6). In some scenarios, land demand for Napier grass, *Stylosanthes spp* and *Trifolium repens* (white clover) exceeded the available grassland area. As a result, CO_2 emissions associated with the conversion of grasslands and forests were quantified (appendices 5 and 6). Crop residues (i.e. maize stovers) were from croplands. Cropland and grassland availability were determined using data from the European Space Agency Climate Change Initiative and FAOs' Global Land Cover-SHARE (FAO 2013, ESA 2016). In modelling this, we made two assumption: (a) that all grassland areas were available for conversion and (b) current croplands were unavailable for additional feed production, this was to avoid compromising the food security in smallholder systems. To quantify emissions from concentrate use, we multiplied concentrate intake by a factor of 1.36 kg CO_{2eq} DM^{-1} (Weiler *et al* 2014). To determine the emission intensities for the dairy production regions and selected administrative locations, we upscaled the calculated emissions using cattle population data (figure 2, appendix 7, tables S7 and S8). We adopted a bottom-up spatial mapping approach to upscale emissions from livestock production systems to the dairy production regions, following Brandt *et al* (2018b). For the administrative unit analysis, we delimit livestock gridded data with polygon features in selected counties and districts (i.e. stakeholders' workshop locations), following spatial aggregation techniques described in Lloyd *et al* (2017). We compared productivity outcomes under the different scenarios against the baseline using two indicators of climate change mitigation, namely: emission intensities per kilogram of fat protein corrected milk (FPCM) and percentage change in the different emission sources relative to the baseline. Furthermore, we used Wilcoxon–Mann–Whitney test to determine whether there was significant (i.e. $p < 0.05$) increase or decrease in milk yield under the different scenarios compared to the baseline.

3. Results

3.1. Stakeholders' priorities and preferences

Stakeholders' priorities for the different management practices were not always unanimous across locations (table 3). Zero-grazing and use of concentrates were considered the most important practices for raising smallholder milk yield, mentioned by 99% and 96% of respondents, respectively. Improved health was also prioritized by most (89%), as was better diets (85%), especially in Nandi and Njombe. Adoption of improved cows received least interest, with only 68% prioritizing genetic improvement. Geographical variation were observed with improved cows, for example, improved cows were considered unimportant in Rungwe and particularly important in Nandi. This certainly points to the importance of geographically-adapted LED strategies.

The analysis of future interventions showed strong preference (>50%) for the cultivation of nutrient-rich feeds (including cultivated fodder and pastures) that could reduce the reliance on feed markets (table 4). Stakeholders had weak preference (<50%) for allocating more land to pasture and replacing on-farm feeds with commercial feeds. However, with the exception of Nandi, stakeholders did prefer to see SHDF use more commercial feeds, albeit not at the expense of on-farm feed production. This can be attributed to perceptions of on-farm feed availability constraints. Weak preferences towards reallocation of arable land to pasture furthermore highlights widespread food security concerns.

3.2. Milk production under scenarios

Improvements to management practices had a positive impact on milk production across all scenarios. Incremental change to feed practices increased milk yield per cow by 2%–15% compared to the baseline (table 5). Under the ACS, milk yield increased by 60%–130% to 6.2–10.1 kg cow^{-1} d^{-1}. Similarly, milk yield increased three-fold under the MCS compared to the baseline. This suggested that widespread adoption of the proposed practices could lead to increased nutrient supply and marketable surplus. In

Table 4. Stakeholders' preferences for the implementation of intervention strategies on SHDFs. Preferences were determined using top-two box analysis and represents the proportion of stakeholders with strongly agree and agree responses. Bold numbers indicate strong preference (>50%) for any given strategy.

		Kenya		Tanzania	
Strategies	Parameter	Bomet	Nandi	Njombe	Rungwe
Most smallholder farms increase the amount of feeds purchased	Total valid responses	16	16	23	30
	Mean	2.3	2.8	3.2	3.1
	Z-score to %	17.4	21.2	49.0	43.9
	CV (%)	41	49	34	28
	Top-two box (%)	**50**	37.5	**78.3**	**86.7**
Most smallholder farms cultivate more nutrient-rich fodder on-farm during the rainy season	Mean	1.6	3.1	2.8	2.9
	Z-score to %	47.1	46.6	30	38.5
	CV (%)	33	28	29	35
	Top-two box (%)	**56.3**	**81.3**	**65.2**	**76.7**
All smallholder farms allocate more land for grazing with higher quality pasture	Mean	2.4	2.4	2.5	3.1
	Z-score to %	25.4	21	11	23.9
	CV (%)	47	43	50	37
	Top-two box (%)	43.8	37.5	17.4	36.7
Most smallholder farms replace on-farm feeds with commercial feeds[a]	Mean	2.4	2.6	2.3	2.7
	Z-Score to %	14.9	14.7	16.7	18
	CV (%)	62	50	40	53
	Top-two box (%)	25	31.3	43.5	26.7
Most smallholder farms replace commercial feeds[a] with on-farm feeds	Mean	3.6	2.8	3.2	3.3
	Z-Score to %	36.5	35.6	48.8	53.1
	CV (%)	35	37	26	27
	Top-two box (%)	**68.8**	**62.5**	**82.6**	**86.7**
Milk price falls and most farmers increase off-farm activities	Mean	3.4	2.7	2.4	2.6
	Z-Score to %	32.8	30.7	24.9	29.3
	CV (%)	37	38	50	42
	Top-two box (%)	**56.3**	**68.8**	43.5	**66.7**
Milk price rises and most farmers reduce off-farm activities	Mean	2.75	2.4	2.9	3.7
	Z-Score to %	33.6	24.3	37.7	41.9
	CV (%)	39	45	37	40
	Top-two box (%)	**68.8**	**62.5**	**73.9**	**73.3**

[a] Commercial feeds refer to concentrate supplements and mineral licks.

Table 5. Effects of scenarios on milk yield reported as mean, median and range.

	Kenya				Tanzania			
Scenario	Mean (kg cow $^{-1}$ d^{-1})	Median (kg cow $^{-1}$ d^{-1})	Range	% increase[a]	Mean (kg cow $^{-1}$ d^{-1})	Median (kg cow $^{-1}$ d^{-1})	Range	% increase[a]
Baseline	3.89	3.85	0.52–8.00	—	4.24	4.34	0.53–8.00	—
Incremental change	4.36	4.43	0.53–8.00	15.1	4.36	4.43	0.53–8.00	2.1
Adaptive change	9.69	6.17	1.82–18.44	60.3	10.08	10.1	8.55–18.52	132.7
Multiple change	12.04	12.00	3.00–20.00	211.7	12.04	12.00	3.00–20.00	176.5

[a] % Increase based on median milk yield in scenarios relative to the baseline.

both countries, there was an increase in milk yield per cow under change scenarios compared to the baseline (p-value < 0.001).

3.3. Dairy carbon footprints at sectoral level

There were no significant differences between emission intensities at both regional and administrative level scales (tables S9 and S10). Nevertheless, the adoption of the proposed management practices by SHDFs would have a varied effect on total GHG emissions in Kenya. Specifically, emission intensities numerically increased from 3.43 kg CO_{2eq} kg FPCM^{-1} in the baseline to 3.75 kg CO_{2eq} kg FPCM^{-1} (9% increase) under ICS (figure 3(A)). However, GHG emission intensities decreased by 28% and 44% in Kenya under ACS and MCS,

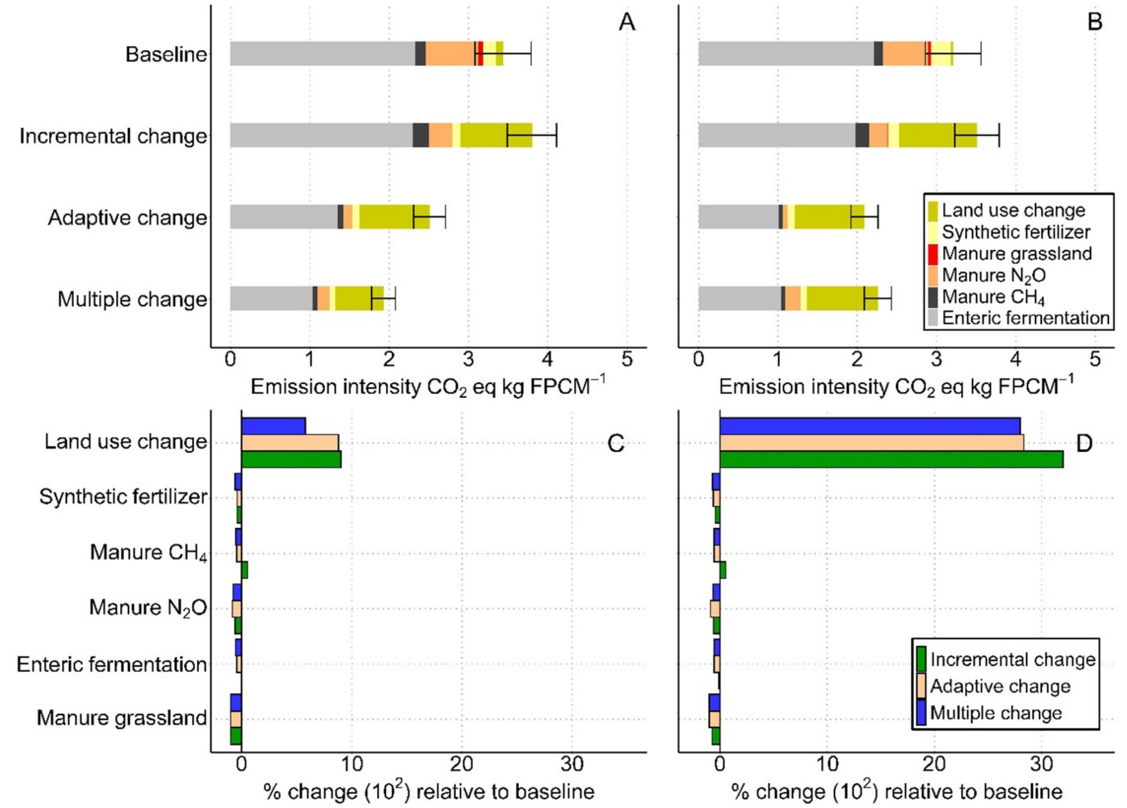

Figure 3. Bar graphs showing the estimated GHG emission intensities from different sources in the dairy production regions of Kenya (A) and Tanzania (B) quantified for the baseline, and the incremental change, adaptive change, and MCSs. Percentage change in the emissions from GHG sources in the dairy production regions of Kenya (C) and Tanzania (D) relative to the baseline. Error bars represent one standard error of the mean calculated from all simulations.

respectively. Under the baseline and ICS low-genetic merit crossbreed cows continued to be kept, while under ACS and MCS genetic improvements were introduced. LUC was the largest source of emissions, increasing by at least 500% in all change scenarios (figure 3(C)). Emissions associated with fertiliser application on croplands decreased by more than 40% in all scenarios. Similarly, emission intensities due to enteric fermentation, methane from manure management and manure on grassland decreased in all scenarios.

For the dairy production region of Tanzania, GHG emission intensities numerically increased from 3.22 kg CO$_{2eq}$ kg FPCM^{-1} in the baseline scenario to 3.51 kg CO$_{2eq}$ kg FPCM^{-1} (9%) and numerically decreased to 2.08 kg CO$_{2eq}$ kg FPCM^{-1} (35%) under ICS and ACS, respectively (figure 3(B)). The total emission intensity decreased by 30% under MCS. In all scenarios, LUC was the largest source for increased emission intensities (figure 3(D)). Emission intensity decreased by more than 70% due to fertiliser application on croplands. Emissions from enteric fermentation and methane from manure management decreased for all scenarios (figure 3(D)). The emissions from forest losses were negligible, accounting for less than 0.01% of total emissions in all locations.

3.4. County/district-level carbon footprint

Kenya's county level analysis of GHG emission intensities revealed differing patterns across change scenarios compared with the baseline (figure 4). For instance, the total emission intensity numerically decreased from 3.2 kg CO$_{2eq}$ kg FPCM^{-1} in the baseline scenario to 2.73 and 2.16 kg CO$_{2eq}$ kg FPCM^{-1} under ICS and ACS, respectively, in Bomet (figure 4(A)). In Nandi, the GHG emission intensity decreased for all scenarios (figure 4(B)). The largest source of increase in emissions was from LUC (>500%) in all scenarios (figures 4(C) and (D)). Emissions intensities from enteric fermentation, manure management and manure on grassland reduced under all scenarios (figures 4(C) and (D)). In both counties, emissions intensities from methane from manure management decreased by a minimum of 90% across scenarios.

In Njombe, the total emission intensity numerically decreased from 3.22 kg CO$_{2eq}$ kg FPCM^{-1} under the baseline to 3.15 kg CO$_{2eq}$ kg FPCM^{-1} under ICS (figure 5(A)), representing a 2% decrease. However, the total emission intensity decreased by 16% and 28% under ACS and MCS, respectively (figure 5(A)). In Rungwe, emission intensities also decreased for all scenarios compared with the baseline (figure 5(B)), ranging from 12% under ICS to

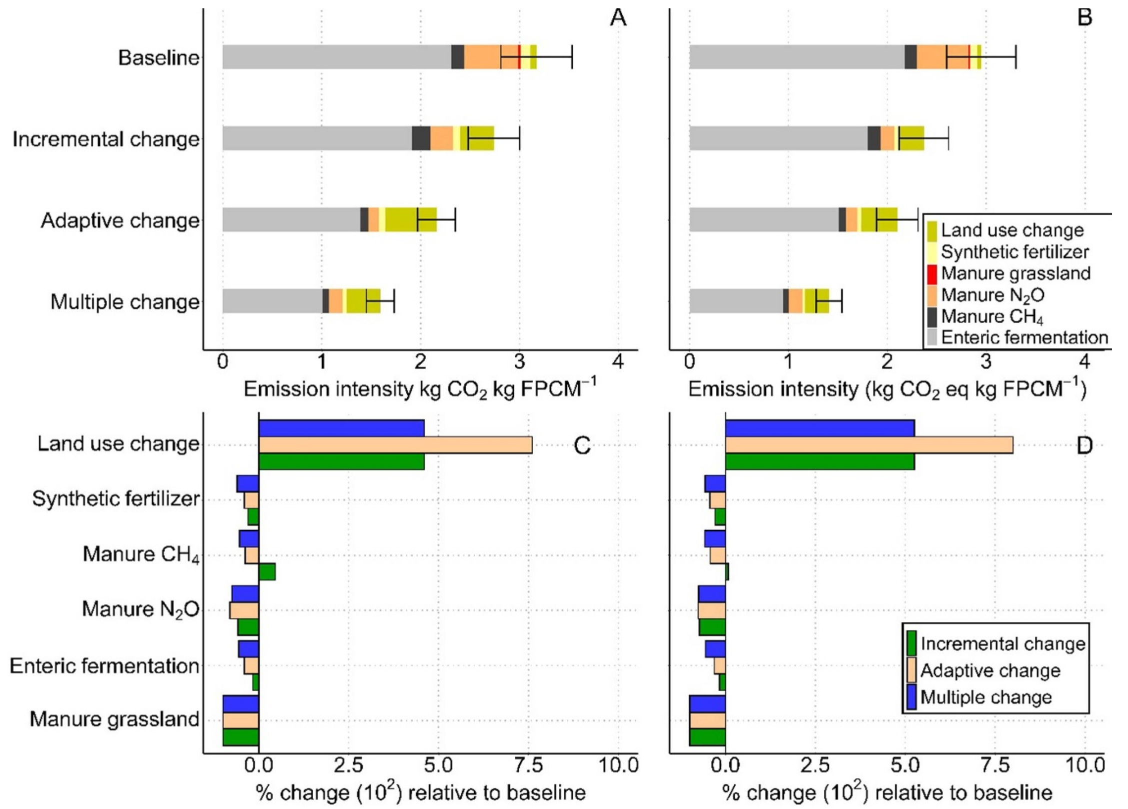

Figure 4. Bar graphs showing the estimated GHG emission intensities from different sources in (A) Bomet and (B) Nandi counties of Kenya. Emission intensities are quantified for baseline, incremental change, adaptive change and MCSs. Percentage change in the emissions from GHG sources in Bomet (C) and Nandi (D) counties relative to the baseline (zero) emissions. Error bars represent one standard error of the mean calculated from all simulations.

40% under MSC. In Njombe and Rungwe, emissions intensities from enteric fermentation, fertiliser application and manure management decreased by at least 90% under all scenarios (figures 5(C) and (D)). Emissions from LUC increased by at least 500% for each scenario. Across the study area, interventions in feed management would reduce emission intensities from manure on grasslands (figures 5(C) and (D)).

3.5. Emissions from the sourcing of concentrates

Concentrate use increased GHG emission intensities across scenarios. GHG emission intensity increased by 21% under MCS in the dairy production region of Kenya (table S11). In Nandi and Bomet, concentrate use increased the GHG emission intensity between 3% and 30% (table S12). Concentrates increased emission intensities by approximate 3% under ACS due to the comparatively small amounts that were used under this scenario. Similarly, concentrate use led to the largest increase on emission intensities under MCS for the dairy production region of Tanzania (table S13). In Rungwe and Njombe, concentrate use increased the total emission intensity by 23% and 18% under MCS, while the least increase in total emission intensity due to concentrate use was under the ACS (table S14).

4. Discussion

Our study shows that stakeholders' priorities and preferences are more heterogeneous across space than across social groups. This points to a miss-match between a hegemonic vision of LED and many subnational development interests. However, what is preferred by stakeholders is not necessarily in line with LED objectives. For instance, we show that incremental changes to feed management, which are more relevant to some areas, increases emission intensities. Adaptive changes to native grasslands and cow genetics in contrast reduced total emission intensities by 28%, while multiple concurrent changes reduce these by an estimated 44%. However, notable intra-regional variations were observed. For instance, emission intensities did reduce under ICS in several administrative areas, suggesting that incremental change was not always incompatible with emission reduction goals. Therefore, in certain areas (in this case Rungwe), resource-constrained interventions may still be impactful. In other areas, LED interventions were only likely to raise yields and lower emission intensities simultaneously with a more encompassing approach that targets multiple practices concurrently. However, in some areas (notably Bomet and Rungwe in this case), some

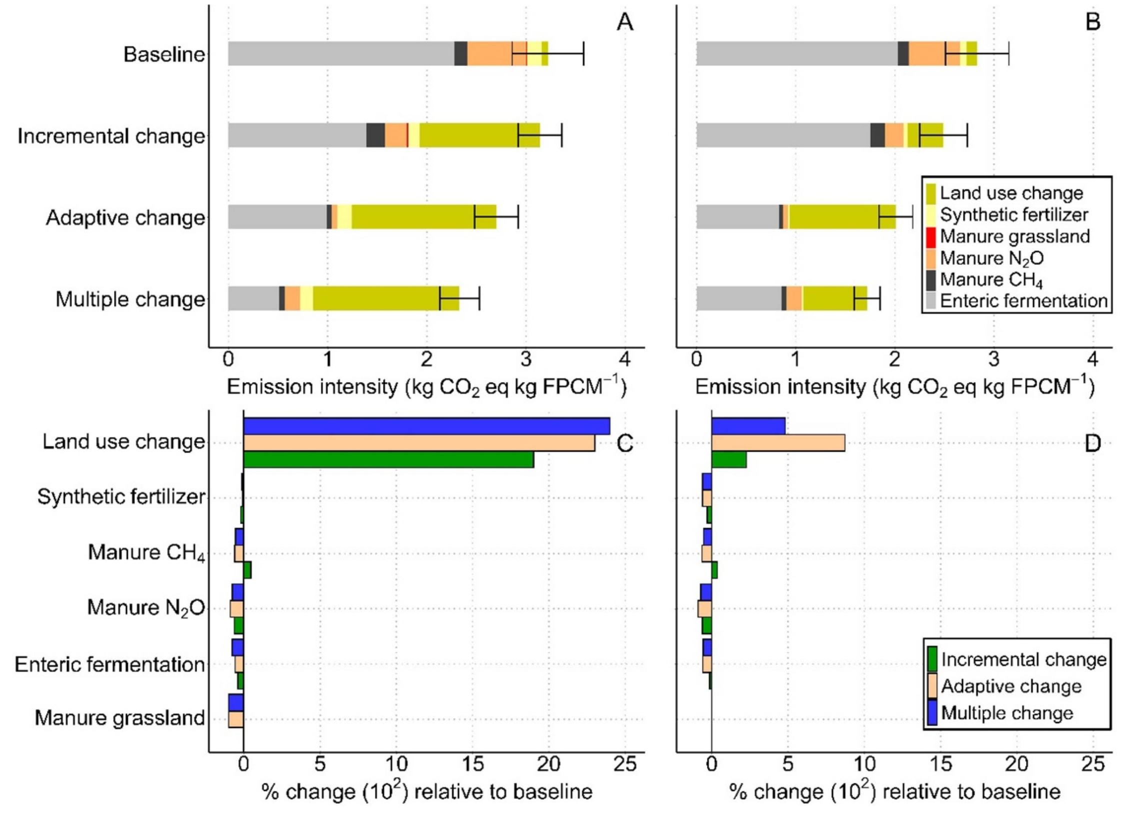

Figure 5. Bar graphs showing the estimated GHG emission intensities from different sources in (A) Njombe and (B) Rungwe districts of Tanzania. Emission intensities are quantified for baseline, incremental change, adaptive change and MCSs. Percentage change in the emissions from GHG sources in Njombe (C) and Rungwe (D) districts relative to the baseline (zero) emissions. Error bars represent one standard error of the mean.

stakeholders were likely to resist such interventions, which could affect efficacy as a result of uptake problems and/or reduced local buy-in and legitimacy. This highlights that LED strategies should be tailored to local interests and practice preferences, or, alternatively, invest more in sensitization. While calling into question one-size-fits-all LED, top-down approaches may still have a place alongside more bottom-up approaches, albeit if the geographic focus of such interventions is restricted to amenable geographies. This, however, is unlikely to be truly transformational without more deliberate large-scale efforts to institutionalize more progressive and reflexive alternatives.

Accounting for stakeholders' priorities and preferences at scale in uncertain contexts clearly requires national-level LED design strategies that are responsive to changing and variegated geographic conditions. This can be achieved by embedding multi-stakeholder processes within all phase of the project lifecycle; from design to implementation and back to re-design. Institutionalizing such processes requires sectoral governance structures that facilitate inter-organizational coordination and helps overcome the fragmented policy space and development programming pervasive in many developing country contexts.

While results had important implications, they also offered some empirical evidence that could help delineate the technical direction of national LED strategies. This study demonstrated that replacing low-quality grasslands and reducing dependence on commercial feeds (e.g., under ACS), were likely to satisfy the interests of the many stakeholders that oppose the allocation of cropland to fodder production. Doing so increased milk yield, reduced emission intensities and aligns with 'food-first' priorities of most districts/counties. However, emissions from LUC increased significantly—as it does under the other scenarios. This study found that feed cultivation raised LUC emissions in particular (in line with Herrero *et al* 2014, Brandt *et al* 2018b). Upscaled results suggest that LUC account for between 25% and 42% of absolute emissions, peaking at 63% in sampled counties/districts. This suggested that LED viability assessments should place more emphasis on LUC-related emissions to increase adoption and effectiveness (e.g. FAO and NZAGGRC 2017, 2019, Michael *et al* 2018).

While LUC emissions could be largely offset by the inclusion of other practices in the scenarios, the results of this study do give reason to caution against land-centric and -intensive intervention strategies, especially in areas experiencing land constraints or comprising ecologically- and socially-significant ecosystems. This is similar to common practices adopted by dairy farmers in high-income countries to reduce GHG emission intensities (van Meijl *et al* 2006). Greater use of concentrates (e.g. under MCS) could also increase milk yield, while reducing the risk of forest disturbance (Brandt *et al* 2018a). However, concentrate use could be associated with increase off-farm and overseas emissions (Styles *et al* 2018), as well as, increasing pressure on existing land capacity (Brandt *et al* 2020). This study also showed that concentrate use under MCS could increase total emission intensity by 17%–29%. While on-farm fodder production is generally more desirable from an emission-reduction perspective (Dawson *et al* 2014), this is considered socially detrimental and therefore, politically contentious by most sampled stakeholders. This further highlights that an acute understanding of contextual factors that condition socio-environmental trade-offs is needed in LED design.

Overall, the emission intensities calculated here were consistent with recent studies on East African smallholder production systems of East Africa (e.g. Mottet *et al* 2017, Wilkes *et al* 2020). However, total emission intensities were not substantially different between scenarios, which could be attributed to lack of drastic changes in proposed feeding interventions (e.g. supplying only Napier grass under ICS). Nevertheless, by calibrating feeding strategies using stakeholders' priorities and preferences, this study added an important social dimension. However, there is a risk that the scenarios co-developed here are biased in favour of the priorities of better represented groups such as dairy farmers and government officials. However, since there was no statistically significant difference in priorities and preferences between groups, therefore, the risk was considered low. In future studies, particularly in areas where priorities and preferences diverge, attention to balanced representation is needed; possibly through larger-scale surveying.

5. Conclusion

This article demonstrates the importance of accounting for spatially differentiated stakeholder priorities and preferences in future LED programming and policy-making. It further shows that there is need for caution when implementing mainstream top-down LED particularly when dealing with smallholder dairy farmers who exhibited different preferences for management strategies in this study. Rather dairy policies should include more bottom-up approaches that can help integrate local priorities and preferences that condition uptake and, by extension, intervention efficacy into national LED strategies. This can be achieved by improving multi-stakeholder participation structures and nesting different scales and aligning different thematic domains of governance. This is also more aligned with ongoing processes of devolution. While this article does show that socio-environmental trade-offs are likely inherent to any feed-oriented LED strategy, these can be managed and optimized through participatory processes. In this regard, we show that land use change dynamics deserved particular emphasis and both social and environmental safeguards should be expressly considered.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Conflict of interest

The authors declare that they have no known competing interests.

Ethical statement

This study includes stakeholders' assessment workshops undertaken in accordance with the Data Protection Act (UK) 2018 and the General Data Protection Regulation (GDPR). For this reason, all stakeholders were aware that their responses were collected anonymously and gave their consent to partake in the survey.

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