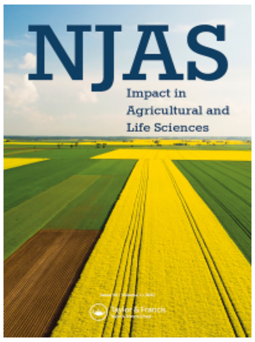

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From fix to fitting: Connecting low-emission development with multilevel smallholder dairy practices in Kenya

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ABSTRACT

Smallholder livestock production systems are targeted for climate change mitigation via Low-Emission Development Strategies (LEDS). LEDS promote the adoption of so-called best agricultural practices for mitigation gains, while also expecting to contribute to socio-economic development. However, the assumed alignment between LEDS and varied realities of smallholder farmers is not self-evident. This study argues for a shift away from problematizing the adoption of ideal-type and uniform LED-practices (or a “fix”) to fitting LEDS to diverse smallholder priorities and capabilities embedded in specific regional histories and conditions. To make this shift, we assess the plausibility of fit of LED-practices into diverse smallholder realities in Kenya’s dairy sector. A mixed-methods approach exposes variation in the use of LED-practices in diverse dairy practices at household and regional levels. We characterize smallholder heterogeneity by distinguishing six clusters through a multivariate analysis of data from 1009 households in three regions of Kenya, and present patterns in uptake and intensity of the use of LED-practices for each household type. Next, the combination of quantitative and qualitative data shows variation in uptake of LED-practices at the level of the three counties, which suggests the importance of regional conditions in shaping the uptake of LED-practices and places the adoption focus beyond household-level decision-making. Subsequently, we identify starting points for LEDS design attuned to variation in smallholder dairy realities at multiple levels, where we consider scale at the start, and shift attention from the adoption of fixes to the creation of spaces conducive to “fitting” LED-practices into diverse realities.

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KEYWORD East Africa; livestock; household typology; agriculture; sustainable intensification

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1. Introduction

In response to the global climate crisis, the environmental policy community is increasingly prioritizing the reduction of greenhouse gas (GHG) emission intensities (kg of CO_2-eq./kg of animal product) from livestock sectors (Mrówczyńska-Kamińska et al., 2021), which globally account for 65% of total GHG emissions from agriculture (Tubiello et al., 2014). In the Global South, most livestock production is performed by smallholders (Herrero et al., 2017). Therefore, smallholder livestock production systems are often identified as an opportunity for mitigation gains (Havlík et al., 2014; Herrero et al., 2016) along with potential for socio-economic development (Kihoro et al., 2021). The latter is foreseen through assumed increasing incomes from livestock such as milk sales as a result of adopting mitigating practices. The dual objectives of environmental and socio-economic development have led to the concept of Low-Emission Development Strategies (LEDS), generally understood as "forward-looking national development plans or strategies that encompass low-emission and/or climate-resilient economic growth" (Clapp et al., 2010, p. 3). LEDS targeting dairy sectors in the Global South emphasize the uptake of practices to increase productivity while delivering high-quality protein with a lower per capita environmental footprint (Gerber et al., 2013).

The smallholder population is, however, very diverse, and successful LEDS uptake is contingent on donor and state ability to align LEDS with diverse local development conditions, capacities and priorities (Kihoro et al., 2021; Yesuf et al., 2021). LEDS might have unintended effects and effectiveness problems because its success depends on largely on effective uptake of mitigation practices by livestock owners. In addition to threatening the success of climate change mitigation ambitions, limited sensitivity to the diverse realities in which these initiatives are embedded can have detrimental effects on social equity and inclusion (see for example Clay & King, 2019; Karlsson et al., 2017; Tavenner et al., 2019). To investigate the commensurability of LEDS and local diversity in the context of Kenya, this study aims to answer the question: "What mechanisms and interactions determine the alignment between LEDS and diverse smallholder priorities and capabilities?" This paves the way for discovering starting points for LEDS aligned with diverse smallholder practices and realities and to enhance the overall success of LEDS implementation.

This study specifically aims to inform LEDS design to align with diverse smallholder practices and realities for Kenya's dairy sector. Emission intensities of cow milk in sub-Saharan Africa are estimated at 9 kg of CO_2-eq. per kg of fat and protein corrected milk (FPCM), which is the highest in the world, and three times the global average (Opio et al., 2013). In East Africa, dairy is typically part of a complex portfolio of livelihood activities of households in mixed crop-livestock farming systems (Scoones, 2009), which are often typified as low-input systems (Abraham & Pingali, 2020) and with considerable yield gaps (Henderson et al., 2016). The Kenyan government has identified the dairy sector for developing LEDS due to relatively high GHG emission intensities and clear technical pathways for gains, as well as socio-economic development needs (Bosire et al., 2016; Ericksen & Crane, 2018; van Dijk et al., 2015). LED-practices for dairy are effectively the same as dairy intensification practices, and focus on improving feeding, manure management, animal health and husbandry practices (Ericksen & Crane, 2018). The emphasis in many climate change policies and intervention strategies on pre-defined technological packages characterizes LEDS as having a top-down "single-fix" design, which may result in sub-optimal adoption rates (Glover et al., 2016). This paper shifts focus to pathways that are responsive to smallholder and regional diversity in three counties in Kenya, which can inform the "starting point" of LEDS that "fit" diverse local and regional realities.

In the paper, we first present the context and explain our methods. The results section starts by analysing farm households and presenting a household typology. We also aggregate the household level data to three counties. We then investigate what the farmers do by assessing how their current dairy practices align with advised LED dairy practices (Ericksen & Crane, 2018), both at household and at county level. For this purpose, the household typology is situated within the institutional environments that shape how households navigate and select practices. Nesting households within regions helps identify how LEDS can better account for geographic contexts. This integrative perspective adds to the growing body of research on smallholder dairy systems that are being targeted for climate change mitigation and adaptation initiatives.

2. Materials and methods

2.1. Research areas

Our analysis draws on data from Murang'a, Nandi and Bomet counties in Kenya where dairy is one of the leading agricultural sectors contributing to rural livelihoods. Kenya's dairy subsector contributes 4% to national Gross Domestic Product (GDP), worth 100 billion Kenyan Shillings (KES),[1] with a growth rate of 3% to 4% per year. The dairy subsector contributes 40% of the agricultural GDP. Milk consumption in Kenya is among the highest in Sub-Saharan Africa at an estimated 110 litres per person per year and is expected to grow to 220 litres per person per year in 2030. This translates into a projected annual production increase from 4.5 billion litres to 12.76 billion

[1]Approximately 727 million USD.

litres of milk in 2030. The average productivity level per cow per day is 5 litres (MoALF Ministery of Agriculture, 2010). Smallholder producers owning one to three cows contribute to about 80% of total milk production, and the sector is estimated to employ two million people directly or indirectly (Tegemeo Institute of Agricultural Policy and Development, 2021). Of all marketed milk, an estimated 15% is absorbed by commercial processors, with the remainder sold raw or processed through cottage industry. Kenya's three largest processors control about 85% of the formal market (Kimenju et al., 2017).

Kenya's livestock production systems are faced with major environmental problems. In Kenya, agriculture is the leading source of GHG emissions, contributing 63% of total emissions in 2019 (Climate Watch, 2023). Of these agricultural emissions, 55% was estimated to be from enteric fermentation from livestock, and 37% due to manure left on pasture (USAID, 2017). Livestock emissions are expected to increase in Kenya, mainly driven by a rising demand for meat and milk due to an increasing population, urbanization, and rising incomes. The Kenyan government is committed to reducing this impact: the livestock sector is central to Kenya's climate ambitions. Therefore, Nationally Appropriate Mitigation Actions (NAMA) specific to livestock were developed that aim to cut emissions by 8.8 Mt CO_2-eq. over a 10-year period (Mbae et al., 2020).

The study sites (Table 1) were selected for their production potential, ecological significance (Lawrence et al., 2023a, 2023b) and relevance to dairy development priorities and policy processes. Murang'a is dominated by more intensified dairy systems. Located in the former Central Province near the capital Nairobi, population pressure is comparatively high and efforts to formalize milk markets are explicitly pursued by the county government (Murang'a county government, 2018). Milk from Murang'a that is not consumed locally is typically sold in Nairobi. While tea is an important cash crop, coffee, banana, and mango are also commonly cultivated in the county. The county has benefitted from significant public sector investment in dairy, resulting in a large farmer-owned milk cooling and marketing infrastructure competing with numerous commercial processors. Along with counties such

Table 1. Characteristics of the three counties.

Characteristics	Unit/description	Murang'a	Nandi	Bomet
Precipitation	Mm/year min-max	400–1600	1200–2000	1000–1400
Altitude	Meters above sea level	900–3300	1400–2300	1700–2500
Area	km^2	2,559	2,884	2,037
Population	Persons	1,128,177	1,022,380	891,168
Population density	Persons/km^2	441	354	437
Dairy cattle population	Number	239,750	223,943	297,439
Dairy system	Dominant dairy system	Intensive	Semi-intensive	Semi-intensive

Source: Extracted from Murang'a county government, (2018); Nandi county government (2018); Bomet county government (2018).

as Kiambu, it is perceived as a dairy frontrunner due to high adoption of zero-grazing systems.

The other two sampled counties, Nandi and Bomet, are both located within the former Rift Valley Province and are united under the Lake Region Economic Bloc (LREB). In both counties, semi-intensive dairy systems dominate, expressing milk production per unit of land. Smaller pockets in Nandi North and Bomet West produce dairy more intensively. Tea is the main cash crop in both counties, with food crops such as maize, beans and potatoes cultivated by most households. At lower elevations in Nandi, sugarcane replaced tea as an important cash crop. Most of the milk produced in Nandi and Bomet is sold within the towns in the counties or large urban centres such as Eldoret and Kisumu. While most of the milk reaches consumers via intermediaries, large processors also source directly from these counties (Bomet county government, 2018; Nandi county government, 2018). The study areas are subject to similar regulatory environments.

2.2. Research design

To find starting points for LEDS responsiveness to diversity, we aim to qualify the diversity of smallholder practices and realities at the household and regional levels. First, we characterize farmer households and farming system diversity by developing a data-driven typology (Alvarez et al., 2018; Schoneveld et al., 2019). This aligns with the work of other scholars who typify dairy smallholders in Kenya and the East African region by exploring variations in resource endowment and commercialization (low, moderate, and high) (Otieno et al., 2021) and gender of the household head and major income categories (Owino et al., 2020a). Other farm system typologies in Kenya find variations in livestock (not explicitly dairy) activities being part of distinct specialized and diversified (Musafiri et al., 2020) and conventional and organic farming systems (Kamau et al., 2018). For a combined dataset of Kenya and Tanzania, dairy households are typified according to livelihood strategies, either specialized on dairy, diversified, or off farm oriented (Hawkins, 2021). For this study, we build on earlier work in Tanzania (Kihoro et al., 2021), where six distinct dairy farmer types were identified, ranging from marginalized to wealthier groups, with subsistence or commercial dairy orientations, and with dairy activities as specialization and as part of a more diversified livelihoods (both on and off farm).

Second, complementary approaches to understanding and characterizing diverse smallholder realities, often for sustainable intensification efforts, adopt a regional perspective (Ollenburger et al., 2019). This responds to limitations of household and farm system typology studies that tend to treat farming systems and households in isolation, by instead focusing on embedding households and farm systems within specific historical contexts and broader institutional environments. This resonates with the observed need for context-sensitive institutional diagnostics to identify how to gear the institutional context towards desired socio-economic development goals (Schouten et al., 2018). Methodologically, this entails adding qualitative insights to statistical analyses (see e.g. Kihoro et al., 2021; Schoneveld et al., 2019). In this research, these suggestions are integrated, and current smallholder farming practices both from a farming household typology level and an administrative regional level, are explored.

2.3. Data collection

The research followed a mixed-methods design. Firstly, we administered a structured questionnaire with 1050 households. This questionnaire was loosely based on the Rural Household Multi-Indicator Survey (RHOMIS) (Hammond et al., 2017) and covered topics such as household demographics, household assets, livelihood activities, dairy and crop management practices, milk marketing, production output, revenues and costs and household psycho-social attributes. Following data cleaning, 1009 households were retained for our analysis: 338 from Murang'a, 330 from Nandi, and 341 from Bomet.

A two-stage stratified random sampling technique was used to select households for the study. A more detailed description of the sampling strategy and survey instrument can be found in the study by Kihoro et al. (2021). First, a spatial cluster analysis was conducted to identify areas with similar agro-ecological characteristics within each county using rainfall, temperature, and elevation data. Following this, 36 locations were randomly selected across the agro-ecological zones (AEZs) in each county; the number of locations per zone were proportionate to the relative size of each zone in the counties. Villages closest to each location were selected for inclusion in the study. Households were then randomly sampled in each village, based on sample frames constructed in collaboration with local authorities and leaders, consisting of all households with at least one cow or an in-calf heifer. The number of farmers sampled per village was then informed by the relative size of each sample frame. Figures 1 and 2 present the AEZs and sampled villages in the research sites. Compared to other semi-arid and arid regions in Kenya, these three counties are relatively similar in terms of agroecology, but with a transition area to semi-arid AEZs in the East of Murang'a.

To contextualize and improve the interpretation of our quantitative analysis, qualitative data generation activities were performed. This involved interviews with key informants ($n = 46$) in each county in 2018, and workshops in Nandi ($n = 2$) and Bomet ($n = 2$) in 2019 (see Yesuf et al., 2021). Topics included the history of the dairy sector in the counties, current dairy development initiatives, preferences, and priorities, and the role of the state and private sector.

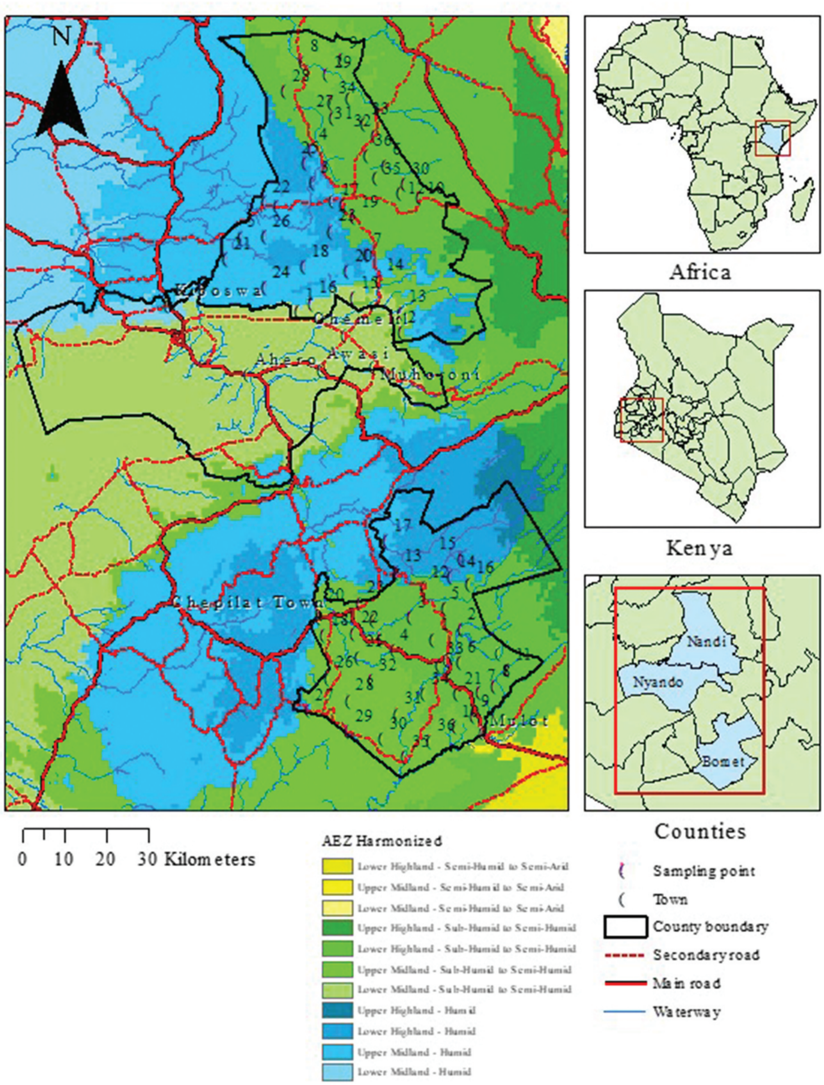

Figure 1. Agro-ecological zones and sampled villages in Nandi and Bomet.

2.4. Data analysis

The next subsections present the methods used to analyse what types of farmers are located where, what different types of dairy practices they adopt, and implications for context sensitive LEDS.

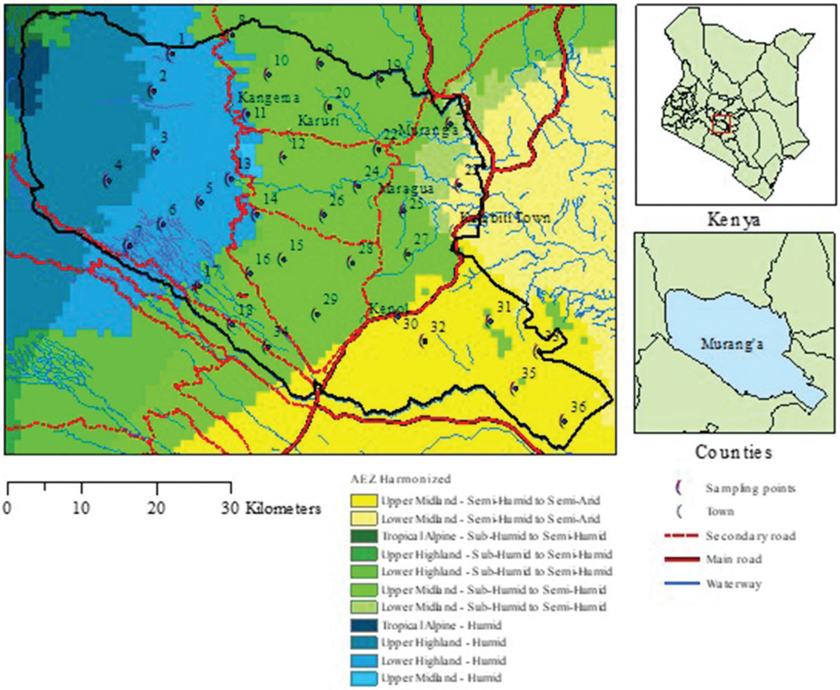

Figure 2. Agro-ecological zones and sampled villages in Murang'a.

2.4.1. Farmer typologies

To develop the farmer typology, we follow the clustering procedure employed by Schoneveld et al. (2019) that only uses socio-demographic data rather than also farm practice data as is often the case. This allows for an analytical separation between farming practices and the farmer; thereby facilitating the exploration of the relationship between what a farmer is and what a farmer does (*ibid*).

Creating typologies involves classification, comparison, and explanation of defined elements (Alvarez et al., 2018). This allows for a synthesis of multiple elements into fewer elementary types or themes. Cluster analysis was employed using the DAISY package in R (3.5.1). DAISY uses Gower distance and partitioning around medoids (PAM), where portioning creates clusters that have the greatest within-group similarity and high between-group dissimilarity. This approach is preferred to the commonly used k-means algorithm when using mixed type data. Because the ideal number of clusters is not pre-defined in this approach, silhouette width from PAM and dendrograms were used to identify the appropriate number of clusters (Mooi & Sarstedt, 2011). To preserve the underlying data structure, we did not perform a Principal Component Analysis (PCA).

Following expert consultation and validation workshops, 17 defining socio-economic variables were selected for the clustering (Table 2). These include demographic variables (Alvarez et al., 2018), and variables that represent livelihood activities and asset endowment, influencing the strategic orientation of households (Dorward et al., 2009; Tittonell, 2014). Livelihood activities were calculated as dummy variables representing whether a household was engaged in the activity or not (Schoneveld et al., 2019). Since we do this analysis to inform LEDS for dairy, income from dairy sales was weighted three times heavier than the other variables in the model. Analysis of variance (ANOVA) was employed to test for significant differences between clusters (for continuous variables) and chi-square tests were used for categorical variables (Kihoro et al., 2021; Michalscheck et al., 2018).

Table 2. Variables used to cluster producers.

Variable	Mean (SD)	Description	Proxy for
Age [years]	53.81 (14.47)	Age of the household head [years]	Demographic
Gender household head [% male]	79.58 (40.33)	Gender of the household head [1 = male, 0 = female]	Demographic
Education [ordered]	3.27 (1.16)	Highest completed education of household head. Ordinal with 6 levels [0 = no formal education, 1 = primary 1–4, 2 = primary 4–8, 3 = secondary 1–4, 4 = college, 5 = university]	Demographic
Ethnicity [% indigenous]	88.40 (32.03)	Dummy variable for indigenous to the area [1 = yes, 0 = no]	Demographic
Household size [number]	5.20 (2.18)	Household members [number]	Demographic
Land [acres]	3.82 (4.15)	Total land holding [acres]	Asset endowment
Assets [index]	0.53 (0.15)	Asset index [score]	Asset endowment
TLU [index]	3.45 (2.36)	Total livestock numbers expressed in Tropical Livestock Unit [score]	Asset endowment
Group Membership [%]	56.19 (49.64)	Dummy variable for group membership [1 = yes, 0 = no]	Asset endowment
Dairy [%]	80.67 (39.51)	Dummy variable for income dairy [1 = yes, 0 = no]	Livelihood activities
Other livestock [%]	47.47 (49.96)	Dummy variable for income other livestock [1 = yes, 0 = no]	Livelihood activities
Food crops [%]	53.12 (49.93)	Dummy variable for food crops revenue [1 = yes, 0 = no]	Livelihood activities
Cash crops [%]	62.93 (48.32)	Dummy variable for cash crops revenue [1 = yes, 0 = no]	Livelihood activities
Casual employment [%]	19.62 (39.73)	Dummy variable for casual income [1 = yes, 0 = no]	Livelihood activities
Formal employment [%]	19.33 (39.51)	Dummy variable for off-farm formal [1 = yes, 0 = no]	Livelihood activities
Business [%]	31.52 (46.48)	Dummy variable for off-farm business [1 = yes, 0 = no]	Livelihood activities
Other income [%]	20.02 (40.03)	Dummy variable for non-labour income (remittances, dividends, pension) [1 = yes, 0 = no]	Livelihood activities

Various clustering procedures produce different results (Alvarez et al., 2018). Factors not considered in this clustering exercise were the diversification strategies of households (Waha et al., 2018), intra-household dynamics (Michalscheck et al., 2018), and agroecological potential, although the agroecological conditions of the included study sites were quite similar and accounted for in the sampling of households. Finally, although the survey questions explicitly meant to incorporate what dairy practices households generally employ, their practices may vary throughout years and seasons, which is not reflected in the modelling results.

2.4.2. LED dairy practices

Subsequently, we sought to determine whether different clusters of farmers are associated with different LED adoption rates. For this, LED-practices were grouped into (1) feeding, (2) animal health and husbandry, and (3) manure management (Table 3). These management practices and associated intensification of production are relevant for reducing emission intensities of milk in the subregion (Brandt et al., 2020; Ericksen & Crane, 2018; Hawkins et al., 2021). Using these variables, a composite indicator was created using factor analysis to express household uptake of all above mentioned variables, scaled from 0 and 1 (Nardo et al., 2005).

Table 3. Low-emission dairy practices at household level.

	Variable	Mean (SD)	Description
Feeding	Grow fodder [%]	77.50 (41.78)	Dummy variable for growing improved fodder
	Feed concentrates [%]	49.26 (50.02)	Dummy variable for feeding cattle concentrates
	Feed conservation [%]	11.10 (31.43)	Dummy variable for practicing feed conservation
	Fulltime water access [%]	34.79 (47.65)	Dummy variable for cows having fulltime access to water
	Zero grazing [%]	29.93 (45.82)	Dummy variable for practicing zero-grazing
Animal health and husbandry	Crossbred cows [%]	92.17 (26.88)	Proportion of crossbred as opposed to indigenous cattle
	Inseminate using AI [%]	42.12 (49.40)	Dummy variable for artificial insemination (AI)
	Spray at least every three months [%]	69.28 (46.16)	Dummy variable for spraying/dipping against ticks at least every three months
	Deworm at least every three months [%]	74.73 (43.48)	Dummy variable for deworming cattle at least every three months
Manure management	Collect and use manure [%]	70.37 (45.69)	Dummy variable for collecting and using manure on farm
	Use manure within 3 months [%]	42.72 (49.49)	Dummy variable for using manure on farm within 3 months after collecting
	Biodigester [%]	0.99 (9.91)	Dummy variables for having a functional biodigester

Between-cluster differences were subsequently analysed, descriptively. To uncover more structural dimensions shaping LED uptake, county differences were analysed. Different patterns emerge when analysing and contrasting uptake at the county and cluster level. Chi-square or ANOVA tests makes it possible to determine statistically significant differences between the uptake of the practices between the farmer clusters in the three counties. Findings are elaborated based on (regional) history of the dairy sector, socio-political conditions, and regional dairy development priorities and preferences in the counties (Yesuf et al., 2021). Finally, patterns resulting from the statistical analysis were contextualized based on additional survey data and qualitative data from key informant interviews and group discussions by the authors.

3. Results

This section assesses the (potential) alignment between ideal typical LED-practices and observed uptake. It investigates uptake through a demographic and socio-economic lens as well as a geographic/county-level lens. First, the results of the cluster analysis present a household typology to typify who the smallholders are; we also know where they are located. We then explore what smallholders do in terms of current LED-practices, both at the household level and by aggregating the data to the county level. Different narratives emerge when examining the household dairy practice data at the household and county level. These different narratives are then combined and explained, leading to the identification of possible starting points for enhancing the alignment between LED-practices and diverse multilevel local realities in the discussion section.

3.1. Farmer typology

The statistical cluster analysis points to a six-cluster solution, meaning that six statistically distinct groups of households can be discerned. The household clusters are described below (Table 4 and Figure 3).

3.1.1. Cluster 1: Entrepreneurs

This group consists of comparatively young, educated, and affluent farm households, who have above-average incomes and assets. They have diverse sources of income, with most of them earning mainly from entrepreneurship or other off-farm activities. Dairy is important for their livelihoods, but they own less land than other groups and grow fewer food and cash crops. They are active in farmer groups that focus on dairy.

3.1.2. Cluster 2: Vulnerable farmers (subsistence)

This group consists of the most vulnerable farmers who have the smallest land size, the lowest livestock units and the lowest wealth index scores. They

Table 4. Characteristics of farmer clusters.

Variable	1	2	3	4	5	6	Chi/F-Statistic
Total cluster size [n]	166	105	245	90	287	116	
Total cluster size [%]	16.45	10.41	24.28	8.92	28.44	11.50	
Demographic							
Age [years]	49.15	53.56	57.86	57.02	53.94	49.32	10.93***
Gender household head [% male]	83.73	78.10	75.92	83.33	75.26	90.52	16.54***
Education [ordered]	3.56	2.78	2.98	3.12	3.13	4.38	36.88***
Ethnicity [% indigenous]	89.76	85.71	93.47	86.67	85.37	87.07	10.22*
Household size [number]	5.47	4.88	4.77	5.7	5.17	5.69	5.15***
Asset endowment							
Land [acres]	2.85	2.90	3.73	5.58	4.07	4.26	6.73***
Assets [index]	0.56	0.48	0.51	0.52	0.52	0.62	14.65***
TLU [index]	3.34	2.53	3.00	3.89	3.82	4.10	9.22***
Livelihood activities							
Group Membership [%]	78.92	24.76	17.55	67.78	74.56	79.31	295.01***
Dairy [%]	100	0	100	0	100	100	1000***
Other livestock [%]	27.11	27.62	19.18	63.33	78.05	66.38	256.14***
Food crops [%]	27.12	19.05	29.80	67.78	87.46	74.14	311.79***
Cash crops [%]	20.48	31.43	77.55	75.56	76.66	77.59	235.35***
Casual employment [%]	16.87	26.67	14.69	26.67	25.44	7.76	27.21***
Formal employment [%]	10.24	19.05	10.61	17.78	0	100	573.84***
Business [%]	77.71	25.71	11.43	32.22	27.53	22.41	218.15***
Other income [%]	16.87	20.95	20.00	24.44	21.60	16.38	3.60

***significant at 1% level.
*significant at 10% level.

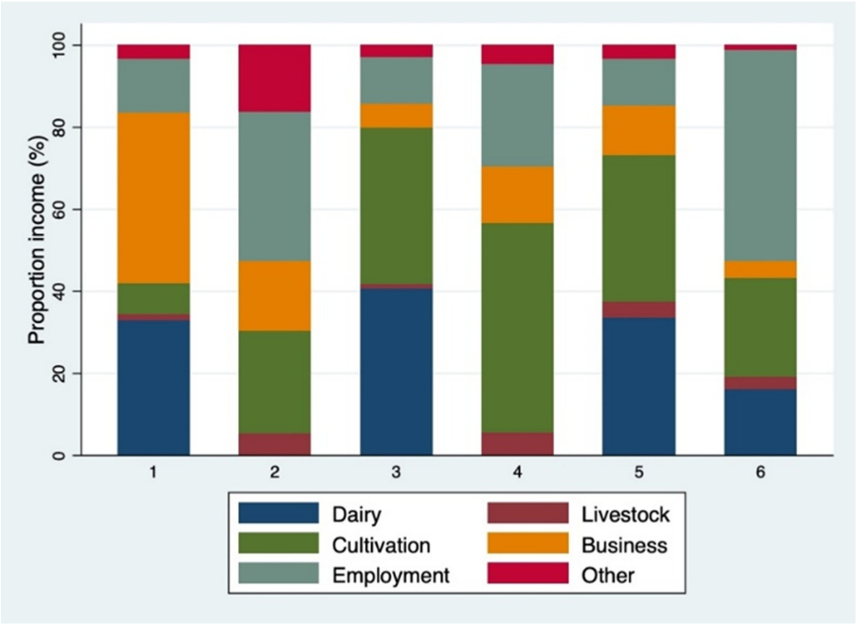

Figure 3. Relative importance of different livelihood sources. Note: "cultivation" includes cash crops and food crops, "employment" includes formal and casual employment; "other" includes remittances, pensions and.

have low levels of education and income diversification and rely strongly on casual employment. Dairy is not produced for sale, but for subsistence. With comparatively few households involved in cultivation activities, they have little involvement in farmer groups and farm-based income activities. This group is the second smallest, representing about 10% of the total sample.

3.1.3. Cluster 3: Dairy-oriented farmers

This group earns more from dairy than from any other sources, but generally also grow cash crops and to a lesser extent food crops. Since households' focus lies on the tea-dairy combination, few are engaged in off farm activities. Farmers in this cluster are often older, less affluent and asset endowed than most. This group and the dairy farm specialists (cluster 5) make up more than half of the total sample.

3.1.4. Cluster 4: Non-dairy farm specialists (subsistence)

This group does not produce dairy for sale, but only for consumption. They are relatively wealthy and have more assets than most. They participate in diverse on-farm activities, partly because they own the largest average land sizes. They grow a variety of food and cash crops, which constitute most of their income. Although they have the resources to produce dairy, cropping activities are preferred.

3.1.5. Cluster 5: Dairy farm specialists

Most included in this group are active across most farm activities, including dairying, which is a major source of income for them. They are similar to clusters 3 and 4, but more actively involved in farmer groups, other livestock activities and food crop cultivation. Despite being slightly less affluent and asset endowed than farmers in cluster 4, their on-farm diversification is similar. A variety of food and cash crops are grown by these farmers. None of them have formal employment. This is the largest cluster, representing more than a quarter of the total sample (28.4%), and is more than three times larger than the smallest cluster (cluster 4).

3.1.6. Cluster 6: Formally employed

This group has the highest wealth among dairy farmers, with incomes about three times higher than the median. Despite owning the largest number of cows, dairy production for sale is not their main income source, with all relying on formal employment, mainly in public service or education. Their livelihoods are diverse, with various crops supplementing their salaries. Household heads in this cluster are comparatively young and have high education levels.

3.2. Household uptake of LED-Practices

Based on the composite indicator, the uptake of LED-practices is highest among the formally employed (0.47), followed by entrepreneurs (0.42), dairy farm specialists (0.41), dairy-oriented farmers (0.39), non-dairy farm specialists (0.39), and vulnerable farmers (0.28). Uptake in the counties is highest in Murang'a (0.48), followed by Nandi (0.39) and Bomet (0.30). Figures 4 and 5 show the uptake per household cluster and county, respectively, for each LED practice.

Interestingly, the graph shape in Figure 4 does not drastically differ between clusters, suggesting a similar uptake of LED-practices, either relatively high (e.g. crossbred cattle), or relatively low (e.g. biodigesters). There are, however, slight uptake differences for most practices where similar clusters show slightly higher or lower uptake than others, with the most affluent farmers (e.g. entrepreneurs and formally employed) most intensified. As expected, farmers not engaged in milk marketing (e.g. vulnerable farmers and non-dairy farm specialists) adopt fewest LED-practices.

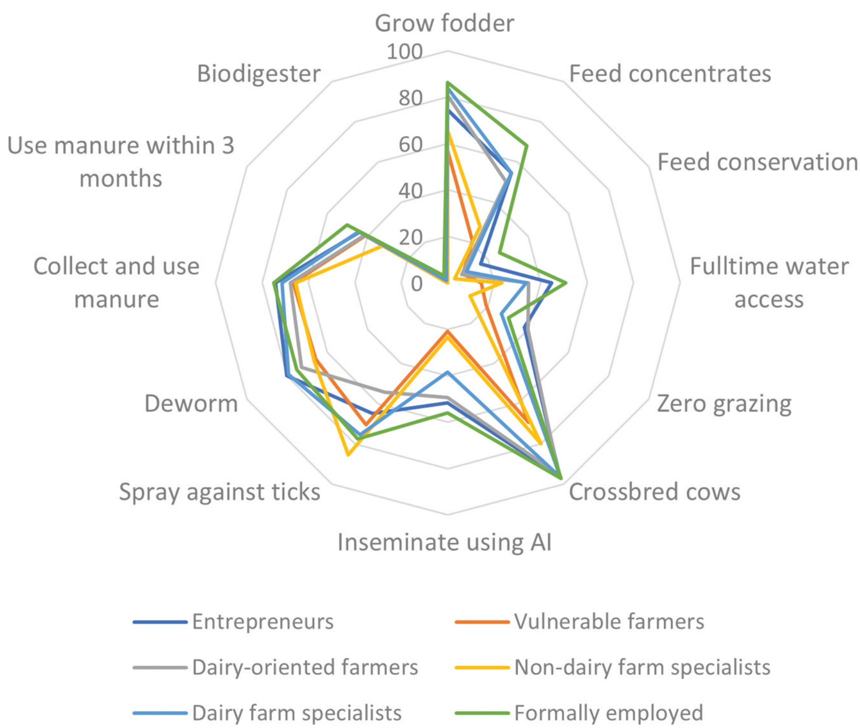

Figure 4. LED dairy practices across the household clusters. Y-axis: percentage (%) of total households.

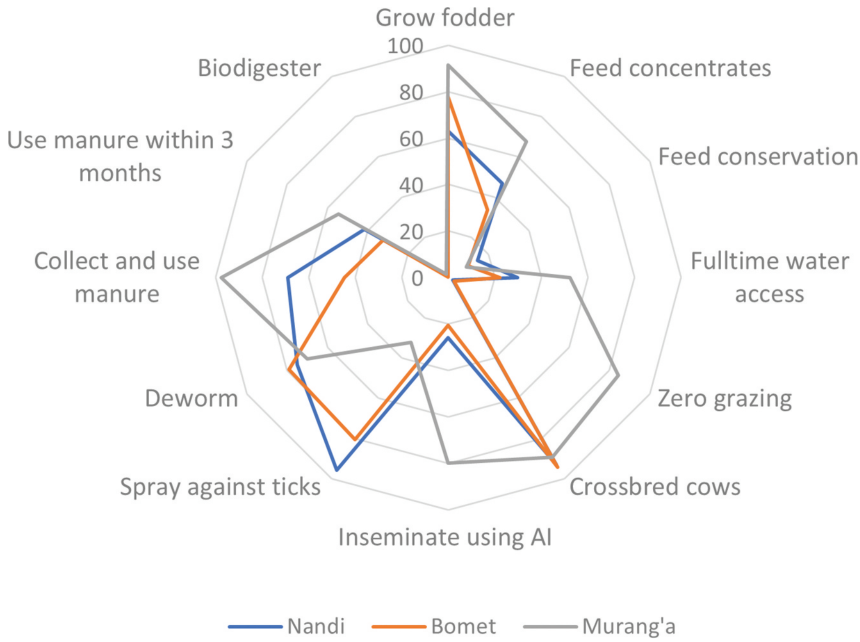

Figure 5. LED dairy practices across the counties. Y-axis: percentage (%) of total households.

In contrast, the shape of county graphs (Figure 5) shows more variation in uptake of practices, particularly between Murang'a and the other two counties. Zero grazing systems are, for example, adopted by most sampled households in Murang'a but by nearly none in Nandi and Bomet. The uptake of zero-grazing has knock-on effects on other LED-practices; for example, there is more manure collection since cattle are confined, growing fodder since cattle do not graze, and fulltime access to water. Additionally, spraying against ticks is much less frequent in Murang'a compared to Nandi and Bomet, presumably because cattle are not roaming freely, thus reducing the risk of ticks.

3.3. Multilevel uptake of LED-Practices

This section explores the LED-practices of household clusters within each county, thereby combining findings about dairy practices at household cluster level and county level for a more comprehensive understanding of dairy practices uptake. Figure 6 shows the distribution of the household clusters across the counties.

From the previous section, we might expect that household clusters with greatest LED dairy practice uptake are located in Murang'a: the county with

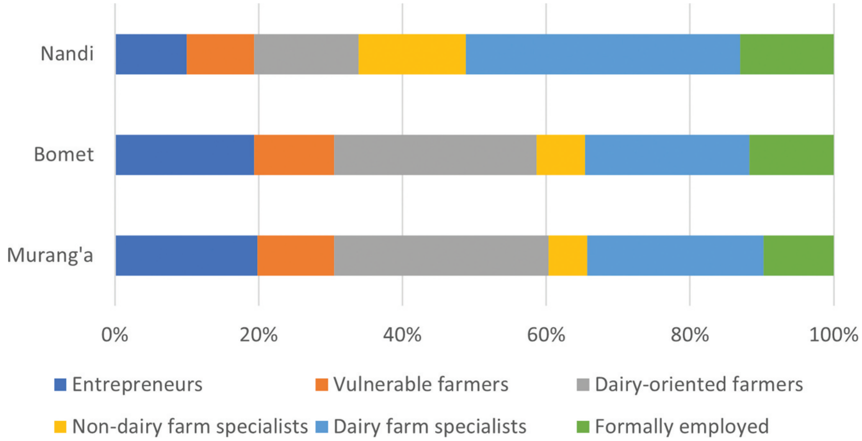

Figure 6. Distribution of household clusters across the counties.

greatest overall LED dairy uptake. Figure 6 however indicates that we cannot assume this. Namely, the six household clusters are relatively equally distributed across the counties, especially between Bomet and Murang'a. In Nandi, we see a comparatively large number of non-dairy farm specialists and dairy farm specialists, and comparatively few dairy-oriented farmers and entrepreneurs. This reveals that despite overall higher uptake of LED-practices in Murang'a, when looking at who the farmers are, there are close to equally distinct household clusters to be identified compared to areas with lower overall uptake of LED-practices.

To further reveal what can be learned about the uptake of LED-practices, we integrate variation among household clusters in the three counties. Table 5 explores what smallholders do and shows the differences in uptake of LED-practices between the clusters within the counties.

The dominance of the dark green colour in the table suggests that for most LED-practices there are highly significant differences in uptake between household clusters within counties. Red indicates that for some practices the uptake differences between the clusters is not significant within counties, suggesting more structural reasons for low uptake. Given that there are county differences for practices with red coloured cells, more structural reasons can differ per country.

The dairy-oriented farmers are most specialized in dairy (closely followed by cash crop cultivation), yet in Nandi and Bomet, households in this cluster are practicing most LED-practices below average, as opposed to Murang'a. The main differences for the dairy-oriented farmers with Murang'a are in the uptake of feeding (incl. watering) and herd management practices. In Nandi and Bomet, cattle are in grazing systems, either free grazing, tethered or rotation grazing on their own -, government -, or rented land. Guaranteeing

Table 5. LED-practices among household clusters in the counties. The colours show if there are statistically significant differences between the six clusters in the three counties. The numbers indicate the clusters that perform better than the expected value (mean). Numbers represent the clusters: 1=Entrepreneurs, 2=Vulnerable farmers, 3=Dairy-oriented farmers, 4=Non-dairy farm specialists, 5=Dairy farm specialists, and 6=Formally employed.

LED-practices	Household clusters in Nandi	Household clusters in Bomet	Household clusters in Murang'a
Grow fodder	1 5 6	3 4 5 6	3 5 6
Concentrates	1 5 6	5 6	1 3 5 6
Feed conservation	1 6	1 6	1 6
Fulltime water access	1 6	1 5 6	1 3 5 6
Zero-grazing			1 3 5 6
Crossbred cows	1 3 5 6	1 5 6	1 3 5 6
Artificial insemination	1 6	4 6	1 3 5 6
Spray against ticks		4 5 6	
Deworm	1 5 6		
Collect and use manure			
Manure use within 3 months			3 5 6
Biodigester			
Overall (CI)	1 5 6	1 5 6	1 3 5 6

Highly significant difference (<0.01)
Somewhat significant difference (<0.05)
Weakly significant difference (<0.1)
No significant difference

24-hour access to water might not be a priority since the cattle keeps moving, and this would then bring extra work for organizing constant water supply. Investing in additional feeding is only possible if you are willing and have the means to invest.

In Bomet, non-dairy farm specialists are practicing above average for more practices than the dairy-oriented farmers. It requires closer investigation to understand why this is the case. It could be that other farm activities of the non-dairy farm specialists prove so versatile that they are able to invest in dairy, in combination with volatile or difficult access to milk markets in Bomet, leaving the dairy-oriented farmers unable to (re-)invest in dairy. It could also be that certain LED-practices for dairy benefit other farm activities.

3.4. Regional conditions affecting LED uptake

This section elaborates on the geographically distinct uptake of LED-practices. Because farmers in Murang'a adopt more LED-practices, this section compares Murang'a to Nandi and Bomet. Except for biodigesters and feed conservation, households in Murang'a practiced most LED-practices and are closest to the "ideal prototype" of what smallholders with dairy cows are capable of. Three region-specific aspects for Murang'a explain this, namely (1) land size, (2) proximity to a large market, and (3) local political economy. Promoting LED within extensive and semi-intensive systems demands a different approach to LED in zero-grazing systems. Promoting zero-grazing for all is not the only pathway, especially in land abundant areas where free grazing remains viable. In Murang'a, the transition to zero-grazing was born out of necessity due to increasing land use competition and pressure. Because of declining land sizes, land fragmentation, and high land costs, zero grazing systems are the only option for many wishing to keep dairy cattle. Respondents in Murang'a only owned 2.26 acres of land, compared to 3.71 acres in Bomet and 4.97 acres in Nandi.

Murang'a is closest to the capital Nairobi, the main milk market of the country, which has attracted companies and encouraged local leaders to heavily invest in and support the dairy sector. Particularly heavy investments have been ongoing in formalizing milk markets via organizing milk suppliers in farmer cooperatives, and all farmer cooperatives in a union. A processing plant was opened to increase in-county processed milk and school milk programs were set up to guarantee a market for the milk that the union was collecting. Agricultural extension programs were intended to reaching majority of farmers in the county via the farmer cooperatives. The survey data showed that households in Murang'a sold significantly more (but not majority of the milk) to formally organized (farmer cooperatives) and large-scale commercial (processors) market outlets, compared to Nandi and Bomet where households sold significantly more directly to individual customers, and middlemen. A combination of these location-specific factors in Murang'a resulted in the dominance of zero-grazing systems and subsequently of a higher average uptake of LED-practices.

Future dairy development trajectories in Nandi and Bomet will most likely be influenced by similar land pressure largely due to the practice of subdividing land among children and other effects of population pressure (Mugizi & Matsumoto, 2020). Both county governments have similar dairy development ambitions in terms of formalizing the sector, and representatives of the counties went for "benchmarking" trips to Murang'a to learn how they have organized the establishment of the union and a union-owned processing plant. Some of the largest and growing cities (and milk markets) besides Nairobi are not far, such as Kisumu and Eldoret.

These developments are taking place in a context of government decentralization (devolution) in Kenya, which was initiated in 2010, meaning that the decisions on how government funds are distributed are taken at regional levels (counties) as opposed to a national level. This has fuelled local political leadership ambitions to align with household ambitions to get/stay in the local government. Because the dairy sectors are significant in each of the three counties, there are also political reasons for (promises of) investments and efforts to formalize the dairy sector. It is, therefore, worthwhile to investigate how LEDS could position itself in relation to this political context.

4. Discussion

Our discussion aims to identify spaces for fitting LEDS into the wide range of Kenya's dairy smallholders' realities (Figure 7). The results demonstrate significant differences in uptake between household clusters in the counties: some practices have low, moderate, or high uptake for all household clusters in the counties, indicating structural reasons. This study started from situated practices at household level and embedded these into regional contexts. We first clustered a variety of farmers into 6 types. Next, we took a multilevel approach to complement this farmer typology. This allowed us to

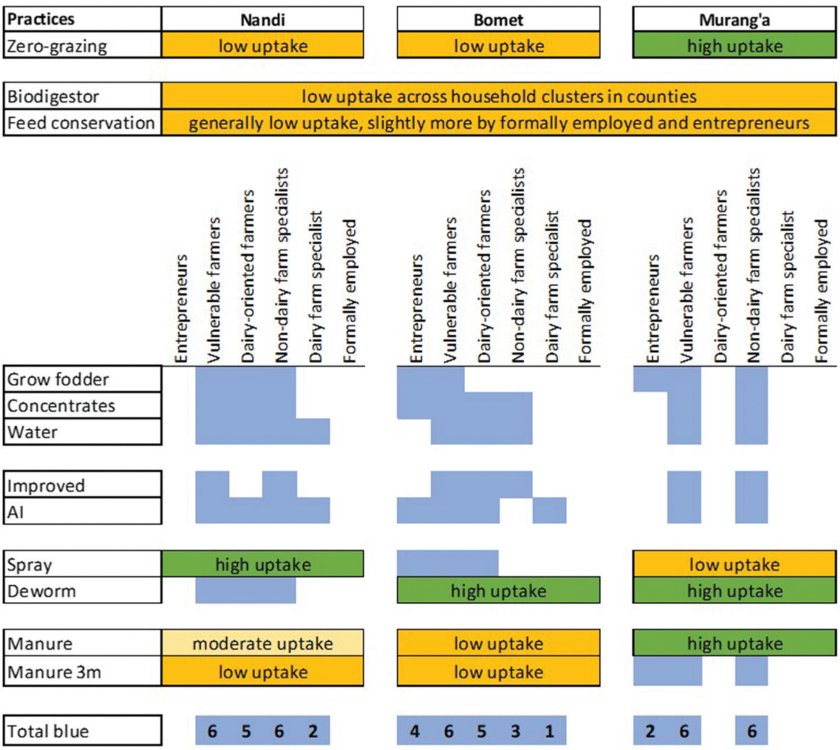

Figure 7. Visual overview of uptake of LED-practices per household cluster in the counties. Read from above to below. In blue is below average uptake, "total blue" below shows which household clusters have most below average uptake. Some practices in green, yellow and orange have no differences in uptake between household clusters in the counties and indicate structural reasons for low/moderate/high uptake.

contextualize the modelling results and recognize that farmers navigate choices available within spatially bounded and dynamic non-static settings. This sets the stage for identifying a set of region and farmer-type specific starting points that capture or create fitting spaces for LEDS and can inform diverse dairy development pathways. As a first step, we look for plausible explanations of the observed variation in uptake of LED-practices at household and regional level. Simplified, we explain the multilevel variation in the uptake of LED-practices according to both more structural and contextual conditions and household type-specific features.

First, an important insight from our study is that the uptake of LED-practices is importantly conditioned by the embedding of households in a zero-grazing system, is the case in Murang'a. Whether and how zero-grazing, as a LED-practice, takes place conditions the space for emerging configurations with other LED-practices. The same holds for manure management practices in Nandi and Bomet (see detailed elaboration on technical and socio-economic constraints to improve manure management in Nandi by Owino et al., 2020b). Manure management practices are very labour intensive in non-zero-grazing systems, which makes labour availability a focus point for LEDS. Because main reasons for the prevalence of zero-grazing systems in Murang'a are greatly found in the institutional environment related to market infrastructure and population pressure, it will likely not be productive to push zero-grazing at smallholder level. Instead, other LED-practices should be designed around whether a household employs a zero-grazing system, and more regional institutional work should address the issues of market – and land availability. LEDS will likely not be effective if interventions fixate on transforming producer practices, and therefore should include regional approaches that will support producers in having options to adjust their farming practices.

Second, our analysis points at the relevance of considering the capacities of dairy farmers to invest in practices that may include relatively high investment costs for future (not direct) benefits. We observed a low uptake of having a biodigester and practicing feed conservation across counties and household clusters, which indicates that these practices require (labour, finance) investments that are unrealistic or are currently not worth the perceived benefits. For example, for animal health practices, government programmes can provide or subsidize these, which could explain the generally high uptake of spraying and deworming, or AI. Most non-subsistence households have improved breeds as a result of government investments already since the colonial days. In some areas local breeds are however preferred because they are perceived to withstand dry periods better. Practicing AI is then also not a priority, and a significant extra cost compared to often free insemination via using a bull. In addition, some households have had unsuccessful instances of

AI which has resulted in distrust of AI. Vulnerable farmers and non-dairy farm specialists do not sell milk and seemingly do not have the means or preference to invest in dairy, yet they have subsistence and perhaps other types of motivations (e.g. cultural) for keeping cattle. LEDS can presumably become meaningful for these households with minimal investment requirements of the households, by supporting their subsistence needs, and by closer investigating additional motivations for dairy cattle keeping.

Third, the uptake of LED-practices partly results from the conditions under which farmer households make choices and navigate enabling or constraining conditions to ensure livelihoods. Priorities of households regarding their dairy activities varied from wanting to meet subsistence needs to engaging in dairy as a commercial business activity. This can be illustrated further by looking at access to fodder. For growing fodder, households need land, and growing fodder competes with growing food crops and using the land for grazing. Purchasing concentrates is generally not perceived to be necessary for the cattle's sustenance but becomes important for increasing milk production. In addition to other production costs and compared to incomes from milk sales, purchasing concentrates is not always an economically feasible investment. In addition, expert interviews and workshops in Nandi and Bomet (Yesuf et al., 2021) exposed a low preference for cultivating (more) feed, and limited preference for allocating more land to pasture, thereby retaining feed market dependability. Some smallholders in Bomet were voluntarily experimenting with collectively organizing their production assets differently, putting cattle in one plot and using the other plots to cultivate feeds. Therefore, LEDS should emphasize to find ways to connect to each household's (type) capabilities, preferences and needs (Mausch et al., 2021) both at smallholder level, but also via exploring how households with diverse capabilities, preferences and needs can complement each other at a regional level.

Our analysis suggests that LED-practices are more likely to materialize if there is a fit with both on-going and embedded practices and bottom-up endeavours that address structural conditions in, for example, feed markets. This points at the relevance of taking a broader ("landscape") approach as opposed to only considering the uptake of particular LED-practices at smallholder farm level. The gradual and unfolding process of fitting LED-practices into area-specific dynamics and diverse realities appears to be essential for working towards a sustainable and viable dairy sector, which contributes to reduced greenhouse gas emissions as well as to livelihoods of diverse smallholders. This assessment makes fitting contingent on three conditions: (1) the presence of zero-grazing systems; (2) the investment capacity of dairy farmers; and (3) the function of dairy in livelihood strategies. Figure 7 epitomizes these insights as starting points for fitting LEDS designs to dairy smallholder realities in the study sites in Kenya.

5. Conclusion

Our analysis suggests that focusing exclusively on the adoption or uptake of a single LED-practices based on decisions made by individual households ignores that LED-practices are no standalone; rather LEDS entail different practices that are combined in a configuration that works under specific conditions. Conceptually, this implies that a LED-strategy is a configuration of practices that works under specific conditions. This can be captured as an evolving process of fitting: to put LED-practices to work in specific places. For LEDS, it is essential to find ways to connecting multiple components, which can be a mix of induced and locally embedded practices, to makes these work as one. This contrasts with looking at LEDS with the lens to mould smallholder practices into ideal-type and uniform LED-practices (or a "fix"). Instead, our results suggest that it is more productive to contextualise LED-related practices, and be attentive to the emergence of starting points for fitting where different types of farming households and practices can integrate and contribute to LEDS. Therefore, we argue for a shift away from problematizing the adoption of predefined LED-practices to a diagnostic lens that detects conditions and spaces conducive for fitting LEDS with diverse smallholder priorities and capabilities embedded in specific regional histories and conditions. This paper outlined a creative diagnostic approach to intervention design in smallholder production systems, which identified starting points for LEDS design attuned to variation in smallholder dairy realities at multiple levels.

By moving from "fix" to "fitting", we open conceptual space to redirect the research gaze from evaluating the adoption of "fixes" to exploring and tracing unfolding processes of "fitting" (Glover et al., 2016; Obeng Adomaa et al., 2022; Glover, 2022). Our study aligns with similar conceptual frames. The notion of "solutions space" used by Ollenburger et al. (2019) describes how top-down approaches can be grounded and aligned with local realities. The idea of "goodness-of-fit" used by Sumberg (2005) underscore the importance of understanding a technology in its context as a prerequisite for potential adoption. The concept of institutional fit (Schouten et al., 2016; Ansari et al. 2010) makes it possible to assess the potential for alignment between technical, cultural, and political characteristics of new practices and locally embedded ways to solve and manage problems (Vellema et al., 2020, p. 718). The socio-ecological niche concept coined by Descheemaeker et al. (2019) incorporates agro-ecological, socio-cultural, economic, and institutional dimensions at various levels to identify which agricultural improvement options fit best. A possible next step is to advance and use an explicit institutional diagnostics approach to qualify the regional conditions for fitting (Schouten et al., 2018; Rodrik, 2010). Fitting to local realities also means incorporating LEDS to vertically align local and national strategies (Clapp et al., 2010) and horizontally align territorial governance modalities (Lamine,

2015) in the areas of climate change and development. Future research can explore the area-specific institutional conditions for creating or reinforcing horizontal and vertical alignments of LEDS with the variation of and dynamics in the Kenyan dairy sector.

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Ethics approval

This research was approved by the Institutional Research Ethics Committee (IREC) of the International Livestock Research Institute (ILRI) in 2017. All participants of the survey and key informant interviews provided written consent; all other participants of the research provided oral consent.

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