Scotland's Rural College

Incentives to the uptake of GHG emission reducing technologies in the global dairy sector: the Kenya case study.

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Executive Summary

- The dairy sector in Kenya is one of the largest in Sub-Saharan Africa and the Kenyan Government has stated ambitions for its transition to higher output and towards lower emissions in line with international commitments. Addressing the yield gap and meeting environmental targets is only achievable through the adoption of climate-smart practices.

- Interventions are being made to join up extension and research services and encourage adoption of key practices that raise productivity and reduce the greenhouse gas burden from current production.

- Structural and institutional issues pervade the sector due, in part, to a long history of liberalisation leading to the majority of dairy milk being sold through informal supply chains from small-holder dairy enterprises. Moreover, Kenya has a range of systems operating at various levels of intensity. The wide range in yields recorded reflects economic, climatic, biophysical and social constraint current practice and adoption.

- We outline the main feasible climate smart practices and approaches that could be adopted across this sector, the major barriers to their adoption, and potential interventions to encourage future adoption to meet Kenya's vision for its dairy sector. These are outlined in the following tables.

- Overall, there is significant potential for improving yields and reducing emissions intensity across a range of practices that are considered cost-effective. Larger scale interventions are also considered which may bring about transitional change, these tend to focus on co-ordination of initiatives to ensure clear messaging and equity of access in growth. This encompasses initiatives both from the private and public sectors.

Table A1. Improving feed quantity and quality

Practice	Description	Current Uptake	Incentives	Potential Instruments	Uptake Potential: Intensive (Zero-Grazed)	Semi Intensive	Extensive	Time Frame
Sustainable forage intensification and storage practices	Adoption of improved forage species and better management practices for increased yields	Hay and silage collection ranges across Kenya's regions and by type of dairy system. Approximately 95% of dairy farmers in the central highlands stored crop residues for their livestock, but the storage methods may not be appropriate to maintain the quality. Hay making is a common practice across East African farms, but the quality is low. Silage making was found on between 0.5% to 5% of farms in semi-arid areas but is becoming increasingly common in urban and peri-urban, as well as large scale commercial farms.	Production varies based on farm size and dairy intensity. There is a limited access to appropriate technology to scale up the practice and inadequate knowledge on good hay making practices. High costs of production inputs such as seed and fertilizers limit adoption. More educated and male farmers have been found to adopt fertilisers. Few markets exist for trade in hay and silage.	There are efforts by the Kenyan government and various agencies to promote hay and silage production and storage through training and provision of information. Co-operatives and private sector initiatives can provide access to credit or joint purchasing of equipment as well as information provision.	High	High	Low	5-10 yrs
Optimize nutrient intake	Most dairy farmers use crop residues to supplement feeding but this should be complemented by appropriate feeding regimes at recommended doses across the production cycle of the cow. Feed supplements are mixtures of nutrients that can be bought in or mixed at home.	Most farmers *(around 80%)* feed cows during lactation but this is usually suboptimal. Around 20% of farmers are estimated to buy concentrates.	High cost of buying supplements limits adoption. Knowledge and trust on the mixtures being offered and distance to urban centres limit options.	The Kenyan government and various organizations have been promoting the use of dairy concentrates among dairy farmers through training and extension services, provision of high-quality and affordable dairy meal, and access to credit for the purchase of feeds. Farmer co-operatives are key to overcoming issues in access to concentrates, supported by information on usage.	High	High	High	1-5 yrs

Table A1 (cont). Improved Grazing

Practice	Description	Current Uptake	Incentives	Potential Instruments	Uptake Potential			
					Intensive (Zero-Grazed)	**Semi Intensive**	**Extensive**	**Time Frame**
Establish nutrient-dense pasture	Kenyan dairy farmers can sow a range of grasses, fodder trees and legumes with high yield characteristics and, in some cases, high drought tolerance, that provide nutrients for grazing cattle. More intensive 'cut and carry' systems for more stall based feeding benefit from high yielding grasses.	There is widespread establishment of high yield fodder grass, such as Napier grass, across a range of systems, but less so for other grasses such as Brachiaria. Their high yield is attractive for cut and carry systems, since they have drought tolerant properties that are also attractive to semi-arid systems. Fewer farmers are integrating legumes within their fodder mix, even though this supplements protein intake.	There is less adoption in extensive systems. Climatic conditions such as higher rainfall leads to high yield and make them more attractive for adoption. Levels of education as well as perceptions towards productivity and fodder availability have been found to drive adoption. Greater market access and proximity to urban centres provide an incentive to raise productivity and can lead to adoption. Extension services may not adequately convey the importance of fodder establishment and nutrient mixtures.	Less common grasses can be promoted given their drought tolerance capabilities. Continued efforts are needed to promote the sustainable use of leguminous shrubs such as Calliandra in dairy farming and fodder trees such as Leucaena to provide farmers with the resources and education they need to adopt as a low-cost feed option.	High	High	High	5-10yrs

Table A3. Manure Management

Practice	Description	Current Uptake	Incentives	Potential Instruments	Uptake Potential: Intensive (Zero-Grazed)	Semi Intensive	Extensive	Time Frame
Integrated manure mangmt.	The production of manure in dairy farms provides a source of grass and crop nutrients but also a potential for income protection, as a replacement for bought in fertiliser, but also sale of nutrients to nearby farmers. Integrated manure management involves adequate systems for capturing nutrients, including urine, as well as proper storage and treatment to reduce loss of nutrients.	A diversity of practices around manure management have been recorded, with smaller farms collecting less faeces (14%) than medium or large farms (40-45% respectively). However, it is common that collection of faeces is inadequate, leading to loss of nutrients. Novel practices have been observed such as more frequent collection of manure, decreasing the period of storage, covering the manure with a plastic sheet and altering the storage unit in order to reduce nutrient losses through leaching and evaporation	Zero grazed and semi-zero grazed dairying which involve stall feeding should allow efficient collection of manure and this practice is common in these systems, though investment in waterproof floors require more investment and therefore a stronger commercial orientation. This could be explained by wealthier farmers often having more knowledge on agricultural practices and implementing farm practices that are aimed at long-term growth. Rather than drying, compositing of manure requires more labour and is therefore suited to farmers with a higher labour resources.	There is currently a lack of any promotion or support for integrated manure management as a result of incoherent or misaligned responsibilities within the institutions around dairy farming. More coherent policies, linking regulation to manure management, supported by directed education and promotion would lead to an increase in these practices.	High	High	Low	5-10yrs

Table A3. Manure Management (cont).

Practice	Description	Current Uptake	Incentives	Potential Instruments	Uptake Potential			
					Intensive (Zero-Grazed)	Semi Intensive	Extensive	Time Frame
Renewables on farm or milk production group	Implementation measures to switch energy use from diesel and fossil fuels on the farm to more renewable sources. This includes the use of biogas using, for example combining an anaerobic digestor and a 'balloon' membrane. Solar panels are also being installed for bulking groups as a means to ensure consistency of supply	Biogas is not a new technology but the reduction in cost has led to higher uptake. In Kiambu a highly productive agricultural area, an estimate of around 85% of homes have installed biogas. In 2018 there was an estimate that around 50 solar cooling plants exist across 10 counties in more intensive milk growing regions.	The shift to renewables is driven in part by the lack of reliable electricity and the high cost of fuel for diesel generators. Main barriers are the initial economic cost of investment, so these tend to be cost-effective in more intensive systems with high throughput. Group based funding is emerging both to support on-farm adoption, but also at milk buying group or co-operative level.	The Kenyan Government has established a national biogas programme with the aim of facilitating transition to biogas across the country. This may engage remote rural regions. A biogas marketing hub has been established for the dairy sector which promotes its use.	High	High	Low	5-10yrs

Table A4. Improved herd structure

Practice	Description	Current Uptake	Incentives	Potential Instruments	Uptake Potential: Intensive (Zero-Grazed)	Uptake Potential: Semi Intensive	Uptake Potential: Extensive	Time Frame
Improving genetic stock	Introducing high yield dairy animals will improve the genetic stock on the farm and lead to higher economic returns. The predominant intervention, promoted through Government and donor support, is artificial insemination (AI). AI has improved in the Kenyan dairy sector over the last two decades through a range of technological and institutional developments, but traditional breeding approaches tend to dominate	A range of uptake estimates have been made dependant on various criteria. These range from 44% for smallholder farms, though this falls to 16% in peri-urban districts. An estimate of 38% uptake for high potential areas such as Nyamira County. An overall assessment is at 18% of total dairy cattle breeding with a potential to grow to 60%. Most uptake is around AI with smaller numbers choosing sexed semen, but this potentially offers significant growth if coverage improves.	AI is attractive to more intensive systems and is linked to past performance of specific breeding methods and perceived success of the approach, as well as other farmers' experiences. Mostly conducted through private companies and co-operatives who have power and credit to support larger scale adoption. Requires infrastructure to optimise delivery of AI to farm and is therefore lower in remote rural areas. Inadequate education both in farmers and support services limit AI's effective use and awareness creation on the benefits of AI. Insufficient government support for the practice in some areas may be hindering its adoption.	Improving access to AI and support services through Government advisory services. Increasing education and awareness creation on the benefits of AI but supporting crossbreeding measures to raise productivity; opportunities for farmer-to-farmer initiatives to promote its use. Investment in infrastructure is needed to raise potential adoption where adoption rates are low.	High	Med	Low	10-20 yrs

Table A5. Animal Pest and Disease Management

Practice	Description	Current Uptake	Incentives	Potential Instruments	Uptake Potential			
					Intensive (Zero-Grazed)	**Semi Intensive**	**Extensive**	**Time Frame**
Animal Health Planning	The main disease of dairy cows in Kenya is tick-borne East Coast Fever, which is managed by dipping or spraying animals once or twice a week, but a vaccine can also be delivered which has high levels of efficacy. Other priority diseases include Foot and Mouth, which can be treated by a vaccine,	Vaccination coverage for East Coast fever (ECF) in Kenya was estimated to be around 30-40%, with significant regional variations. There is widespread use of dipping of cows but there is variable use of vaccination coverage for East Coast Fever. In many cases, dairy farmers in Kenya rely on traditional or home remedies to treat sick animals instead of seeking professional veterinary care. This can result in delayed treatment, which can lead to more severe illnesses and increased economic losses for the farmer.	Main barriers are lack of knowledge and limited access to veterinary services. Lack of regulation affects costs and trust in the efficacy of the treatments. Inadequate knowledge of the importance of vaccination, and high vaccine costs. The vaccine requires a cold chain infrastructure which limits rural area access.	Kenyan government and various non-governmental organizations aim to increase vaccination rates among dairy farmers. These interventions include the provision of subsidized vaccines, awareness campaigns, and capacity building for veterinary service providers and farmers. However, challenges such as limited access to vaccines in remote areas, inadequate funding, and poor infrastructure limit coverage. Despite these efforts, there is still a need for increased awareness and education among dairy farmers on the importance of timely treatment and the use of appropriate veterinary care. Additionally, more needs to be done to improve the accessibility and affordability of veterinary services and treatments for dairy farmers, especially those in remote and marginalized areas.	High	High	Med	10-20yrs

Table A5. Animal Pest and Disease Management

Practice	Description	Current Uptake	Incentives	Potential Instruments	Uptake Potential: Intensive (Zero-Grazed)	Semi Intensive	Extensive	Time Frame
Animal Health Planning	Mastitis can be prevented through proper hygiene and treatment.	The adoption of early detection and treatment practices for mastitis can vary among Kenyan dairy farmers, with some farmers being more diligent than others.	Factors that may influence the adoption of good mastitis management practices include access to education and training on proper mastitis management, access to veterinary services and drugs, and the availability of resources for implementing good management practices, as well as access to clean water and cleaning materials, and the availability of resources for maintaining clean and dry bedding.	Kenyan government and various non-governmental organizations aim to increase vaccination rates among dairy farmers. These interventions include the provision of subsidized vaccines, awareness campaigns, and capacity building for veterinary service providers and farmers. However, challenges such as limited access to vaccines in remote areas, inadequate funding, and poor infrastructure limit coverage. Despite these efforts, there is still a need for increased awareness and education among dairy farmers on the importance of timely treatment and the use of appropriate veterinary care. Additionally, more needs to be done to improve the accessibility and affordability of veterinary services and treatments for dairy farmers, especially those in remote and marginalized areas.	High	High	Med	5-10 yrs

Contents

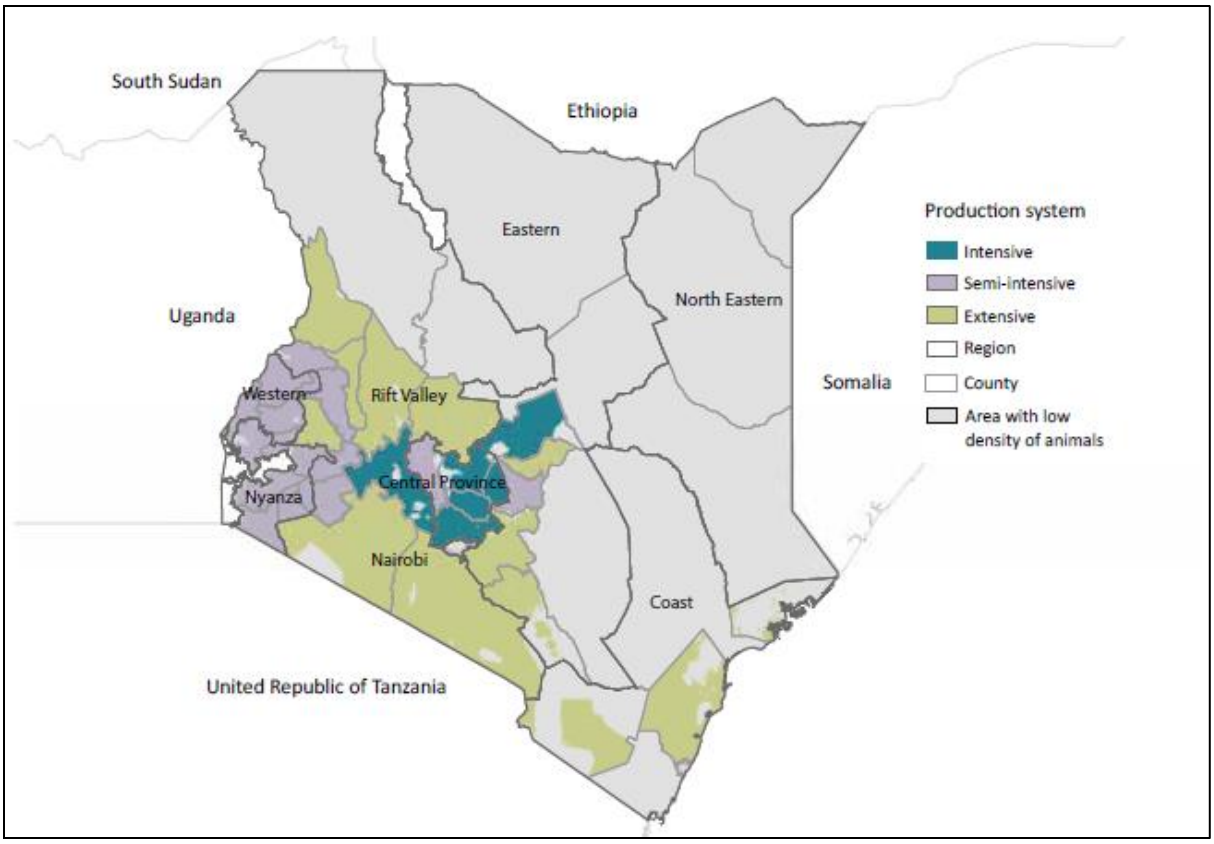
The Kenyan Dairy Sector

Kenya has one of the largest dairy herds in Africa and the dairy sector is the largest agricultural sub-sector in the country (FAO and NZAGRC, 2017). The sector accounts for about 4% of the country's GDP. Additionally, dairy farming provides livelihoods for more than 1.8 million small-scale farmers who own an average of two to three cows. Kenya produces around five billion litres of milk annually, with around five million dairy cows (Mbae et al., 2020). Milk production is projected to increase to 12 billion litres by 2030 (Kibogy et al., 2019).

Despite the sector's importance, it faces various challenges that hinder its growth and development. One significant challenge is the low productivity of cows due to inadequate feeding, poor animal health, and limited access to quality inputs such as animal feeds, vaccines, and breeding services. Milk is primarily produced by smallholders. Around 80% of producers have between 1-3 cows, with the remaining 20% from larger commercial operations. These consequently represent different production possibilities and technology adoption options.

The sector can be divided into three systems: intensive production (zero-grazed, stall fed), semi-intensive (partial zero-grazed), and extensive (open grazed). Zero-grazing is common in central Kenya because average farm size is small and more milk per hectare can be produced than in grazing or semi-zero grazing systems (Bebe et al., 2003, quoted in Wilkes et al., 2020). Semi-intensive farms produce the largest share of milk, with the remainder from more extensive dairy systems and intensive, zero-grazed systems. Wilkes et al. (2020), who conducted a survey of dairy production in Central Kenya, found an average annual yield per cow of 2,450 kg FCPM (± 1,422) across all systems. Zero grazing produced the highest yield (2,657 kg FCPM), followed by extensive grazing (2,110 kg FCPM) and semi-intensive (2,085 kg FCPM), albeit with large variances in yield for each system.

Figure 1. Dairy Systems in Kenya

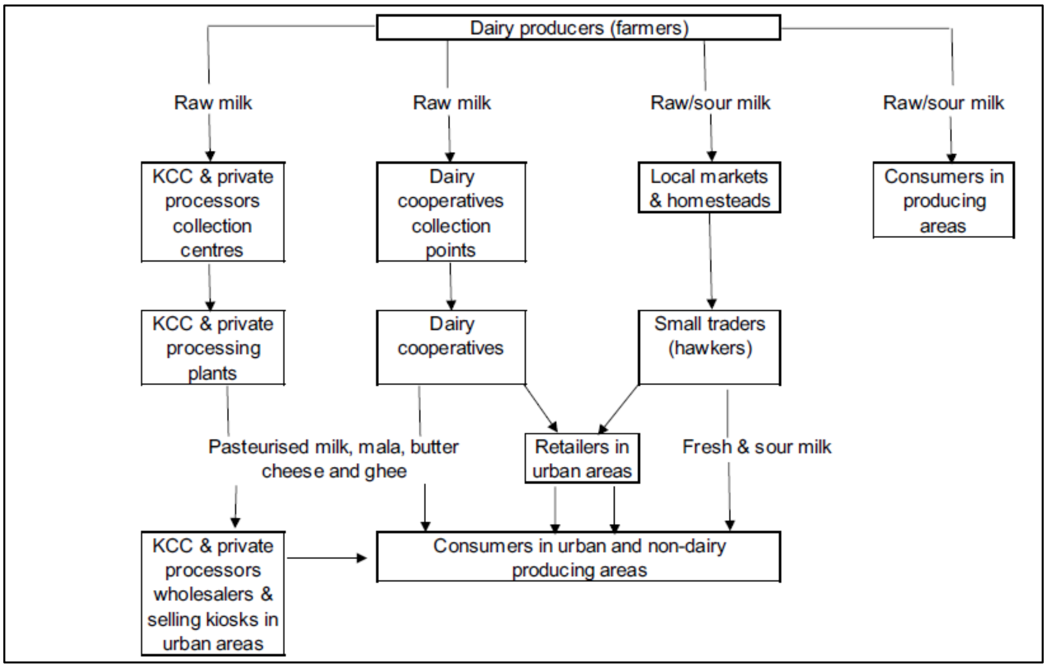


Source: GLEAM, 2017 (quoted in FAO and NZAGGRC, 2017)

Kenya has the highest milk consumption per capita in Africa. Inadequate infrastructure around milk collection centres, chilling facilities, and processing plants also limits the sector's development. Currently, there are around 30 milk processors and 67 mini dairies operating within the country (Food Business Africa, 2020). Moreover, the sector faces competition from cheap imports of powdered milk and dairy products, which undercut local prices and discourage local production.

The majority of milk in Kenya is sold through informal actors (Rademaker et al., 2016), leading to limited value added for these producers. In 2004, informal markets were deregulated and small-scale producers were allowed to sell milk through informal channels (Zavala Nacul & Revoredo-Giha, (2022). Since this time, a number of initiatives have occurred to promote formalised milk marketing in Kenya, and 'semi-formal' markets have developed, where some milk may be pasturised through small scale units or sold to local retailers under agreement (Blackmore et al., 2022). Figure 2 shows a schema of how dairy producers currently sell their milk.

Figure 2. Overview of current milk supply chains in Kenya



Source: Zavala Nacul and Revoredo-Giha (2022).

Kenyan Extension Infrastructure

Kenya has had a public agricultural extension service since the 1990s. However, the efficacy and coverage of the service had been criticised and recently private partnerships have emerged. The national agricultural research service (KALRO) established a dairy institute in 2013 (KALRO, 2023)[1]. The dairy institute's goal is to develop appropriate, sustainable innovations and cost-effective technologies that will enhance productivity. Moreover, the funding and support network for climate-smart approaches is complimented by industry along the supply chain, and public-private partnerships are emerging in areas around feed-and fodder delivery and value chain development (Lammers and Winter, 2022). These are complimented by regional dairy co-operatives, as well as cooling and collection services. To date the Kenya Dairy Board has around 335 regional farmer-led organisations focused on support for milk production[2].

Policy towards dairying

Productivity growth

The government has initiated programs aimed at improving productivity. The Dairy Master Plan (2010) set a vision for reducing yield gaps and to guide the development of the sector to 2030. The government has established the National Dairy Development Programme (2013) to enhance milk production, processing, and marketing and established the Kenya Dairy Board, whose mandate is to regulate, develop, and promote the dairy industry.

Recent policy statements include the Agricultural Sector Transformation and Growth Strategy (2019-2029) and there has been an effort to increase the genetic potential of local and imported breeds through a National Artificial Insemination (AI) Programme. This aims to support access to improved breeding material. The Kenya Animal Genetic Resource Center

[1] See: https://www.kalro.org/divisions/livestock/livestock-institutes/dairy-research-institutes/#:~:text=About%20the%20Institute,focusing%20on%20dairy%20related%20research.

[2] See: https://www.kdb.go.ke/milk-producers-groups/

(KAGRC) also collects and stores genetic material for breeding purposes. However, access to these services varies by region.

A number of stakeholders in the sector have also initiated interventions aimed at improving productivity and value addition. For instance, various NGOs and private sector players have established milk collection centres, which provide farmers with a market for their milk and access to extension services (Odhong et al., 2018).

Greenhouse gas emissions

The Kenyan Government has a Nationally Determined Contribution (NDC) for reducing GHG emissions by 30% by 2030 compared to business-as-usual. However, GRA/CCAFS point out that emissions have exceeded the projected baseline in every year since 2007 leading to the sector potentially contributing 33 Mt CO_2e in 2030, more than double estimated emissions in 2010 (Wilkes et al., 2020).

Kenya's Dairy NAMA (Nationally Appropriate Mitigation Action) was developed in 2017 by the State Department for Livestock (SDL). The Dairy NAMA aims to reduce GHG emissions from the dairy sector in Kenya while increasing productivity and promoting sustainable production practices. The programme targets smallholder dairy farmers who are responsible for most of the milk production in the country.

Table 1. Mitigation potentials in Kenya's Dairy Sub-Sector

Intervention	Mitigation potential (million tCO_2e)
Increased on-farm dairy productivity (152,000 households) *	4.14
Biogas promotion (20,000 units) *	0.98
Energy-saving from the dairy processing plant retrofit (151 plants) *	2.96
Reduction in milk loss and waste in cooling centres (all national milk)^	1.70

*SDL; ^Gromko and Abdurasulova (2019) Source: Mbae et al. (2020)

The key interventions under the Dairy NAMA include improving animal feeding and nutrition, promoting the use of renewable energy in dairy production, and enhancing waste management in dairy farms. The programme also aims to increase the adoption of sustainable land use practices and improve the efficiency of milk collection, transportation, and processing. Moreover, Wilkes *et al.* (2020) identified the quality and quantity of concentrate feed per farm, herd size and herd structure all had positive impacts on improving the dairy sector's carbon footprint. This infers GHG savings can be made from productivity enhancing activities, as well as management and post-farm gate activities.

On-farm adaptation measures

In order to address yield gaps and meet GHG requirements in Kenya, a range of adaptation measures have been identified by numerous authors (Maindi et al., 2020, Caulfield et al., 2023). These climate-smart measures principally assume that an underlying productivity gain will support mitigations in GHGs. Moreover, to secure adoption on farm or across the supply chain these must be seen as cost-effective solutions and therefore attractive for the smallholder to incorporate within their enterprises.

Figure 2 shows the summary technology/practices from these studies and the potential options for smallholders in more detail with subcategories. A substantial area of improvement is feed quantity and quality. This covers both home grown cultivation and storage but also grazing management and related to that, manure management and storage.

An area that improves productivity per animal - animal health - includes regular vaccinations, udder hygiene, and overall management. Herd structure and improvement also includes the major intervention of artificial insemination and the roll out of improved breeds to which the government is directing efforts. Finally whole-farm management practices cover some of the activities indicated in Table 2, in terms of adoption of approaches which improve productivity.

Figure 3. Typology of mitigation on-farm and the main subcategories of practice outlined in the report

Background on barriers and incentives to practice adoption in the dairy sector

A significant literature exists on the uptake of technologies and practices, as well as the main barriers to their adoption. Ogisi and Begho (2023) summarise these for climate-smart adoption in sub-Saharan Africa and we modify this framework for this document. Key factors around adoption can be summarised as:

Farm and economic factors: Farm household size, income levels and asset base; size of farm; financial wellbeing; market orientation; transaction costs in setting contracts and gathering information (Birch, 2018).

Personal and social-psychological factors: Composition of family structure and its influence on innovative behaviour; access of household to paid labour; access to skilled labour; attitudes to risk and motivations for growth and innovation; gender; education levels.

Environment, physical and ecological factors: Perception of climate change and impact of weather variance, in particular increased length of drought; biophysical constraints; access to decision-support tools and climatic information.

Institutional conditions: Relationships between farmers and local, national and transnational institutions; security of land tenure; gender equality measures (FAO, 2023); availability of social and formal networks, e.g. co-ops; provision and support for training; access to market information; role of the farmer within the overall supply chain and the power imbalance between farmers and processors; challenges with contract negotiation as well as infrastructure gaps around electricity and roads; widening access to information technologies.

Key practices and constraints to optimal adoption

The adoption of climate smart practices assumes some level of intensification of activities through increased uptake and this section provides an overview of the above characteristics and links them to specific barriers found for each technology group.

Sustainable forage and storage practices

Practice: The collection of silage and hay allows farmers a ready source of feed during the dry seasons. A key intervention has been on improving the quality of feed and storage by adoption of more productive species to maintain nutrient levels. Sustainable forage intensification, based on improved forage species and better management practices for increased yields, is needed to enhance feed availability (Njarui et al., 2022).

Current Adoption: Whilst forages may be abundant in rainy seasons the collection of these varies across Kenya's regions and by type of farming system. Hay making is a common practice across East African farms but the quality is low (Creemers & Aranguiz, 2019). Various surveys throughout the last two decades have found that adoption of silage making ranges from between 0.5% (Lewa & Muinga, 2013; Muinga et al., 2015) to 5% in semi-arid areas (Njarui et al., 20121). However, Balehegn et al. (2020) noted that silage making is becoming increasingly common in urban and peri-urban as well as large scale commercial farms (Aranguiz & Creemers, 2019a). The central highlands have the most intensive dairy activity, and a large amount is zero grazed. Here high adoption rates have been noted and involve the use of plastic wraps and mixtures of additional saved silage materials (Tufail et al., 2020). According to Njarui et al (2012) approximately 95% of dairy farmers they surveyed in the central highlands stored crop residues for their livestock, but the storage methods were generally inappropriate to maintain the quality.

Farm and Economic barriers: The principal barriers to collection and storage of forages tend to be lack of access to capital for collection and limited knowledge for storage. More intensive dairy systems are adopting silage making techniques, whereas for extensive semi-arid systems the adoption is low, suggesting that a higher level of productivity is needed to generate the pay-off for investment. A more commercially orientated smallholder farm will also use bought in fertiliser, which itself has been found to improve fodder quantity and quality. Producing hay commercially is limited by costs of equipment, but large landowners can make this profitable[3]. Distance to market has also been found to limit access to quality fodder (Balehegn et al., 2022).

Personal and Social-psychological barriers: The position of women in the farm household tends to change as dairy farms intensify (Gallani, 2018), nevertheless a study of two Kenyan regions finds adoption of fertiliser for fodder intensification was conducted by a higher proportion of male head of households (Njarui et al., 2012). Najuri (2022) finds a significant proportion of those farmers with more education were likely to adopt fertiliser application of forage.

Institutional Factors: Few markets exist for commercial hay enterprises given the expense of equipment, and some intervention is needed to support the making and distribution of hay (KMAP, 2023) ([4]. Trade in inputs is limited by high transaction costs between farmers and input suppliers (Gollin and Rogerson 2014). Because milk genetic resources can be openly shared between farmers, there is little incentive for the private sector to engage in development.

Maximise nutrient intake

Practice: Supplements are mixtures of nutrients that can be bought in or mixed at home (Kalro, 2018). The adoption of high protein content supplements supports improved milk yields. Most dairy farmers use crop residues to supplement feed but, to maximise nutrient intake, feed supplements should be complemented by appropriate feeding regimes at recommended doses.

Current Adoption: A survey of Kenyan farmers in 2001 found less than 20% of farmers use bought in or home-made concentrates (Staal et al., 2001) and this declines as costs of these supplements rises. Njarui et al. (2011) determined that between 88-92% of farmers provided supplements of dairy meal concentrates to lactating cows, but these were provided at lower than recommended levels of application. A similar level of uptake was found by Alaru et al. (2022) for Kiambu County, Kenya.

Farm and Economic barriers: The purchase of concentrates is a significant proportion of most smallholder's input costs. This requires judgement of the optimal levels required as well as the most appropriate mix to make them cost-effective. Given the high proportion of concentrates to overall budgets, intensive dairying systems are more likely to adopt concentrate feeding, whereas lower levels of adoption are found in semi-arid extensive systems.

Personal and Socio-psychological barriers: The quality of concentrates available as well as trust in the mixture itself have been found to be key motivators for adoption/non-adoption (Muriuki et al., 2003). To judge the benefit of the mixture, farmers need to understand the optimal level of application as well as the nutrient mix needed. Accordingly, there are clear knowledge gaps given that use occurs at lower than recommended levels and only during lactation.

Institutional barriers: Ouma et al (2007) identified increased market access, e.g., distance to urban centres, as a key predictor of adoption of concentrate feeding. This agrees with previous work by Staal et al. (1998) who found distance to major towns as significant. These authors found less than 10% adoption in remote rural regions which rises to 70% in areas near major towns (Staal et al. 1998). Alaru et al (2022) identified a high awareness of supplements from a sample of farmers in the Central province of Kenya.

[3] See: https://www.kilimogram.com/hay-farming-in-kenya/

[4] See: https://beamexchange.org/practice/snapshots/kmap-dairy-farmers/

This was mostly driven by farmer co-operatives. However, they also found low levels of adoption and application, which led them to argue for more engagement from these organisations to convert awareness into adoption. Concentrates are mainly driven by private sector interests, and this leads to a variety of claims around the efficacy of mixtures which creates dissonance in understanding around optimal feeding strategies.

Establish nutrient-dense pasture

Practice: The management of pasture is a key intervention in raising productivity in semi-intensive and extensive systems. Kenyan dairy farmers can sow a range of grasses, fodder trees and legumes with high yield characteristics and, in some cases, high drought tolerance, that provide nutrients for grazing cattle. The use of fodder trees such as Leucaena has been shown to be positive for milk yield and emissions intensity (Franzel et al., 2014). Whereas semi-intensive and extensive systems benefit mainly from quality improvements, zero grazing systems, i.e., so-called intensive 'cut and carry' systems, benefit increased forage quantity via high yielding grasses. Further benefits of adopting deep rooting grasses include preventing soil erosion and minimising pest damage.

Current Adoption: Staal et al. (2002) found, through a number of large-scale surveys over the period 1996-2000, half of all farmers sampled were growing Napier grass. To a much lesser extent farmers were growing fodder legumes (Mwangi et al., 2005). Intensive Napier grass production is being taken up in more commercially oriented farming areas. Njarui et al. (2021) found a range of uptake rates for 'new' grasses, with Brachiaria grass among the most common forages, whereas improved Napier grass and Desmodium were less common.

Farm and Economic barriers: Ouma et al. (2007) predicted increased uptake of Napier grass in intensive systems, or systems that are intensifying with market orientated production. These authors also predicted uptake of the legume Desmodium and Calliandra to be a consequence of both natural conditions as well as socio-economic characteristics, including high human population and cattle densities. Staal et al. (2002) showed the likelihood of adopting *P. purpureum* increased as the number of years of farming experience of the household head increased. Moreover, the higher yields of these grasses make them attractive where land is limited, and consequently in more extensive systems adoption tends to be lower.

Personal and Socio-psychological barriers: A range of personal perspectives have been identified as influencing adoption of productive grasses and legumes. Maina et al. (2021) ran a number of focus groups with farmers in Western Kenya and found that perceptions of the subsequent productivity of milk and fodder availability influenced adoption of Brachiaria grasses. Mouni et al. (2019) examined farmer perceptions of legumes and found for Kenya that most farmers had some knowledge of the legumes but little knowledge of their characteristics. They argued that as fodder legumes provide only a longer term benefit these are recognised above other fodder species.

Environment, physical and ecological barriers: The adoption of grasses and legumes are dependent on agro-climatic potential which affects the yield of grasses grown. Staal et al. (2002) found that more adoption is likely in areas of increased rainfall which leads to higher yields.

Institutional barriers: Farmers with greater market access, represented by shorter distances to urban centres, and farmers who are able to sell more milk are more likely to grow Napier grass (Staal et al., 2002). Market access itself is a key factor in growing grain legumes but their influence on growing fodder legumes is less clear (Mouni et al., 2019). Overall, most studies argue that extension services and interventions tend to ignore the underpinning role of pasture management, and this could be improved to increase awareness. The public sector has a strong role in promoting forages and feed mixtures and working with seed suppliers to ensure wide-spread adoption.

Integrated manure management

Practice: The production of manure in dairy farms provides a source of nutrients for grasses and crops but also has the potential for income protection as a replacement for bought in fertiliser as well as sale of nutrients to nearby farmers. Integrated manure management involves adequate systems of capturing nutrients, including urine, as well as proper storage and treatment to reduce loss of nutrients. Composting of manure is common in most parts of Africa, however this tends to refer to leaving manure into heaps, whereas 'true' composting is less common[5] (Edwards and Araya, 2011).

Current Adoption: A survey of 60 households within the Central Highlands of Kenya found a diversity of practices around manure management, with smaller farms reporting they collected less faeces (14%) than medium or large farms (40 and 45% respectively) (Lekasi et al., 2001). A common finding is the inadequate collection of faeces and the loss of nutrients. Casu (2018) found a range of practices that led to large losses in nutrients and that current practices do not leave the farm with enough nutrients to cover the farm needs. Novel practices cited in the foregoing study include more frequent collection of manure, decreasing the period of storage, covering the manure with a plastic sheet, and altering the storage unit to reduce nutrient losses through leaching and evaporation.

Economic and Farm barriers: Zero grazed and semi-zero grazed dairying, which involve stall feeding, allow efficient collection of manure and this practice is common in these systems, though loss of nutrients occur throughout the activity chain of collection, storage, and field application. As mentioned above under "current adoption", small farms reported they collected less faeces than medium or large farms (Lekasi et al., 1998). This could be explained by wealthier farmers often having more knowledge on agricultural practices (Kebebe et al., 2015) and implementing farm practices that are aimed at long-term effects. Moreover, wealthier farmers may be able to waterproof the floors of stalls to prevent run-off of nutrients. Rather than drying, compositing of manure requires more labour. In this regard, Owino et al (2020) identified access to labour as the main concern from a survey of smallholder farmers in Nandi County.

Personal and Social-psychological barriers: Lekasi et al. (2003) argued that small but intensive farmers perceived they did not have enough nutrients to cover the farm needs, though the researchers found significant amounts were available to manage the farm's requirements (Lekaski et al., 2001). Hence this perception may lead to an underapplication or nutrients or more buying in of fertilisers to cover perceived gaps which, in turn, leads to a lack of interest in preserving nutrients.

Institutional barriers: Ndambi *et al* (2019), in a review of manure management across several countries including Kenya, found the lack of any promotion or support for manure management led to incoherent policies and unclear responsibilities with respect to manure management.

Renewable Energy

Practice: Implementation measures to switch energy use from diesel and fossil fuels on the farm to more renewable sources. This includes the use of biogas, for example combining an anaerobic digestor and a 'balloon' membrane. Solar panels are also being installed for milk bulking groups[6] as a means to ensure consistency of supply (Njagi, 2018).

[5] See for example: http://www.farmlinkkenya.com/how-to-make-compost-manure/

[6] Milk bulking groups provide a central point of collection for processors of smallholder milk delivery.

Current uptake: Biogas is not a new technology but the reduction in cost has led to higher uptake. In Kiambu a highly productive agricultural area, an estimate of around 85% of homes have installed biogas. In 2018, there was an estimate that around 50 solar cooling plants exist across 10 counties in more intensive milk growing regions.

Economic and Farm barriers: Biogas may be cost-effective but requires a large payment for installation. However, there are partial payment plans available or loans can be acquired from co-ops. Due to the need to digest waste, a biogas collector may prove profitable in agriculturally rich areas where waste, both from dairy and crops, provide enough feedstock, although smaller plants can be installed for farms with 1-2 livestock[7] (Bioenergy Insight, 2022). Solar chilling tends to reflect a higher throughput and consequently relies on more intensive dairying or farms in urban areas that allow access to the chilling plant.

Personal and Social-psychological barriers: Few studies have explored factors affecting barriers to uptake of renewables on farms. Gitone (2014) found that education and household factors were related to uptake of solar and biogas for households within the crop and livestock sectors.

Institutional: The shift to renewables is driven in part by the lack of reliable electricity and the high cost of fuel for diesel generators. However, more remote regions of Kenya are part of a national biogas programme with the aim of facilitating transition to biogas across the country. A biogas marketing hub has been established for the dairy sector which promotes its use[8].

Improving genetic stock

Practice: Introducing high yield dairy animals will improve the genetic stock on farms and lead to higher economic returns. The predominant intervention, promoted through Government and donor support, is artificial insemination (AI). AI has improved in the Kenyan dairy sector over the last two decades through a range of technological and institutional developments, but traditional breeding approaches still tend to dominate. Within AI the use of sexed semen will increase the probability of a female dairy calf and, whilst seldom used in Kenyan dairying, offers potential to reduce waste and the improve the carbon footprint of the sector.

Current Adoption. Muia et al (2011) reported AI use at 44% in smallholder farms. Amuge (2019) identified an adoption rate of around 38% for dairy farmers in the Nyamira County, Kenya. Mutavi et al (2016) found only 16.4% of the smallholder farms in peri-urban districts were currently using AI. Makoni (2015) estimated that AI covers 18% of total dairy cattle breeding with a potential to grow to 60%. Fewer studies exist for the use of sexed semen within AI services. A recent survey of farmers (Susan, 2020) found that whilst the majority of farmers were aware of AI, only 15% knew of sexed semen and only 2-4% claimed to use this technology.

Economic and Farm barriers: Omondi et al. (2017) found farmers who use AI tended to be more likely to keep performance records, purchase more animal feeds, and hire more labour. They also found a negative influence of herd and land size, which may imply that more intensive, zero-grazed operations have the highest potential for AI adoption.

Personal and Social-psychological barriers: Zander et al. (2013) found factors such as farmer's experience in dairy farming, the influence of neighbours, and management practices such as water provision and availability of feeds were associated with AI usage. They also found conception success led to a high probability of continued use of a specific breeding method, which may limit adoption of newer approaches. Murage and Ilatsia (2011) in surveys of various intensive dairying regions in Kenya found that more dairy farmers in Kiambu County used AI services compared to their counterparts

[7] See: https://www.bioenergy-news.com/news/kenyan-dairy-farmers-benefit-from-biogas-facilities/

[8] https://kenyabiogas.com/about/#who-we-are

in Nyandarua, who mainly used natural bull services. This may have been a consequence of this latter region's more extensive dairy systems.

Institutional barriers: The government liberalized the dairy industry in the early 1990s, leading to entry into the industry of private milk processors and AI service providers, as well as to informal milk marketing and use of bulls (Owango et al. 1998). AI increased with the privatisation of service delivery and Makoni (2015) found that around 95% of all inseminations were conducted through private companies or cooperatives. Moreover, the rise in extension services and cooperatives enable increased powers to buy AI services as a collective group, through access to credit and training. Breed improvement is, however, uncoordinated (Muriuki et al 2003) and this may have slowed down progress in improving the genetics of the dairy herd at national scale. Omondi et al. (2017) explored the role of dairy hubs[9] in promotion of AI, finding an overall positive perception of AI from farmers. The authors also found that farmers would also want to have access to provision of follow up services, such as pregnancy detection, as well as flexibility in input credit to enable sharing of costs of AI.

Animal Health Planning

Practice: The main disease of dairy cows in Kenya is tick-borne East Coast Fever, which is managed by dipping or spraying animals once or twice a week, although a vaccine can also be delivered which has high levels of efficacy. Other priority diseases include Foot and Mouth, which can be treated by a vaccine.

Other diseases, such as mastitis, can be prevented through proper hygiene and treatment and 'dipping' the teat in disinfectant. Tapeworms and nematodes, which lead to, amongst others diarrhoea, are treated through deworming solutions administered to the cow.

Current Adoption: High levels of mastitis have been found from surveys in Kenyan regions (Mbindyo et. al., 2020; Mureithi et al., 2016) which suggests low levels of dipping at the right time and use of optimal hygiene and sanitation procedures. There are variable rates of vaccination of East Coast Fever, dependant on region. Okello et al (2021) from a survey of 682 households in Murang'a County in Kenya found around 51% of the sample adopted vaccination and 72% were using deworming approaches.

Economic and Farm barriers: Diseases will exhibit through lower productivity, lower fertility and higher mortality. Hence, if untreated there tends to be early culling of cattle and the purchase of cattle from outside the farm which lead to significant costs and increased risks of disease incursion. Farmers are also reluctant to move cattle and expose them to risk of infection. Requirements of storage lead to vaccines only sold as a 40 pack, which means only larger herds to make them cost-effective[10]. Attempts at reducing the vaccine pack size lead to higher per unit costs and make them more restrictive to smaller herds. Homewood et al (2006) found the uptake of vaccination is related to having higher livestock numbers and greater economic security. Okello et al (2021) also found a positive relationship between number of cows, but also a higher milk price. A larger herd size was also linked to deworming, as well as having a milk contract. The authors argued that contractors expect consistent volumes and quality milk, which triggers smallholder dairy farmers to invest on improved feeds and adopting routine control measures such as deworming and vaccination services.

Personal and Social-psychological barriers: A study by Karanja-Lumumba et al., (2015) of smallholder dairy farmers indicated that more educated farmers, larger herds, and application of tick-control measures were positively correlated with vaccination of ECF.

[9] An example of a dairy hub is described here: https://www.tetralaval.com/sustainability/food-for-development/new-dairy-hub-in-kenya

[10] https://www.sciencedirect.com/science/article/pii/S2352771416300210#s0100

Jumba *et al.* (2020) identified gender differences, with lower adoption rates in animal health in female-headed households compared to male-headed households. Moreover, different drivers of adoption were found for vaccination with age, size of land holdings, and group membership being important for female adopters. Delayed treatment occurs due to lack of knowledge regarding symptoms of early onset of ECF.

Environment, physical and ecological barriers: Reviewing studies on the ECF vaccine, Allan and Peters (2022) identified concerns that vaccines would not protect against all strains of *T. parva* that are found within its geographical range. Moreover, since immunising with live parasite isolates can result in carriers or individuals that are persistently infected, there is also a risk that *T. parva* strains could be introduced into areas that were previously free of them via the vaccine. Gachohi et al (2012) identified factors such as the agro-ecological zone, the livestock production system, as well as animal breed and age as potential environmental factors behind virulence animal disease exposures.

Institutional barriers: The vaccine must be kept frozen using liquid nitrogen and then batch thawed and used within four hours, which results in need for extensive cold chain infrastructure. Due to the complexity of developing the vaccine, there are doubts over commercial-scale manufacturing of the vaccine (Allan and Peters, 2022). However, acaricides, drugs, and vaccines are available at local agro-vets and sub-county veterinary offices. Ndung'u (2006) identified the lack of formal regulatory bodies supervising the products and no state restrictions as concerns voiced by sellers of tick-based products. Moreover, the authors found limited access to these treatments in rural areas due to high transaction costs.

Main Incentives for Increasing Uptake

The adoption of climate smart practices is reflective of the smallholder dairy farmer's economic ability to invest, perception of the benefits of adoption, and underlying knowledge and engagement with external services. Further constraints include the role of family structure and labour availability, biophysical and climatic constraints, as well as the institutional infrastructure. This also implies that the nature of the practice itself must be reflective not only of the producer's needs and knowledge for them to adopt the practice but must also be accepted within the wider supply chain to recoup investments. Those practices which do require a degree of system change tend to infer large capital outlays (e.g., switching to renewable energy, concrete floors for stalls) and will need more support through on-farm demonstrations, from local and international agents, as well as potential support structures, e.g., supply chain reform, to lead the farmer to adopt them.

Whilst uptake of the above approaches varies by region and by system, a significant potential for closing yield gaps and generating income growth may be possible through the appropriate mixture of incentives and instruments to promote development of the sector.

*Harmonising regulatory instruments***:** Beebe et al (2017) argues that policies and enforcement of standards and regulations for dairy within Kenya are limited. The Government of Kenya supports dairy policy frameworks, but county governments deliver veterinary, breeding, and extension services (Rademaker et al., 2016). Coherence within policy as well as viable enforcement and monitoring would support increased engagement by supply chain actors and knowledge institutions. It would also provide an incentive for innovation if regulatory baselines were set and then raised for the sector to feasibly meet net-zero targets.

*Formalising Milk Markets***:** Kenya liberalised its dairying industry during the 1990s which resulted in the loss of some end markets and agreed pricing contracts. Since 2009 onwards there have been calls to formalise milk markets in Kenya, which would remove some of the obstacles to investment and adoption by assuring supplies and providing clear regulations. Nevertheless, the burden of costs continues to be placed on producers and distributors leading to lower returns when compared with informal chains. This dissuades engagement, especially from small-scale producers.

Co-ordination of economic instruments: Because of liberalisation there is limited support for uptake of technologies within the Kenyan dairy sector but directed support would allow greater access to these technologies and reduce some of the risk of investment. Most support comes in partnership with international donors, which can lead to greater opportunities for entry of female, youth and poor households into dairying (Rademaker et al., 2016). These subsidies are not distributed at the national level but vary by county to support dairying contexts. Support for AI, nitrogen cylinders, and renewables are available at county level which may help overcome some of the economic barriers to the adoption of quality breeding stock and use of chilling tanks. However, it is unclear how these are targeted and whether there is crowding out of private enterprises as a result of these initiatives.

Public-private partnerships: these have recently been growing between Kenyan private processors and co-operatives and international companies. For example, Tetra Pak East Africa[11], in partnership with, amongst others the New Kenya Co-operative Creameries, supports demonstration and training aimed at around 30,000 dairy farmers with the purpose of raising productivity growth.

Support for Entrepreneurialism and skills development: The sector is dominated by small holder farms who could intensify their activity to justify economies of scale and further investment. This implies a support for a degree of risk taking and entrepreneurial behaviour. Whilst the Kenyan Dairy Supply chain offers flexible routes to market this is typified by uncertainties in end product sale and price which adds a disincentive to individual investment in behaviour.

Coordination of innovation system and engagement processes: The adoption of climate-smart dairy farming practices requires the involvement of stakeholders such as farmers, policymakers, researchers, and development partners. This involvement can lead to the development and implementation of policies and programmes that support climate-smart dairy farming, such as training and capacity building programs for farmers, the development of climate-resilient dairy value chains, and the promotion of sustainable land management practices. Kenya has a number of institutions focused on supporting research and extension. Whilst there is a long history of intervention coordination between activities is relatively recent and dairy research and extension may overlap with specific initiatives, such as artificial insemination and vaccination services. Conversely as some of these services are delivered by the private sector, gaps may emerge in the provision of clear information, trust in the efficacy of interventions and equal access to new technologies.

Development of viable and lucrative markets: Across Sub-Saharan Africa local and international investment is occurring in supply chains. Within Kenya a range of actors are now populating the supply chain which may diffuse current market power dynamics. The further development of milk contracts that could provide an assured return should assuage producers to invest in the practices outline here. This requires oversight and robust regulatory frameworks to support transparency in price setting and the conditions around contracts. Initiatives such as the dairy hub networks are relatively new but may offer routes to secure assurance and trust within these market supply chains.

Implications for GLEAM

- There is potential from all the above technologies to be adopted but also to support targets for greenhouse gas emissions. The tables E1-E4 show the potential of these

[11] https://www.tetrapak.com/en-gb/insights/cases-articles/milk-production-kenya

measures across the three systems (intensive, semi-intensive and extensive) which could be modelled through improvements in input to output ratios.

- We would expect that the sector will increase in intensity and expect a high rate of technical change over the next two decades as the system integrates these new practices.

- A further modelling scenario may be a structural change to dairy farming in Kenya, which can usefully be divided into three main systems, namely intensive production (zero-grazed, stall fed), semi-intensive (partial zero-grazed), and extensive (open grazed). Zero grazing has been found to produce the highest yield, albeit with large variability. As the sector progresses then it is conceivable that a movement to higher yielding, more intensive systems would occur.

- Moreover, it is also conceivable that some farms will move away from dairy production and focus on supply of inputs, e.g.. forage, or a wider set of outputs, dependant on their locality and demands of consumers

- A further spatial point will be the pressure on land which may be a driver for intensification in most scenarios due to the expected increase in animal numbers to meet growing demand for milk over the coming decades. At present, GLEAM only includes emissions from land use change (LUC) associated with soybeans, but this ought to be expanded to include other crops to fully capture potential for emissions due to LUC in Kenyan dairy systems.

- Scenarios should look not only at livestock interventions, but also at crop/fodder interventions, since crops and livestock tend to be highly integrated in Kenya dairy systems. For example, increasing crop or fodder crop production may increase feed availability for livestock, but could also result in an increase in emissions due to increases in fertilizer application rates.

- Animal numbers will likely increase dramatically to meet growing demand for milk. It will be necessary, as discussed in the preceding points, to model how this will affect the sustainability of Kenya dairy systems and whether sufficient feed can be produced for livestock to meet growing demand for milk on existing land, as well as whether and how much LUC will occur in order to provide feed for additional animals.

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