Meridian Institute
Connecting People to Solve Problems

Potential Opportunities in Livestock Production

Major transformations are required to create sustainable food systems, but near-term immediate actions can support longer-term, more fundamental transition to sustainability. For incremental steps to contribute to long-term changes, stakeholders should define sustainability, measure unsustainability, and understand what interests, ideas and institutions contributed to the current structures, ideas, institutions, policies, and practices. Such understanding will enable stakeholders to choose near-term actions that can lead towards sustainability.

The tables, below, are intended to provide a starting point for stakeholders who are working to build sustainable food systems and are considering a range of near-term interventions. Much additional experience and knowledge by farmers, peasants, indigenous groups and other practitioners should be consulted for a full understanding of these and additional potential interventions.

The following tables summarize mitigation opportunities, adaptation potential, and food system implications in livestock production systems in four regions: Central and Latin South America, Africa, North America, and New Zealand. Although the opportunity tables focus on mitigation opportunities, the tables identify adaptation potential of most opportunities.

Opportunity Table: Livestock (Intensive; USA)

Opportunity	Species	Mitigation Potential	Adaptation Potential	Co-benefits	Challenges	Food System Implications
	AR= all ruminants, AS= all species, BC= beef cattle, DC=dairy cows, SW= Swine	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available			Potential feedbacks and interactions
Manure: Anaerobic digestion	Most common in DC, BC, SW	High mitigation potential up to 30% (GRA 2014;Montes et al. 2013). Alternative energy options for on-farm or grid use.	Use of manure can increase SOC and water holding capacity	Farmer can offset on-farm energy costs, renewable energy generation	While scalable across different systems, they can be expensive on a large-scale and require capital investment	Offers potential to create circular waste economies and generate renewable energies while also reducing farmer energy costs. Capital investment for large systems often includes public investment sources through grants or loans, but may be currently prohibitively expensive for many farms.
Manure: Solids separation	DC, BC	High mitigation potential (Montes et al. 2013)	Potential for incorporation in soils	Bedding in confinement systems or composted. Can reduce farmer costs for bedding.	Requires equipment and costs. May require shift in animal housing if bedding will be used.	Separation of manure enables capture of bedding for use on farm, which can reduce imports of straw, sawdust, and other cow bedding. This can save farmers money, and reduce nutrient inputs imported to a farm. Farmers may require technical assistance to implement these changes in systems.
Manure: Manure acidification	AS	High mitigation potential (Montes et al. 2013)	NA	Can reduce odors and improve in-barn air-quality. Reduction in odors would maintain N for fertilizer inputs.	Costs are variable for the acid inputs- however, these inputs can reduce loss of N, which reduces N fertilizer costs. Some additional research may be needed in certain systems.	Manure acidification could improve rural relations by reducing odors around farms. Further, emission losses ultimately are nutrient losses, so acidification may help reduce N losses to farmers, which reduce the need for imported N fertilizer inputs to the farm. Potential public health benefits from better air-quality and reduced farm odors.

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Manure storage	AS	Can reduce runoff and downstream emissions, high mitigation potential (up to 30%) compared with no storage (GRA 2014)	Can enable farmer flexibility to spread manure outside heavy rainfall periods or periods of frozen ground. Storage facilities however should be built to consider future climate impacts.	Assists with water quality goals; can enable use of manure as fertilizer. For farmers spreading more frequently, storage can reduce fuel and labor costs.	Infrastructure and investment costs	Manure storage can provide farmers great flexibility in terms of spreading manure at optimal times rather than daily or many times a week. Usually small farms lack storage capacity, and some storage options are very expensive. Potential for significant water quality and public health benefits.
Manure storage: Decrease storage time	DC, BC, SW	High mitigation potential (Montes et al. 2013). Warmer temperatures can increased GHG emissions, so particularly in warmer climates, emptying manure stores prior to summer is critical.	May help with storage capacity to ensure that heavy precipitation events wouldn't cause adverse impacts on full manure storage facilities		Some farms may not have the land to apply manure more frequently. Some places ban spreading manure in colder climates in winter (though manure storage in winter would result in fewer GHGs than summer)	Keeping manure stores low during summer temperatures would mean potentially incorproating manure onto fields when it is not needed for crop nutrient needs. However, it can reduce GHGs in warm climates. Farm infrastructure may be a significant barrier.
Manure Storage: Covers and Crusts	DC,BC,SW	Crusts can range from natural to wooden covers to vegetable oils or leaves. Mitigation potential up to 20% GRA 2014; Montes et al. 2013)		Can reduce odors. If impermeable cover, can flare emissions	May increase N2O	Crusts can offer significant GHG reductions, but vary by cover type and can have significant cost differentials. Greater assessment of non-natural crusts (which are free) can help further assess GHG reductions per cost of implementation
Manure Storage: Aeration and Temperature	DC,BC,SW	Cooler temperatures results in less CH4; aeration can decrease CH4 and N2O. Mitigation potential 0-20% depending on climate (GRA 2014; Montes et al. 2013)		May reduce odors	May increase NH3 emissions; challenging to achieve in warmer climates. Cooling could cost money and result in energy GHGs	Balance should used when considering the costs and potential CO2 emissions of cooling significant amounts of manure. Decreasing storage times to minimize rising temperatures may be more effective and feasible for many farms.
Manure Storage: Composting	DC, BC, SW	High mitigation potential (Montes et al. 2013)	Composting can add SOC to soil and improve soil health including drought mitigation potential.	Can reduce soil N2O emissions	May increase N2O,NH3	Manure composting can provide multiple ecosystem services but could generate GHG emissions in the composting process, which would vary by technique. While feasible now, research is needed to quantify full system emissions and ecosystem benefits.
Enteric Fermentation: Feed quality and forage digestibility	AR	Poor quality feeds (straw, residues, etc.) can be processed to improve digestibility. As well, coarse straws (corn, millet, sorghum) have better quality than slender straws (Rice, wheat, barley). Potential reductions in emissions intensity up to 30% (GRA 2014). Shifting from grass to grain-fed or higher quality feeds can reduce enteric emissions, but may have system level GHG implications	Crop shifts especially from perennial to annual systems may reduce system resilience to climate impacts.	can improve productivity and efficiency in animal systems.	Nutritional benefits- grass-based systems have known omega 3 benefits. Most existing studies comparing grain-fed and intense feeding systems with grass based systems don't include the potential SOC associated with perennial grass systems, so these reductions are largely based on enteric fermentation benefits alone, and may not consider system level impacts of such feeding shifts.	Further research is needed to better understand the system implications of such shifts since existing studies don't include SOC in grassland systems or assess social or public health impacts of different systems. Further, consumer acceptance of expansion of one system over another, as well as yield impacts should be considered.

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Enteric Fermentation: Plant compounds	AR	Tannins, saponins, essential oils have low potential mitigation effects, little long-term research (Hristov 2013a)	Unknown	Unknown	Little long-term research	There is little long-term research on the effect of such strategies on animal health and welfare, or sourcing of such potential strategies.
Enteric Fermentation: Lipids	AR	Medium potential- medium chain fatty acids are most significant potential. Meta-analyses by Moate et al. (2011) and Grainger and Beauchemin (2011) documented a consistent decrease in CH4 production with fat supplementation. Other concentrates such as distillers grains could be explored (GRA 2014).	Unknown	Unknown	In some studies, lipids had a significant and negative impact on dry matter intake, which could affect their productivity. Not recommended to feed edible oils more than 7% DMI of diet because not recommended to exceed 7% of total dry matter intake (Grainger et al., 2008). Also, these lipids could themselves have environmental implications (i.e. palm kernel oil).	Lipids research is needed to further understand long-term implications and related environmental impacts of certain lipid production.
Enteric Fermentation: Feeding Strategies & Concentrates	AR	Feeding good-quality feeds can increase animal productivity and feed efficiency. "High-quality (more energy-dense or more digestible) diets provide more energy for production as a proportion of the gross energy intake (GEI) and dilute the costs of maintenance than low-quality diets; therefore less CH4 is generated" Overall reduction potential is modest (0- 20%) (GRA 2014; Knapp et al. 2014). However, A recent review of life cycle assessments of cattle production strategies concluded an overall 28% lower global warming potential (GWP) from concentrate feed systems versus roughage-based systems (de Vries et al., 2015).		Concentrates and other byproducts can be utilized in agricultural production rather than become food waste, potentially winding up in landfills.	Potential environmental impacts associated with Concentrates may increase growing associated crop emissions.Research needs to consider whole supply chain level impacts associated with feed changes, could have tradeoffs (GRA 2014). Some concerns over feeding of certain byproducts or concentrates for animal health impacts, including e. Coli increases with distillers grains	High quality feeds are a significant priority to reduce enteric methane emissions, but care should be given to assess system level impacts of such shifts of emissions across food systems, rather than just on enteric methane. Additional LCA of concentrate feeding could include more detailed assessment of GHGs associated with their production; however, there is great potential for concentrate and byproduct feeding to reduce food and agricultural waste.
Enteric Fermentation: Feed Additives/ Biological Control	AR	A wide variety of supplements exist that can be administered to reduce CH4, such as chemical inhibitors, organic acids, and electron receptors. A maximum potential of **5% CH4 reduction** for energy corrected milk yield. Experts believe there is need for greater research, but that there are other better short-term strategies (Knapp et al. 2014)	Unknown	Unknown	Most have been demonstrated in vitro, and long-term reductions in emissions from in-vivo studies are limited, Many inhibitor strategies are not safe for the animals (Hristov 2013a). Many have unknown environmental impacts (Hristov 2013a)	There is little long-term research on the effect of such strategies on animal health and welfare, or sourcing of such potential strategies. Further, consumer acceptance of such strategies is unknown.

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Precision Feeding	AS	Potential for major efficiency gains in tailoring dietary needs to an animal's changing life history (GRA 2014)	Unknown	Can increase efficiency, profitability	Requires advanced technological systems, so most relevant for high-value technological systems.	Offers potential for larger systems especially with required capital and labor/training to implement such strategies. Additional research could greater understanding of potential GHG benefits.
Genetics	AR	Widespread consensus exists that increasing the productivity of an animal will decrease the proportion of CH_4 produced per unit of product (Johnson et al., 1996; Moss et al., 2000; Boadi et al., 2004; Beauchemin et al., 2008; Pinares-Patiño et al., 2009; Clark, 2013) Genetic selection for yield/product efficiency, feed efficiency and lifetime health. Mitigation potential up to 20% (GRA 2014;Knapp et al. 2014)	Maintain yield. Improved genetics could be selected for cattle that can withstand heat stresses	Potential for reduced feed inputs, improved animal welfare and health	Requires significant laboratory testing and research investment. Genetic selection may have some moral, ethical or consumer acceptance issues depending on what technology is utilized.	Utilizing publicly acceptable strategies for animal breeding to increase efficiency and reduce GHG emissions in the short-term is possible. Consumer acceptance of animal traits and ethical and moral implications should be assessed. Longer-term research is needed to select animals for more specific GHG reducing traits, and should be coupled with consumer acceptance studies.
Other Management Approaches (Reducing stresses, animal health, fertility)	AS	Such approaches include 1) heat stress abatement: A 25% improvement in heat stress tolerance is estimated to have a net reduction in CH_4/ECM of 10% in intensive dairy systems (St-Pierre et al., 2004).; 2) disease reduction: A 5% reduction in culling for disease can reduce whole-herd emissions by 8 to 12% CH_4/ECM; 3) production enhancing agents (e.g. rBST, ionophores); 4) fertility: A reduction in culling due to poor reproduction from 35 to 30% is estimated to reduce whole-herd enteric CH_4 emissions by 3.1%; 5) Reducing dry cows and replacement heifers. These improvements in animal and herd performance are estimated to lower enteric CH_4/ECM by 9 to 19% overall. (Knapp et al. 2014).	Improved animal welfare through heat and disease reduction.	Potential for reduced feed inputs, improved animal welfare and health	Awareness of climate benefit of disease reduction is largely unknown; Disease resistance, information access and understanding of disease transfer	All existing strategies to reduce heat stress, disease and other strategies could be undertaken currently; however all should be accessed for consumer acceptability. For example, use of rBST has been largely rejected by most consumers and is banned in many countries, making it potentially irrelevant for reducing GHGs. Other future strategies should be similarly assessed to ensure the industry isn't investing time and economic resources into strategies that will be unacceptable to consumers.
Vaccination	AR	Vaccination has the potential to require hardly any farm system changes, but could enable an animal to produce antibodies against methanogens (that produce methane). In vitro experiments indicate emissions reductions up to 30%	Unknown	Unknown	Low research, unknown technology at the moment	Vaccination to methane has potential to reduce GHGs, but little is known about system impacts on animal health and welfare and/or consumer acceptance. Further, whether farmers will use it and be willing to pay for it is also unknown.

Opportunity Table: Livestock (Extensive; New Zealand)

Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Challenges	Food System Implications
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available			Potential feedbacks and interactions
Grazing: Improving pasture quality	Can reduce GHGs through enteric fermentation and manure. Pasture quality can improve digestibility (Hristov 2013) as well as animal productivity (GRA 2014).	May improve soil C sequestration	Improved productivity	May require increased N application rates	Improved pasture quality could increase farmer income and profitability, thereby reducing need for agricultural expansion and associated LUC. Increases in fertilizer requirements could drive demand for synthetic fertilizers.
Grazing: Standoff or feeding pads	keeping the animals off the paddocks, in “stand-off” or “feed pads” for most of the day during the wet months of the year (autumn–winter), has been shown to be an effective N2O mitigation practice in intensive grazing systems (de Klein, 2001; de Klein et al., 2002; Luo et al., 2008a).	May assist farmers with paddock quality with increased extreme rainfall	Reduces compaction, can reduce nutrient losses and improve water quality	This practice results in much greater NH3 emissions (Luo et al., 2010) due to urine and feces being excreted and allowed to mix in the stand-off or feed pad area. Proper manure management should be implemented (GRA 2014)	Stand-off pads are sometimes associated with confinement systems, and may need to consider consumer perceptions and acceptability. Standoff pads for farmers, while an initial cost investment, could improve farm productivity and environmental outcomes.
Grazing: Reduced in wet weather	Not allowing grazing during wet weather also increases pasture productivity due to reduced sward damage and soil compaction (de Klein, 2001; de Klein et al., 2006). "Combination approach" of daytime grazing and night housing can be effective (GRA 2014)	May assist farmers with paddock quality with increased extreme rainfall	Reduces compaction	Infrastructure investments- costly	In extensive systems, some farmers may not be able to implement this practice unless they have stand-off pads or a sacrificial pasture, which are costly in the short-term, but provide long-term paddock quality.
Nitrification Inhibitors	Extensive studies have been done in New Zealand for example to explore the potential of this practice with variable results. Recent research suggests that, taking into account the estimated indirect N2O emission from deposited NH3, the overall impact of nitrification inhibitors ranged from −4.5 (reduction) to +0.5 (increase) kg N2O-N ha−1. suggesting N2O emission reductions can be undermined or even outweighed by an increase in NH3 volatilization (Lam et al. 2016). Another recent New Zealand study found that there was no effect of nitrification inhibitors on N2O emission factors (van der Weerden et al. 2016).	May increase productivity- but still variable	May increase productivity- but still variable	Long-term ecological studies lacking, costly. Highly challenging for extensive livestock systems- application is usually concentrated around watering areas where urine and feces would concentrate	Nitrification inhibitors have been banned in some countries for their potential public health implications as they've been found in milk. Thus, consumer acceptance is important to assess. The cost of such mitigation options is unlikely to work well for extensive systems, but is more feasible in intensive systems. Potential productivity gains would help offset costs, but gains are not universal.

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Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Challenges	Food System Implications
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available			Potential feedbacks and interactions
Feed: Legumes	22 in vivo studies with a total of 112 observations and the authors concluded that ruminants fed C4 grasses produced 17% more CH_4 (per kg of OM intake) compared with animals fed C3 grasses and 20% more than animals fed warm climate legumes. (Archimede et al. 2011). A comprehensive overview of the various aspects of feeding corn vs. legume vs. grass silages for lactating dairy cows was recently offered by Dewhurst (2012). Based on this review, the lower fiber content and higher passage rates of legumes appeared to decrease CH_4 production compared with grasses, which was reported in earlier studies (McCaughey et al., 1999). (Hristov et al. 2013).	May help reduce N fertilization applications	May help reduce N fertilization applications	Could require different planting times or strategies. Farmer planning for crop rotations required.	Legume integration could have positive feedbacks for farmers for reduced costs associated with N inputs and potential benefits for efficiency. However, this may require additional farmer training and planning for crop rotations. Legume emissions should also be accounted for in GHG accounting.
Pasture and cropping diversification	One study found that diverse pastures resulted in 46% less N20 while fodder beet resulted in 39% less N_2O compared to kale. These results suggest that N_2O emissions can potentially be reduced by incorporating diverse pastures and fodder beet into the grazed pasture farm system. (Di et al. 2016).	Diversification for increasing resilience	Fodder beet has a much higher yield than other forage crops in NZ like brassicas	Cropping compared to pasture	New Zealand especially is known for its innovative cropping strategies for livestock including kale, brassicas and fodder beet. Such strategies have potential opportunities in other regions, but are also possible given New Zealand's climate. For farmers, yield benefits are significant and can provide increased farmer incomes and/or reduced costs. Annual cropping compared to perennial grasslands would result in less SOC gains.
Swift to grain-fed/concentrates/feedlot system	High quality feeds that are more readily digestible including coarse straws (corn, millet and sorghum) as compared to slender straws (rice, wheat and barley) can significantly reduce emissions intensity up to 30% (GRA 2014). A recent review of life cycle assessments of cattle production strategies concluded an overall 28% lower global warming potential (GWP) from concentrate feed systems versus roughage-based systems (de Vries et al., 2015). However, existing LCAs have not included potential SOC benefits of grassland systems, so current studies are incomplete.		May offer greater flexibility for farmers to manage animals.	Consumer acceptance of feedlot systems varies by country. Further, while grain and concentrates may reduce enteric methane, these systems could increase GHG emissions elsewhere.	Further research is needed to better understand the system implications of such shifts since existing studies don't include SOC in grassland systems or assess social or public health impacts of different systems. Further, consumer acceptance of expansion of one system over another, as well as yield impacts should be considered.

Opportunity Table: Livestock (Extensive; West Africa)

Country Examples: Burkina Faso, Mali, Niger, Senegal, Ghana, Nigeria

Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Food Systems Implication
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		Potential feedbacks and interactions
Fodder production	The possible opportunities for livestock-related mitigations through pasture management have been quite widely described (Amole and ayantunde 2016, Zougmoré, et al. 2016). This involves the use of improved seed and adapted species. Grass-legume mixture have been found to reduce the use of inorganic fertilizers, increase carbon sequestration and feed quality (Amole and Ayantunde 2016). ILCA and its partners developed a fodder bank that involved about 27,000 smallholder farmers covering an area of about 19,000 ha for the whole of West Africa (Elbasha et al., 1999). The main species that were promoted were Vigna unguculata (cowpea), Dolichos lablab, Macroptilum atropurpureum (Siratro), Panicum maximum, Cenchrus ciliaris, Chloris gayana, Cajanus cajan, Leucaena leucocephala, Stylosanthes and Brachiaria ruziziensis.	However, most of the adoption of fodder species are concentrated in the sub-humid zone, perhaps due to their adaptability. In Burkina Faso, many institutions such as l'Institut de l'Environnement et de Recherches Agricoles (INERA) and Ministry of Animal Resources and Fishery have been involved since 1961 in the introduction and testing the adaptability of fodder plants.	Cowpea is a species expanding in the Sahelian zone as a multi-purpose crop, the grain being used for human consumption while fodder is used for animal feeding.	Adoption of some fodder legumes such as cow pea result in better livelihoods for farmers as indicated by more livestock, maize output, assets and farm incomes. On the other hand Food production costs are likely to increase due to increasing costs of climate adaptation and mitigation. Given the increase in temperature and drought occurrences, it is likely that feed prices will increase. Water scarcity, rise in feed prices and increase in demand for quality feed and energy for climate adaptation will drive up production costs. This will increase food prices and hence access to food.
Fodder Conservation	Some projects in Burkina Faso introduced a silage production technology to farmers and further organized training for women farmer groups in silage production using locally available herbage, such as grasses, cereals and salt (Bayala et al., 2011, Zougmoré et al. 2016). For silage making, naturally growing wild grasses, mainly Andropogon gayanus, Brachiaria ruziziensis, Digitaria ciliaris Echinocloa and Pennisetum pedicullatun, were harvested at the early flowering stage when the moisture content is about 30 – 40%. Green cereals residues of poorly developing maize, rice, sorghum or millet crops are also harvested for use in silage production. The herbage is then left to ferment and cure for about 3 weeks after which it is ready and collected for feeding to livestock.	The condition for its realization requires careful selection of species, harvesting at vegetative stages, heights and at proper weather condition. Technical training on conservation technique. Through FAO/INERA collaboration, extensive studies in Western Burkina Faso showed that the opportunity cost of silage and salt lick production using this technology is low with a cost-benefit ratio of 527%, and therefore highly profitable and beneficial to small holder livestock farmers.	Feeding Azawak cows on silage supplements resulted in a dramatic tenfold increase in milk production, while ewes fed on silage supplement maintained milk yields throughout the year (Bayala et al., 2011). Farmers quickly adopted this silage production technology not only to successfully feed livestock during the dry season but also as an income generating opportunity through the sale of silage and salt-lick blocks.	The main implication of adopting fodder conservation on food systems is that it ensures that farmers can still attain food security even during dry seasons. Besides livestock productivity will have not fallen dramatically.
Forage Quality Management	In West Africa farmers are improving feed digestibility by processing of locally-available crop residues (e.g. treatment of straw with urea) and by supplementation of diets with better quality green fodder such as multipurpose leguminous fodder trees, where available (Amole and Ayantunde, 2016). Other method involves urea treatment of crop residues to improve its quality and digestibility and hence reduced enteric methane emission.	The adaptation potential of this intervention is moderate. Improving the feed value chain to facilitate delivery of agricultural by-products from producer to farmers requires institutional support.	Better feed digestibility leads to better animal and herd performance.	Food production costs are likely to increase due to increasing costs of climate adaptation and mitigation. Given the increase in temperature and drought occurrences, it is likely that feed prices will increase. Water scarcity, rise in feed prices and increase in demand for quality feed and energy for climate adaptation will drive up production costs. This will increase food prices and hence access to food.

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	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		Potential feedbacks and interactions
Intergration of Forage Legumes into arable crops	Research in West Africa have found that legumes have have a potentially significant role to play in enhancing soil carbon sequestration (Amole and Ayantunde 2016). The role of legumes in supplying nitrogen (N) through fixation is increasingly seen as important as and more beneficial in terms of overall GHG balance than had once been thought. Powers et al. (2011) reported increases in soil carbon stock when forest or savanna was converted to pastures (5–12% and 10–22%, respectively). Legumes are likely to have a role to play in reducing GHG emissions from ruminant systems. An approach to reducing methane emissions of current interest and supported by some initial evidence is the use of tannin containing forages and breeding of forage species with enhanced tannin content. In the context of maintaining N fertility, Nichols et al. (2007) have called for greater efforts to improve annual tropical legumes to complement species such as lablab (Lablab purpureus L.) and cowpea (Vigna unguiculata L.).	Despite farmers' recognition of the potential contribution of forage legumes to crop-livestock farming systems in the West Africa, their integration is relatively slow. The use of forage legumes in many parts of the tropics is limited because they do not contribute directly to the human food supply.	Intercropping forage legumes with cereals offers a potential for increasing forage and, consequently, livestock production in sub-Saharan Africa. This intercropping has been shown to improve both the quantity and quality of fodder and crop residues leading to better system efficiency (Ayarza et al., 2007).	In terms of food systems, intercropping forage legumes only help in livestock production. Thus indirectly improving food security.
Grazing Management	One of the main strategies for increasing the efficiency of grazing management in West Africa is through rotational grazing, which can be adjusted to the frequency and timing of the livestock's grazing needs and better matches these needs with the availability of pasture resources. Rotational grazing allows for the maintenance of forages at a relatively earlier growth stage. This enhances the quality and digestibility of the forage, improves the productivity of the system and reduces CH_4 emissions per unit of LWG (Eagle et al., 2012).	Rotational grazing is more suited to manage pasture systems, where investment costs for fencing and watering points, additional labour and more intensive management are more likely to be recouped.	Grassland management practices have potential to contribute towards food security and agricultural productivity via increased livestock yield and reducing land degradation.	Improve on food security via improved livestock
Agro-silvo-pastoral practices	Through the Sahel agroforestry network, leguminous fodder shrubs and herbaceous legumes have been grown together with food crops with the aim of improving crop productivity and providing fodder for livestock in West Africa(Amole and Ayantunde, 2016). Leguminous fodder shrubs have high nutritive value and can help to improve the diets of ruminants while they can also sequester carbon. Forages from the fodder shrubs can effectively replace some of the concentrates and part of the basal diet of dairy livestock leading to increased milk production per cow. Ultimately, this can result in the reduction of the number of cattle on the farm and thus reduce the amount of methane emission from individual farms (Thornton and Herrero, 2010). Wider use of the right fodder trees in substitution for other feed options also provides mitigation opportunities through dietary intensification, tree carbon sequestration and savings through foregone concentrate and annual crop production and use.	Trees also provide other functions important for climate adaptation, including shade for animals and, possibly, the provision of ethno-veterinary treatments to counter increased disease threats (such treatments are often relied on in areas with poor state veterinary services, especially in pastoral systems with poor infrastructure (Dharani et al., 2014).	Combination of leguminous fodder shrubs and herbaceous legumes can be grown together with food crops with the aim of improving crop productivity and providing fodder for livestock. Trees and shrubs are planted on farms as live fences, boundary markers, windbreaks, soil conservation hedges, fodder banks, and woodlots.	Improve on food security through striking a balance between livestock and crop productivity.
Conservation Agriculture	Conservation agriculture has the potential to sequester soil carbon, thereby contributing to climate change mitigation (Corbeels et al., 2006).	The beneficial effects of mulching with crop residues on the soil water balance (through reduced water runoff and soil evaporation) may enhance adaptation to future climate change, when rainfall is projected to decrease and become more unreliable (Scopel et al., 2004; Thierfelder and Wall 2010).	According to Corbeels et al.,(2014), meta-analysis of CA studies in SSA showed that crop grain yields are significantly higher in no-tillage treatments when mulch was applied and/or rotations were practiced in comparison to only no-tillage/reduced tillage without mulch and/rotation	

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	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		Potential feedbacks and interactions
Agriculture Water Management	Livestock feed resources in West African Sahel is largely dependent on exploitation of natural pastures in the wet season and crop residues in the dry season, therefore improved agricultural water management practices will invariably contribute not only to crop production but also livestock production through increased feed resources (Rockström et al. (2002), Amole and Ayantunde 2016).In-situ micro-catchment strategies aim at enhancing rainfall infiltration in the soil, improve soil water storage and limit top soil losses through wind and water erosion. They can be based on the construction of a physical barrier against run-off and/or on the improvement of soil water holding capacity through improved soil structure and soil fertility. Some of the in-situ micro-catchment strategies of relevance to climate smart livestock interventions include: Zaï and half-moon pits, Earthen contour bunds, Rock bunds/stone rows	As can be inferred from the agricultural water management practices, building climate smart water-crop-livestock farming systems requires integrated approach, as the interaction between livestock production and the other components sometimes create win-win situations but also it creates trade-offs and potential conflict. Climate smartness adds another complexity to the table as not all proposed interventions are necessarily climate smart.	Livestock feed resources in West African Sahel is largely dependent on exploitation of natural pastures in the wet season and crop residues in the dry season, therefore improved agricultural water management practices will invariably contribute not only to crop production but also livestock production through increased feed resources.	Cost of livestock production, which is heavily dependent on water, will likely increase due to higher water prices
Herd Management	Blench (1999) describe how Fulbe herders in Nigeria, faced with a shortage of grass in the semi-arid zone, switched to keeping the Sokoto Gudali cattle breed, which copes well with a diet of browse, instead of the Bunaji breed. In a related study carried out in Burkina Faso, Sanfo et al (2015) reported that the main adaptation strategies among the people remained diversification of their livestock species and transhumance practice. Although, cattle remains their most important species, the small ruminants are becoming more and more important because they are less vulnerable to warming (requiring less water and food). For them, this is a risk-free strategy: the use of the scarce natural resources by reducing the risk of livestock losses during extreme climate events. The small ruminants play an important role in their livestock system by allowing them to meet their immediate social and economic needs (Malonine, 2006).	However among the Fulani, the principal pastoral ethnic group in West Africa, a shift from cattle to small ruminants will require overcoming a significant cultural barrier since cattle represent such a central part of the group's identity. Agro-pastoralism could be an alternative to shifting from cattle to small ruminants, a shift that represents a significant loss in material and financial wealth. (Fratkin, 2012).	Various species also have different production attributes and uses, with camels providing transport in addition to milk and meat, goats providing rapid rates of post-drought herd recovery, sheep providing seasonal income opportunities related to Islamic festivals, and camels and cattle providing prestige and social status in some communities (Sanfo et al., 2015).	Shift to small ruminants and camels might reduce productivity of livestock products such as milk and beef. Endemic ruminant cattle that do not require a lot feed are less productive. Transition feeding more on vegetables and white meat like chicken and fish will be on the increase. Animal numbers will increase. However, monogastric production (pork and poultry) will grow at faster rates than ruminants (especially for meat and less so for milk).
Breeding Strategies	Identifying and strengthening local breeds that have adapted to local climatic stress and feed sources is a breeding strategy that is climate smart option. Improving local genetics through cross-breeding with heat and disease-tolerant breeds has been viewed as one of the climate smart option for livestock production in West Africa. Within species, there are also differences in the capacity of different breeds to utilize particular kinds of feed. For example, Blench (1999) reports that the Sokoto Gudali cattle of West Africa specialize in eating browse and will feed on woody material that other breeds find very unpalatable. Among cattle in general, zebu (Bos indicus) breeds tend to deal better with low-quality forage than do taurine (Bos taurus) breeds, while the latter have better feed conversion ratios when fed on high-quality feed (Albuquerque et al., 2006).	A number of breeds have been shown to possess superior resistance or tolerance to specific diseases or parasites. In many cases, such adaptations enable these breeds to graze in areas that are unsuitable for other animals. For example, several studies have shown that the ability of Kuri cattle to tolerate insect bites enables them to remain close to Lake Chad during the rainy season when other cattle have to leave the area (Blench, 1999).	Goats also have the advantages of being able to rear up on their hind legs, climbing well and having mobile upper lips and prehensile tongues that enable them to pluck leaves from thorny shrubs and select the most nutritious parts of the plant (Barroso et al., 1995). Keeping browsing animals has certain advantages when feed is in short supply as they make use of forage that cannot easily be used by other species – i.e. there is a degree of complementarity if grazing and browsing animals are kept together – and because shrubs tend to provide a source of green forage during the dry season.	Crossing of indigenous livestock and exotic breeds might help in mitigating total food loss due to reduced livestock numbers and milk shortage. The breeding strategy adopted in the face of climate change can help both the environment if it targets more on non-ruminat animals such as pigs and poultry.

Opportunity Table: Livestock (Extensive; West Africa)

Country Examples: Burkina Faso, Mali, Niger, Senegal, Ghana, Nigeria

Opportunity	Mitigation Potential	Adaptation Potential	Co-benefits	Food Systems Implication
	Qualitative description plus quantitative if available (range of possible emission reductions?)	Qualitative description plus quantitative if available		Potential feedbacks and interactions
Manure Mangement	Animal manure management is defined as a decision making process aiming to combine profitable agricultural production with minimum nutrient losses from manure, for the present and in the future. Good manure management will minimize the negative and stimulate the positive effects on the environment. Gas emission and leaching of nutrients, organic matter and odour have undesirable effects on the environment. Efficient treatment of manure can reduce the emission of GHGs and raise agricultural productivity (Amole and Ayantunde 2016, Zougmoré et al. 2016). In Niger and Mali, to exploit the benefits of urine and to minimize nutrient losses, corralling livestock on fields is preferable to the application of farmyard manure (Schlecht and Buerkert, 2004).	However the adaptation of this intervation is low. The main constraints to corralling are the low number of animals with an average of 2.5 to 3.4 TLU (1TLU represents 250 kg live weight, equivalent to 1 camel, 1.43 cattle or 10 small ruminants) per farm and the lack of means of transport (Balaya et al., 2011).	Yields obtained on manured crop field are always much higher than fields that are not manured.	While this strategy ensures increase in yield, it also reduces the emission of methane into the atmosphere.
Anaerobic digesters for biogas and fertilizer	Reduce methane emission and pressure on crop residue as energy source	Very high given that there is sufficient manure and crop residues.	Biogas provides additional energy for fuel. Fertilizer improve soil fertility hence increased crop yield	Improve on food security
Appropriate institutional support:	Without appropriate institutional structures in place, livestock-related CS innovations may overwhelm smallholder farmers. There has been many institutions and stakeholders, including farmers (and farmer organizations), private sector entities, public sector organizations, research institutes, educational institutions, and Civil Society Organizations that play important roles in supporting the adoption of climate-smart agriculture (AGRA, 2014). They have been promoting inclusivity in decision making; improving the dissemination of information regarding GHG mitigation technologies, providing financial support and access to markets; providing insurance to cope with risks associated with climate shocks and the adoption of new practices, and supporting farmers' collaborative actions.	Very high given that climate change is a real threat in the region.	Improved food security, cleaner environment, improved livestock and human health	With proper regional institutional framework countries both exporting and importing countries should adopt a "no-regrets" approach to adaptation actions in food systems. "No regrets" approach refers to the need to take proactive adaptation actions. This is to preempt adverse conditions given the lack of accuracy in future climate projections. Most importantly, as climate impacts will affect domestic production, it is necessary for producing countries to identify potential impacts and possible adaptation actions on local production centres. Early identification of the impacts of climate change on current crop yields, livestock production and fish in producing countries will be important for these countries' food strategy decisions. For importing countries, such an approach ensures minimum supplies in the least and cuts down on fears of price volatility.
Condicive Policy	Governments in West Africa have enacted policies that promote climate smart agriculture. The aim of these policies is to mitigate GHG emission.	There is high adaptation potential given that there is government support	More food security, environmental management.	Improve on food security through proper policies. To avoid higher costs of adaptation, agriculture and livestock production are likely to shift to regions with more favourable climate conditions — regions of higher latitude or altitude. This will change the regional distribution of food production and export, potentially opening up new food source countries and new supply chains. The balance-of-power between food exporters and importers will shift, with repercussions for regional and bilateral relations. Thus condicive policies will be need to deal with climate change and food production.

Opportunity Table: Livestock (Intensive and Extensive; Central and South America)

Information to come.

Appendix: Methodology

Authors used a systematic approach to review the peer reviewed literature for mitigation opportunities along food systems. The approach followed five main phases and ten methodological steps.

Phase 1. Definition of variables and criteria

1. Identification of important food production systems globally. Cereals, horticulture and livestock were identified as important food systems according to previous reports data which highlighted it relevance for food security and as focus of GHG emissions worldwide (Burney et al. 2010; FAO 2016 a,b; Gerber et al. 2013; Herrero et al. 2013 and 2016; IPCC 2007; Jensen et al. 2012; Leff et al. 2004; Smith et al. 2007 and Weinberger & Lumpkin 2007). Fisheries and aquaculture are important production systems, but are not included in this report.
2. Identification of major food production systems across global regions. Authors made a first attempt to identify food systems categories across four selected regions: Central and South America (CSA), North America (NA), South Asia (SA) and Africa (A) based on existing food production systems reports for Cereals, Horticulture (Dixon et al. 2001, Annex 1) and Livestock (Steinfeld and Mäki-Hokkonen 1995, Annex 2). Major food production systems were defined in terms of coverage (percentage of population, food exports and imports, percent of employment in agriculture), use of resources (area harvested) and GHG emissions from Agriculture, Forestry and other Land of Use (AFOLU) for each of the four selected regions.

Phase 2. Search of technical and scientific information

3. Literature review of mitigation opportunities. A list of potential mitigation opportunities along the three food production systems and four selected regions was developed based on recent scientific and technical literature available until April 2017. Searches were conducted using key words regarding quantification of emissions from food systems worldwide (i.e. mitigation, GHG emissions, livestock, cereals, horticulture, CO2 quantification, Carbon foot prints, Life cycle assessment, etc.) in common scientific and technical database networks (i.e. Google Scholar, Cab Direct, Springer, Elsevier, FAOSTAT, World Bank, International Labor Organization, etc.). Peer-reviewed journals papers, national and international technical reports, books, and research dissertations were included and are listed in the reference section for consultation.
4. Identification of opportunities with mitigation potential. Across the literature review, opportunities were identified with any quantitative or at least qualitative attempt to measure mitigation potential over the emissions of one or several greenhouse gases (Carbon dioxide (CO2), Methane (CH4) and Nitrous oxide (N2O)).
5. Identification of co-variables associated to mitigation potential interventions. In addition to the mitigation potential, the co-benefits, challenges and adaptation potential related with the implementation of the described opportunities, were reported when any qualitative description provide by the cited literature or in consultation with external experts.

Phase 3. Classification of the opportunities along the food systems

6. Identification of mitigation potential opportunities along food systems components and stages. The interventions with mitigation potential were addressed along the five different stages identified for the food systems: Pre-production, Production, Post-production, Consumption, and Waste. The interventions were also organized according to the particular stages (i.e. agronomy practices, grazing management, manure management, waste management, etc.) where interventions are expected to take place inside each food system component (i.e. inside Production stages).
7. Identification of mitigation potential opportunities across global regions. Interventions with quantified mitigation potential were also classified into the four previously selected global regions according the countries where measurements takes place. Data from Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Uruguay and Venezuela, were available for Central and South America (CSA); data from India was available for South Asia (SA); data from USA and New Zealand were grouped as North America (NA); and data from Burkina Faso, Mali, Niger, Senegal, Ghana, Nigeria, Kenya, South Africa, Tanzania, and Uganda was available for Africa (A).

Phase 4. Identification of main patterns for intervention with Mitigation Potential

8. Analyses of the distribution of the number of interventions across food systems components. The resulting literature included over 160 potential interventions for mitigation along the three food systems and the four global regions. The number of interventions with any mitigation data were described in terms of the amount of research, expert confidence, cost estimate, implementation time, and scale and action category were summarized based on the specific information by region in consultation with other experts.

Phase 5. Input from Global Scientific and Technical Stakeholders

9. Presentation of the opportunities for mitigation along food systems in an international dialogue. The mitigation opportunities were presented during the 2nd International Dialogue: The Future of Food in a Climate Changing World a Climate Changing World organized by The Global Alliance for the Future of Food on 2-3 May 2017.