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Review

An Overview of Mitigation and Adaptation Needs and Strategies for the Livestock Sector

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Abstract: The livestock sector is vulnerable to climate change and related policy in two ways. First, livestock production and performance are directly impacted by climate with many projected effects being negative. Second, the sector may need to alter operations to limit the effects of climate change through adaptation and mitigation. Potential adaptation strategies involve land use decisions, animal feeding changes, genetic manipulation and alterations in species and/or breeds. In terms of mitigation, livestock is a substantial contributor to global non-CO_2 greenhouse gas emissions. Mitigation opportunities involve altered land use for grazing and feed production, feeding practices, manure treatment and herd size reduction. In addition, strengthening institutions that promote markets and trade, as well as local support programs can help both mitigation and adaptation. Previous literature has summarized the options available to individual producers. This overview extends the literature by including sector-level response as well as the relationships between adaptation and mitigation activities.

Keywords: land use; feed production; feeding strategies; manure treatment; breeds

1. Introduction

Livestock are an important protein and calorie source for humans and are an important income source for rural households [1]. Animal productivity can be negatively or positively affected by climate change (CC). In turn, this stimulates adaptive measures like altering management, location, animal numbers, or herd characteristics.

Additionally, the livestock sector emits an estimated 14.5% of total global anthropogenic greenhouse gases (GHGs) [2]. As a consequence, livestock management alterations have been argued to have significant potential for mitigating atmospheric GHGs and reducing future CC [3]. Livestock emission abatement opportunities include managing grazing land resources, altering feeding practices, improving treatment or use of animal manure, altering processing and transport of animal products and altering species and breeds in animal production.

This paper presents an overview of the vast livestock related CC literature on impacts, adaptation and mitigation. In doing this, we try to reference exemplary pieces and/or recent contributions that offer an entry point into the literature. Rivera-Ferre et al. (2016a) [4] and Rojas-Downing et al. (2017) [2] have recently presented reviews of livestock adaptation and mitigation activity options, suitable within various types of livestock systems and across locations. To expand this knowledge base, this article considers adaptation options with an economic orientation plus includes broader sectoral level CC response options and incentives. Additionally, the relationships between mitigation and adaptation options are explored as they relate to co-benefits and shared costs.

2. Climate Sensitivity and Adaptation

Evidence and theory indicate that CC affects livestock growth, appetite, disease incidence, health, immune functions, mortality, animal reproduction rates and quality of dairy products, directly [5–7]. It also alters quantity and quality of feed and forage, in turn impacting productivity [8]. Mader et al. (2009) [5] also indicate CC will lengthen feeding periods in hot regions and shorten them in cool regions. In the face of this, producers have been adapting operations and will continue this into the future. Below, we elaborate covering both vulnerability and possible adaptation.

2.1. Feed and Land Resources

Livestock are vulnerable to effects on feed supply. Wheeler and Reynolds (2013) [9] examined climate impacts on crops grown for animal feed. They find that CC imposes risks on volume produced, yield volatility and nutritional quality. Consequently, livestock adaptation strategies can involve overcoming feed supply issues. Thornton et al. (2009) [10] summarized the possible adaptation strategies as: (1) farm level production adjustments including diversifying and intensifying agricultural production, altering the schedule of operations, changing land use and using irrigation; (2) introducing or revising crop, livestock and flood insurance schemes, credit schemes and income diversification opportunities that help keep agricultural producers in business or find new growth channels; (3) institutional changes such as removing or putting in place subsidies, enhancing local agricultural markets and promoting inter-regional trade; (4) technological developments such as introducing more climate resilient crop and grass varieties and improving water and soil management. Simply put, to stabilize animal feed supply, the agricultural sector can adopt farm- and institution-level changes, as well as assume new technologies.

Forage quality is also an issue. Craine et al. (2010) [8] examined CC impacts on forage quality and resulting nutritional status of cattle. They found that in the United States (US), increasing temperature and declining precipitation levels decrease forage crude protein, digestible organic matter and quality. Moreover, they found precipitation increases are unlikely to compensate for the temperature induced forage quality declines. The resulting diminished forage nutrition and quality increases nutritional stress and cost, with the effect growing as climate change evolves, in regions with continental climates. Supplemental feeding may well be required.

These impacts are of particular importance in warmer climates, which characterize many developing countries. Megersa et al. (2014) [11] investigated the impacts of CC and variability on pastoral cattle production in southern Ethiopia, finding a decreasing production trend. The authors attribute this to a warming, more variable climate; diminished quantity/quality of forage; and increased water scarcity.

CC is also influencing the land allocation between feed production and grazing. Mu et al. (2013) [12] found that, in the continental US, increases in temperature and precipitation levels have caused cropland shrinkage and pastureland expansion. They also found that cattle stocking rates respond to CC, trending downward in hot regions as the temperature-humidity index rises and summer precipitation decreases. They projected implications under future CC, finding land shifting from cropping to grazing, with the stocking rate declining. Similarly, Seo et al. (2009) [13] find that under CC, high elevation African regions are hotter and drier and favor a move to livestock, out of cropping. Seo (2010) [14] finds a wetter climate increases the joint production of crops and animals. Weindl et al. (2015) [15] projected that future CC will shift production systems towards mixed crop-livestock systems. Rivera-Ferre et al. (2016a) [4] find CC will shift the livestock production system mix.

Generally, livestock producers have adapted to the changing climates by (1) shifting out of cropping into grazing; (2) adopting mixed crop-livestock systems; and (3) decreasing stocking rates and/or herd sizes. However, these responses do not necessarily overcome all adverse effects and increases in supplemental feeding may be needed. Additionally, each of these adaptation strategies has an impact on the GHG emission profile of the livestock sector, as further discussed in Section 3.

2.2. Genetics/Breeds/Species

Adaptations can also involve altered characteristics of livestock incidence, species and breeds.

2.2.1. Ruminants

In a modeling study, Mader et al. (2009) [5] found elevated US temperatures, with the rises ranging from +1 to 2 degrees Celsius under the doubling scenario where the atmospheric CO_2 level is about twice the baseline period (1850–1985) level and +2 to 4 degrees Celsius under the tripling scenario, would decrease Southern US animal weight gains and milk produced as a result of decreased appetite and increased energy requirements. In turn, they find that beef cattle would require 4–5% longer of a feeding period to reach market weight. They suggest adaptation strategies involving the installation of shade, sprinklers, or evaporative cooling services. For larger temperature increases, they suggest facility modifications, changes to herd genetics and perhaps changing enterprises.

Gaughan and Cawdell-Smith (2015) [16] reviewed studies of CC impacts on livestock production and reproduction, concluding that findings largely indicated detrimental effects. They argue that adaptation in the form of genetic manipulation, breed change and/or species change may be needed. Silanikove (2000) [17] indicates a switch to goats from cattle may be in order as: (a) goats have been found to be better adapted to hotter conditions; (b) goats possess skillful grazing behavior; and (c) the goat digestive system is more efficient as the rumen can serve as a fermentation vat and water reservoir. One should note that animal physiology and genetics limit an animal's adaptive capacity and that livestock breeders can alter traits to enhance adaptation [16].

Breeds and species changes are also possible adaptations. Seo et al. (2010) [18] examined climate influence on choices among five primary South American livestock species. Their results suggest that as CC shifts toward hotter and drier conditions, producers would reduce beef cattle, dairy cattle, swine and poultry but increase sheep. Zhang et al. (2013) [19] examined breed choice between *Bos taurus*, *Bos indicus* and composite breeds in Texas, finding summer heat stress influenced breed selection, with heat stress increasing favoring *Bos indicus*, while reducing *Bos taurus* and composite breeds. Wu (2015) [20] examined how CC influences the distribution of yak breeds in China, finding breed incidence has mainly shifted northward or westward (which is upward in elevation), partly as a response to the thermal conditions.

Animal incidence is also affected by climate "extremes". Seo (2015) [21] found in Australia that under high temperature conditions, sheep production increases in arid ecosystems while beef cattle remain about the same. The study also predicts under hotter and more arid CC futures that crops will decrease and numbers of beef cattle and/or sheep will increase. They indicate this shift is due to increased comparative advantage of raising livestock and reduced prevalence of livestock diseases. For small-ruminants, Seo (2016) [22] found that, as the monsoon climate intensifies, Indian farm households would increase goat numbers.

Finally, regional adaptation will be in order as a shift in livestock species and incidence will alter needs for supporting industries providing feed, animal and feed transport, animal slaughter and meat packing and final product transport [3].

To summarize, different ruminant livestock species or breeds respond differently to climate alterations and that livestock producers can adapt to CC by changing species or breeds.

2.2.2. Non-Ruminants

As pointed out in Rojas-Downing et al. (2017) [2], most of the livestock research has focused on ruminants but a few studies have addressed other species.

Lara and Rostagno (2013) [23] reviewed research on heat stress, poultry production and producer adaptation. They found heat stress reduced poultry growth, decreased poultry and egg quality and led to a declining immune response. They also argued that the basic mechanisms underlying such detrimental effects are not well understood. On adaptation, they indicate that there have been ambiguous adaptation strategy effects, including the results of efforts on environment modification, nutritional and drinking water manipulation. For swine, Mader et al. (2009) [5] found that southern US swine would require 74% more time to reach market weights under certain CC scenarios, due to lowered feed intake and increased demand for energy for thermoregulation, maintenance, protein and fat synthesis.

Canario et al. (2013) [24] reviewed genetic effects on swine, poultry and fish performance along with beef and dairy cattle, finding altered behavioral traits can be an adaptation. For broilers and dairy cattle, they indicate that improving locomotor capacity enhances adaptation, while for beef cattle, greater docility would be desirable. For swine, they indicate desirable adaptations would reduce aggressiveness while enhancing maternal behavior. Regarding laying hens, they found reducing sensitivity to environmental stress such as changes in physical environment, social setting and human handling, would be desirable. In brief, behavioral traits can be an area for exploring adaptation strategies.

Sjöberg et al. (2011) [25] examined CC impacts on wild mallard ducks in northern Sweden. They found that moderate CC had minor effects on duckling survival and this could be due to a trait that copes with CC. However, whether and how this translates to adaptation strategies for domestic poultry production remains to be explored.

Zheng et al. (2017) [26] find that genetic trait modification can decrease low-temperature susceptibility and that there is substantial potential to explore this, as CC portends changes but there has been little recent work on animal climate resilience.

2.3. Diseases

The literature on livestock diseases under CC is rather sparse. Gale et al. (2009) [27] reviewed how CC affects livestock diseases in Great Britain. They list disease related factors that would be affected by CC, including the molecular biology of pathogens, vectors, zoological factors, farming practices and the establishment of new microenvironments. Gale et al. (2009) [27] further indicate that for endemic livestock pathogens, CC induced flooding would increase occurrence and outbreak severity. For exotic livestock diseases, CC would increase the range and/or competence of the non-vertebrate vectors, plus alter immunity within vertebrate host reservoirs.

Other studies have addressed diseases and pests and the relationships to breed choice in adaptive response. White et al. (2003) [28] studied the impacts of CC-induced changes in cattle ticks (*Boophilus microplus* Canestrini) on cattle performance in Australia, projecting increases in tick induced losses (annual beef losses of nearly 8 thousand tons by 2030, rising to over 21 thousand tons by 2100). They suggest adaptation by switching to more tick-resistant breeds, as well as increasing tick control treatment frequency. Additionally, they found that reducing tick numbers per animal below 100 for European breeds and 700 for crossbred breeds would reduce losses dramatically. They argue optimal adaptation strategies lie in between using breeds with *Bos indicus* traits for tick resistance and excluding ticks in cattle-rearing areas.

Wittmann et al. (2001) [29] examined key contributing CC attributes to the advance of *C. imicola* ("a vector of bluetongue virus and African horse sickness virus" [29]) into Europe. They found monthly minimum temperatures, maximum temperatures and the number of months per year with mean temperatures exceeding 12.5 degrees Celsius, statistically were the factors. The authors projected that CC, to date and as projected, would increase disease incidence.

For poultry, Mu et al. (2014) [30] found CC to date has enhanced incidence of avian influenza globally and that projected CC would future increase the spread.

Thornton et al. (2009) [10] discussed multiple aspects of CC related to livestock diseases, including pathogens, vectors, hosts and epidemiology. They pointed out that existing studies have tended to oversimplify the mechanisms of disease dynamics and that studies are particularly lacking in developing countries with more work needed.

2.4. Trade and Local Institutions

Godber and Wall (2014) [31] found that sub-Saharan Africa countries and some in Asia are among the most vulnerable to CC as their food security will be under threat. They also argue that in those countries, the lack of economic and technical support for CC adaptation can make the situation worse. Note that livestock are an important rural food source in these regions, especially during poor harvest years [31].

Mosnier et al. (2014) [32] modeled CC impacts on food security in four east Asian countries. They found that trading/imports has the potential to offset the negative direct food security impacts of CC. Moreover, they find the price signals generated by the trading mechanisms can induce adjustments in regional production. However, while food security overall improves with trade, increased dependence on foreign food sources creates a source of political and transportation cost risk.

Trade cannot always overcome CC effects, especially when countries interconnected by trade are subject to similar CC impacts. In such a case, local agrometeorological and agronomic/livestock production support programs may be helpful. For example, Duru et al. (2012) [33] found that holding adaptation strategy workshops for stakeholders increases credibility when introducing adapted livestock systems. They argue workshops improve producer understanding of presented options and researcher understanding of real-world practice concerns, both enhancing adaptation.

Local agriculture traditional knowledge is of great importance too for adapting to CC. Rivera-Ferre et al. (2016b) [34] argue that local institutions can make essential contributions to CC adaptation. This includes institutions that help secure water access under both flooding and drought.

To summarize, adaptation strategies that develop or improve trading networks, or promote local support programs, would be of value to reduce the impact of individual producers, avoiding larger sectoral adjustments that would disrupt the sector. Trade liberalization of livestock products can also reduce direct CC vulnerability.

3. Mitigation

According to the Intergovernmental Panel on Climate Change (IPCC) [35], GHG emissions are the main anthropogenic driver of CC. In recent decades, global negotiations have taken place regarding net GHG emission reductions which is called mitigation. The livestock sector is certainly in that conversation [36,37], as it emits 14.5% of global GHG emissions [2]. There is interest in mitigating GHGs by altering livestock incidence, management and land use. We will visit potential mitigation options below.

3.1. Land Resources Management—CO_2 Emissions

Livestock need feed, and feed comes from land, both in grazing form and from harvested agricultural products. Land use practices on feed producing crops or grasslands offer opportunities for mitigation. Less soil disturbance, deeper rooted vegetation and greater plant litter retention leads to larger volumes of carbon retained by the soil. Also, improved grazing management can enhance sequestration. Legume sowing on pasturelands can increase sequestration but it must be balanced against legume induced nitrous oxide (N_2O) emissions [3].

Henderson et al. (2017a) [38] derived a global marginal cost schedule for livestock abatement options, finding that optimal strategies vary regionally. Regarding land-based options, the authors projected that improved grazing management would be particularly cost effective in Latin America and Sub-Saharan Africa, while legume sowing on pastureland would work best in Western Europe and Latin America.

Deforestation is another major livestock and land related mitigation concern. Studies have shown that livestock are a principal user of newly deforested land [39,40]. Cohn et al. (2014) [40] suggest that intensifying cattle ranching on traditional lands can help reduce deforestation and consequent GHG emissions.

Focusing on ruminant livestock, Havlík et al. (2014) [41] found that by 2030, autonomous transitions towards more efficient livestock production systems can bring about 736 million tons of

CO_2-eq savings per year and this would be largely realized via avoided land use conversion. Moreover, they suggest that mitigation via targeting land-use change instead of livestock would be more efficient, from a GHG abatement perspective.

Steinfeld et al. (2006) [42] argue that prudent management of land resources is critical for preserving or gaining GHG savings. Land conversion prevention options for CO_2 savings include: better management of existing protected areas; facilitating eco-services payment mechanisms to conserve carbon sequestered savannah lands. Furthermore, other land use mitigation actions involve conversion of cropland to grassland, reduction in grazing intensity, limiting biomass burning, implementing climate-friendly plant species mixes, erosion control and nutrient amendments for restoring degraded rangeland [36,37].

In brief, livestock systems are typically intertwined with land resources and the management of which bears potentially promising strategies. Activities such as improving grazing management, legume sowing and avoiding deforestation, can mitigate GHG emissions.

3.2. Reducing Fertilization for Feed Production—N_2O Emissions

The livestock sector consumes a large share of feed crops, as well as hay and silage, and is thus indirectly responsible for a share of cropping emissions [42]. Approximately 0.2 billion tons of CO_2-eq N_2O emissions are released as a consequence of synthetic fertilizer application on cropland, plus fertilizer manufacture produces about 0.04 billion tons of CO_2-eq emissions, meanwhile applying manure to cropland accounts for almost 20% of total anthropogenic N_2O emissions [42]. Collectively emissions occurring during production, processing and transport of feed have been estimated to make up 45% of livestock GHG emissions, among which about half are N_2O emissions [42–44].

Rafique et al. (2011) [45] found that N_2O emissions are non-linearly related to the nitrogen (N) quantity applied on grazed grassland in Ireland. For example, when N applied on grassland increased from 300 to 400 kg/ha per year, the resultant N_2O emissions doubled from 5.0 to 10 kg N_2O-N/ha per year. They indicate that smart management of N fertilizers would make a mitigation contribution.

To sum, fertilizer management on feed and forage lands can yield GHG mitigation benefits. Additionally, the tradeoff between manure, as will be discussed later in this section and synthetic fertilizer application must be compared from a radiative forcing standpoint, since the activities generate different GHG gases.

3.3. Enteric Fermentation—CH_4 Emissions

Enteric fermentation methane (CH_4), emitted from ruminants during digestion, is a main source of global methane emissions [42]. Enteric fermentation is responsible for 25% of global methane emissions or 4% of overall anthropogenic GHG emissions. Among the sources of enteric fermentation, animals in mixed crop-livestock systems make up for 64%, followed by grazing systems at 35% and industrial systems at 1%. By animal, cattle emit 77%, buffalos 13% and small ruminants the remaining 10% [43].

Gerber et al. (2013) [43] synthesized studies on enteric fermentation mitigation potential, indicating it can be reduced by manipulating animal diets to improve feed digestibility and by using feed additives. One contributing factor is the extent of roughage consumption, with emissions getting reduced by using higher quality diets with more cereal grains and oil meals [2]. Caro et al. (2016) [46] estimated that, by adding lipids into ruminant diets, the enteric CH_4 emissions can drop by 15.7%. Also, Henderson et al. (2017a) [38] found that treating crop byproducts with urea can mitigate CO_2, N_2O and CH_4 emissions and using feed dietary lipids and nitrates can reduce enteric CH_4 emissions.

3.4. Manure—N_2O and CH_4 Emissions

Livestock manures emit both N_2O and CH_4. Emission amounts depend on animal type, feeding and manure management practice. According to the US Environmental Protection Agency (EPA) [47], manure is the source of approximately 10% of livestock-related CH_4 emissions or 2.0% of total global non-CO_2 emissions, also, manure accounts for about 4% of global N_2O emissions or 1.3% of total non-CO_2 emissions.

Steinfeld et al. (2006) [42] estimated that global CH_4 emissions from manure decomposition amount to 17.5 million tons, with swine manure being the source of almost 50%. A look at country-specific numbers reveal that China has the highest manure-related CH_4 emissions, due to the presence of large-scale swine production. Emissions shares vary across countries. For example, Gac et al. (2007) [48] found in France that cattle emissions far outweigh swine and poultry portions and that CH_4 emissions mainly take place in livestock housing and manure storage facilities.

The IPCC reports on agriculture (2007, 2014) [36,37] summarized mitigation opportunities for CH_4 and N_2O emissions in the livestock sector, indicating mitigation can come from improving manure storage and handling, using anaerobic digestion and utilizing manure efficiently for fertilization. Apart from manure-related strategies, mitigation opportunities come also from feeding practices, such as using dietary additives.

Manure handling related mitigation practices include reducing the exposure of manure to water (e.g. dry scraping rather than washing into a pond) and changing management from anaerobic to aerobic conditions. One additional mitigation strategy for manure-related non-CO_2 emissions is to alter diets [43], since the GHG contents of manure is diet dependent. Specifically, the ration composition and feed additives can influence the amount of N in urine and feces and the amount of fermentable organic matter in feces, consequently resulting in alterations in manure-based CH_4 emissions. For example, in dairy cattle sectors, lipid supplementation reduces enteric CH_4 emissions but increases N_2O emissions [46].

Regarding manure N_2O emissions, Hou et al. (2015) [49] indicate the major emitting sources are (a) animal excreta in livestock housing and manure storage systems; (b) excreta from grazing animals on pastures; and (c) emissions from land applied manure. Often, housing and manure storage facilities are seen in confined livestock systems. Also, among the sources above, soil N_2O emissions originated from land applied manure is a significant one, as reviewed above in Section 3.2. In fact, a breakdown of global N_2O emissions shows that the stored manure-related N_2O emissions are 0.7 million tons of N per year, with the manure-related soil N_2O emissions being estimated as the largest contributor, incurring at approximately 1.7 million tons annually [3]. A study in France using a mass-flow approach [48] found that most of the N_2O emissions occurred after depositing manure on the soil.

Manure-related N_2O emissions during application/deposition plus management total about 1.17 billion tons of CO_2-eq, far greater than fertilizer-based N_2O emissions (application and indirect emissions) which total about 0.2 billion tons of CO_2-eq, according to Steinfeld et al. (2006) [42].

There are GHG performance differences between different types of livestock systems as well. Steinfeld et al. (2006) [42] found that confined industrial production systems emit 90% less N_2O emissions compared with mixed crop-livestock systems. However, since the overall size of industrial systems' contribution to livestock GHG emissions is small, the mitigation potential for N_2O emissions in such systems is limited.

Summarizing above, to reduce manure CH_4 emissions, amending diets can be of help but can increase N_2O emissions simultaneously. Manure management, such as shortening manure storage duration and anaerobic digestion can also be options. In addition, there is regional heterogeneity in the composition of non-CO_2 emissions by livestock systems and species. Finally, fertilization practices can alter manure soil N_2O emissions.

3.5. Reducing Livestock Numbers, Altering Breeds and Mix

A major mitigation strategy involves reducing herd size or composition. Thornton et al. (2009) [10] mention that the only effective way to reduce livestock CH_4 emissions in pastoral systems would be to reduce livestock numbers, as does Ripple et al. (2013) [1].

Patra (2017) [50] suggests that crossbreeding can be a mitigation strategy. For example, he estimates that if half of the indigenous cattle populations in India were replaced by crossbred cattle, then the carbon footprint of milk production could drop by 30% due to increased productivity.

Patra (2017) [50] also compared GHG emissions associated with hen and duck eggs production in India, finding that duck eggs' carbon footprints are in general much lower than hen eggs, thereupon the study suggests shifting poultry mix towards ducks to help mitigation.

More broadly, for the entire livestock sector, shifting the mix of livestock population towards more productive crossbred cattle, buffalo and ducks may not only satisfy the demands for animal products but also reduce the overall associated carbon footprints.

To sum, while reducing the livestock numbers may be the only effective and straightforward way for GHG emissions mitigation [1,10], there are still possibilities to alter livestock mixes and breeds [50].

3.6. Market and Trade

Mitigation strategies can also be implemented via market mechanisms. Henderson et al. (2017b) [51] explored the power of market forces on reducing ruminant GHG emissions. They focused on market-based carbon policies incorporating production substitution and trade. These forces were found to incentivize a restructuring of cattle production, raising the share of dairy animals relative to beef. Considering that the reduction in beef might be politically unpopular, they introduced scenarios with subsidies for producers, in combination with carbon policies. They found that market-driven shifts in regional production can help keep the production levels of ruminant products unchanged, meanwhile reducing associated GHG impacts, with emissions-intensive regions producing less livestock products under this type of policy combination.

On the demand side, changes in consumption of meats or dairy products have the potential to reduce both livestock numbers and feed production with accompanying reductions in GHG emissions. For example, Ripple et al. (2013) [1] indicate that swine and poultry typically have a lower carbon equivalent footprint than ruminants. Shifts in dietary preferences can thus alter sector-wide livestock GHG emissions. An Environmental Working Group report [52] argues that this can be substantial, since they estimate that the life cycle GHG emissions for beef is 27.0 kg CO_2-eq per kg consumed, pork 12.1 and chicken 6.9, while for non-meat alternatives it is smaller—for rice 2.7, tomatoes 1.1 and lentils 0.9.

Nonetheless, compared with the supply side, mitigation via altering consumption may not be efficient. For example, Havlík et al. (2014) [41] projected that policies regulating agriculture and land use change on the supply side would be much more efficient than adjustments on the demand side.

4. Strategy Summary

Table 1 summarizes mitigation and adaptation strategies based on the literature reviewed above, for developed versus developing countries, considering the remarkable differences in consumption and production ways and/or patterns between these two [3]. While the lists are not totally comprehensive, they offer a glimpse into the scope of the issue and the difference in human responses between developed and developing countries. In particular, developed countries are more likely to take expensive adaptation measures, such as modifying housing, making data-based decisions on breed selection and turning to biotechnology for adaptive crossbreeding. On the other hand, developing countries may choose directly changing species, or altering livestock numbers. As for mitigation, it may be more effective for developing countries to implement land use policies that prevent livestock related deforestation or other land use change. Meanwhile, for developed countries, the focus of mitigation could be on improving the efficiency of livestock systems by becoming more industrial, manipulating diets and advancing manure management, along with the reduction of feed supply related GHG emissions.

Table 1. Mitigation and Adaptation Strategies for Developed versus Developing Countries.

Adaptation/Mitigation	Section	Developed	Developing
Adaptation	Feed and Land Resources	Forage quality: • Use supplemental feed [8] Land use: • Shift land use from cropping towards grazing [12] • Decrease stocking rates [12]	Animal feed production: • Farm-level production adjustments [10] • Introduce/revise insurance/credit schemes; enhance income diversification opportunities [10] • Institutional changes such as introducing subsidies, strengthening markets and trade [10] • Adopt new technologies [10] Land use: • A move to livestock out of cropping [13] • Increase the joint production of crops and animals [13]
	Genetics/Breeds/Species	Ruminants: • Installation of shades, sprinklers, or evaporative cooling services [5] • Facility modification [5] • Changes to herd genetics [5] • Choose breeds with *Bos indicus* influence [19] • Increase beef cattle and/or sheep, out of cropping [21] Non-Ruminants: • Environment modification [23] • Nutritional and drinking water manipulation [23] • Use information on behavioral traits for decision-making on breeds selection [24]	Ruminants: • Switch from cattle to goats [16] • Increase sheep [18] • Increase goats [22]
	Diseases	Cattle: • Adjust breed structure by switching toward breeds with *Bos indicus* tick-resistance [28]	
	Trade and Local Institutions	Trade: • Trading can induce adjustments in regional production [32] Local Institutions: • Hold workshops inclusive of multi-stakeholders [33]	Trade: • Trading can induce adjustments in regional production [32] Local Institutions: • Local agriculture traditional knowledge can be of essential help [34]

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Table 1. *Cont.*

Adaptation/Mitigation	Section	Developed	Developing
Mitigation	Land Resources	Land Use: • Legume sowing on pasturelands [38]	Land Use: • Better management of existing protected area [42] • Facilitate eco-services payment mechanisms [42] • Improve grazing management [38] • Legume sowing on pasturelands [38] Land Use Change: • Intensify cattle ranching to avoid deforestation [40] • Transition towards more efficient livestock production systems [41]
	Fertilization	N fertilizers: • Smart management of N fertilizer application on grassland [45] N efficiency: • Increase N efficiency during both feed production and livestock assimilation stages [42]	N efficiency: • Increase N efficiency during both feed production and livestock assimilation stages [42]
	Enteric Fermentation	Nutrition: • Manipulate diets and use feed additives [2,43,46]	Nutrition: • Treat crop byproducts with urea in mixed crop-livestock systems [38]
	Manure Management	CH_4: • Reduce exposure of manure to water [42] • Shift management toward aerobic conditions [48] N_2O: • Shift towards industrial production systems [42]	CH_4: • Reduce exposure of manure to water [42]
	Livestock Numbers, Breeds and Mix		Numbers: • Decrease herd size [10] • Increase feeding efficiency, especially for swine and poultry [10] Breeds and Mix: • Increase crossbred shares [50]
	Market and Trade	Supply: • Shifts in regional production [51] Demand: • Shifts in dietary preferences [41]	Supply: • Shifts in regional production [51] Demand: • Shifts in dietary preferences [41]

5. Adaptation and Mitigation Synergies

Strategies in the adaptation and mitigation spaces can influence both endeavors. Figure 1 presents a Venn Diagram of the reviewed strategies for mitigation and adaptation in the livestock sector. The strategies falling in the overlapping area have implications for both mitigation and adaptation. For example, increased grains in the animal diet can reduce enteric fermentation CH_4 but this may increase the related GHG emissions from land use and fertilization. Further complicating this decision space are the relationships across mitigation and adaptation, as a variety of activities can affect both mitigation and adaptation in different ways.

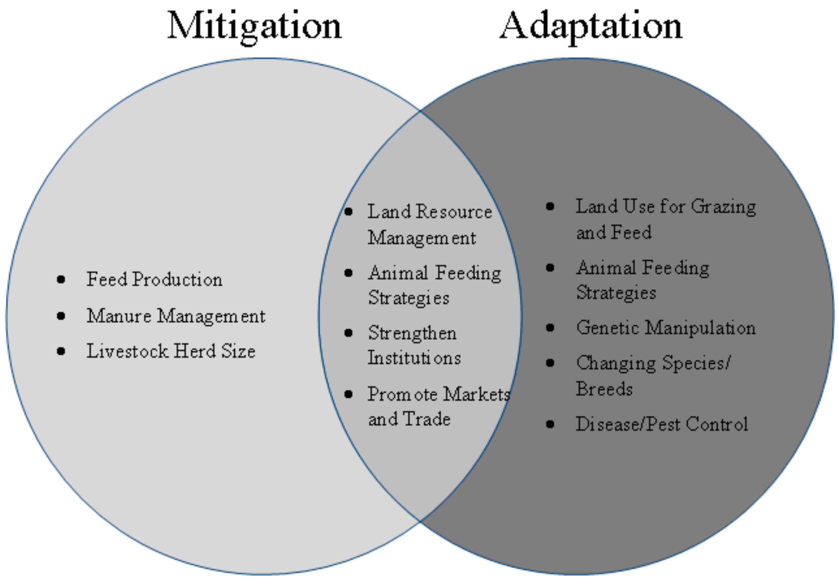

Figure 1. Venn Diagram of Strategies for Mitigation and Adaptation in Livestock Sector.

This naturally raises questions that could be explored for further research. For example,

- With the shifting power of market and trade, will mitigation and adaptation lead to the same-direction geographical changes in animal commodity movements and production relocation?
- As adaptation tends to induce a shift to livestock activities out of cropping, how would this change reconcile with the mitigation needs focusing on non-CO_2 emissions?
- On the consumer side, how will diet preferences be shaped or influenced by adaptation and mitigation, respectively? Would adaptation and mitigation automatically result in changes in the composition of animal commodities that are in accordance with human preferences?

6. Concluding Comments

Climate change has implications for livestock from impacts through changes in operations to adapt and mitigate. CC impacts livestock agriculture in two fundamental ways. First, CC impacts rates of gain, pest and/or disease incidence, alterations in feed supply, fertility and mortality. In the face of such impacts, adaptation is a desirable pursuit to abate the damages or exploit opportunities. Adaptation strategies can involve land use management, alteration of stocking rates, genetics, species mix, breeds and production relocation.

Additionally, as an important source of global anthropogenic GHG emissions, the livestock sector may face pressures or incentives to mitigate GHG emissions. The mitigation strategies mentioned above include alterations in land use for grazing and feed production, feeding practices and manure treatment. In general, land use strategies primarily mitigate CO_2 emissions, feed management reduces CH_4 emissions, while manure treatment impacts both CH_4 and N_2O emissions. Future research can focus on identifying strategies that work best for given local conditions.

In addition, strengthening institutions such as agricultural support programs, intra- and inter-regional trade can be of value for both mitigation and adaptation. The market-driven reallocation of production activities across regions involved in trading can be geared toward better performance in overall GHG emissions reduction, as well as assisting in food security and livelihood support. Further research on production and animal health under CC is needed. Observing livestock production globally across a diverse set of species, breeds, practices and climate conditions can help researchers identify possible adaptations.

Regarding the interactions of mitigation and adaptation, one can notice that strategies may contribute to both or move in opposite directions. For example, adapting to CC may imply increasing livestock activities and moving away from cropping for some regions, which would be against the tendency to reduce livestock numbers under mitigation. Despite of the differences, there are common grounds also. For example, strengthening trade mechanisms and local institutions would be of help for both mitigation and adaptation.

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Abbreviations

CC	climate change
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
CH_4	methane
EPA	Environmental Protection Agency
EWG	Environmental Working Group
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
N	nitrogen
N_2O	nitrous oxide
US	the United States

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