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Sustainable Livestock Production in the Context of the European Green Deal

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Abstract

Climate change is one of the major environmental challenges affecting natural resources, ecosystems, and food production systems worldwide. Livestock production plays a strategic role in food security and rural development; however, it also contributes to greenhouse gas emissions through enteric fermentation, manure management, feed production, energy consumption, and waste generation. This review evaluates the contribution of the livestock sector to greenhouse gas emissions within the framework of the European Green Deal and assesses the potential of sustainable livestock production practices to reduce emissions and enhance environmental sustainability. To this end, climate change, livestock-related greenhouse gas emissions, and sustainable production approaches were examined, with particular emphasis on sustainable pasture management, feeding strategies, manure management, renewable energy use, and resource-use efficiency. The available evidence indicates that methane emissions, declining pasture productivity, drought, rising temperatures, and increasing pressure on water resources pose significant threats to the sustainability of livestock production systems. Given its substantially higher global warming potential than carbon dioxide, methane has become a major focus of climate mitigation efforts. The European Green Deal and the Farm to Fork Strategy promote the transition toward more sustainable and resource-efficient livestock production systems. Within this framework, sustainable pasture management, high-quality forage production, efficient feed utilization, improved animal nutrition strategies, manure and waste management, renewable energy use, and enhanced resource-use efficiency have emerged as important practices for reducing environmental impacts. The review highlights that reducing greenhouse gas emissions while maintaining production efficiency is essential for the long-term sustainability of livestock systems. Consequently, sustainability-oriented livestock policies and production practices are critical for environmental protection, conservation of natural resources, and future food security.

Keywords: *European Green Deal; sustainable livestock production; greenhouse gas emissions; methane emissions; climate change; livestock production systems*

Introduction

Climate change is currently recognized as one of the most significant global challenges, with profound environmental, economic, and social implications for humanity. Since the Industrial Revolution, increased fossil fuel consumption, rapid population growth, urbanization, industrialization, deforestation, and the unsustainable use of natural resources have led to a rise in the concentration of greenhouse gases in the atmosphere. Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) contribute to global warming, resulting in rising temperatures, drought, extreme weather events, biodiversity loss, and reductions in water resources (IPCC, 2023). These developments have significantly affected the agricultural sector, which is highly dependent on natural resources, particularly livestock production systems.

Agriculture is considered not only one of the sectors most affected by climate change but also one of the major sources of global greenhouse gas emissions. Agricultural and food systems accounted for approximately 32% of global greenhouse gas emissions in 2023 (FAO, 2025). Livestock production, an important component of the agricultural sector, contributes substantially to greenhouse gas emissions through processes such as enteric fermentation, manure management, feed production, fertilizer use, and energy consumption (Bellarby et al., 2012; Nugrahaeningtyas et al., 2024). In particular, methane emissions from ruminants contribute substantially to climate change because of methane's high global warming potential (Gerber et al., 2013). Despite these environmental impacts, the livestock sector is of strategic importance for ensuring food security, sustaining rural livelihoods, and supporting agricultural economies (Steinfeld et al., 2006).

In this context, sustainable livestock production is defined as a holistic approach that integrates environmental, economic, and social dimensions while aiming to reduce environmental impacts, conserve natural resources, and maintain production efficiency (Dumont et al., 2013).

The European Green Deal, introduced by the European Union (EU) as part of its efforts to combat climate change, represents a comprehensive transformation policy aimed at achieving net-zero greenhouse gas emissions by 2050 (European Commission, 2019). The Farm to Fork Strategy, developed within the framework of the European Green Deal, aims to establish sustainable food systems, reduce environmental impacts, conserve natural resources, and promote environmentally sustainable production practices (European Commission, 2020a).

Accordingly, the development and implementation of sustainable production strategies in livestock farming are becoming increasingly important for environmental sustainability. This study aims to assess the contribution of the livestock sector to greenhouse gas emissions within the framework of the European Green Deal and to examine the potential contributions of sustainable livestock practices to emission reduction and environmental sustainability. In this regard, the roles of practices such as sustainable pasture management, feeding strategies, manure management, renewable energy use, and resource use efficiency in the livestock sector are reviewed.

Climate Change and Greenhouse Gas Emissions

Global Climate Change

Global climate change refers to long-term changes in temperature, precipitation patterns, and climatic events associated with increased concentrations of greenhouse gases in the atmosphere. In particular, the increased use of fossil fuels following the Industrial Revolution, together with industrialization, urbanization, deforestation, and the intensive use of natural resources, has led to increased concentrations of greenhouse gases in the atmosphere and accelerated global warming (IPCC, 2023). While global warming refers to the increase in the Earth's average temperature, climate change encompasses the environmental, ecological, and socio-economic changes resulting from this temperature increase (Diffenbaugh & Burke, 2019; IPCC, 2023).

The greenhouse effect, one of the fundamental components of the climate system, occurs when certain gases in the atmosphere allow incoming shortwave solar radiation to pass through while retaining part of the longwave radiation emitted from the Earth's surface. Although the natural greenhouse effect is essential for sustaining life on Earth, the increase in greenhouse gas concentrations resulting from human activities disrupts the natural balance of this process and accelerates global warming. The major greenhouse gases in the atmosphere are carbon dioxide, methane, nitrous oxide, and fluorinated gases (IPCC, 2023). The mechanism of the greenhouse effect and the major radiation processes in the atmosphere are schematically illustrated in Figure 1.

Climate change leads to major environmental problems, including rising temperatures, drought, extreme weather events, floods, reductions in water resources, biodiversity loss, and ecosystem degradation. These environmental changes have significant impacts on natural resources, ecosystems, and human life. Therefore, reducing greenhouse gas emissions and promoting sustainable production models have become increasingly important for mitigating climate change.

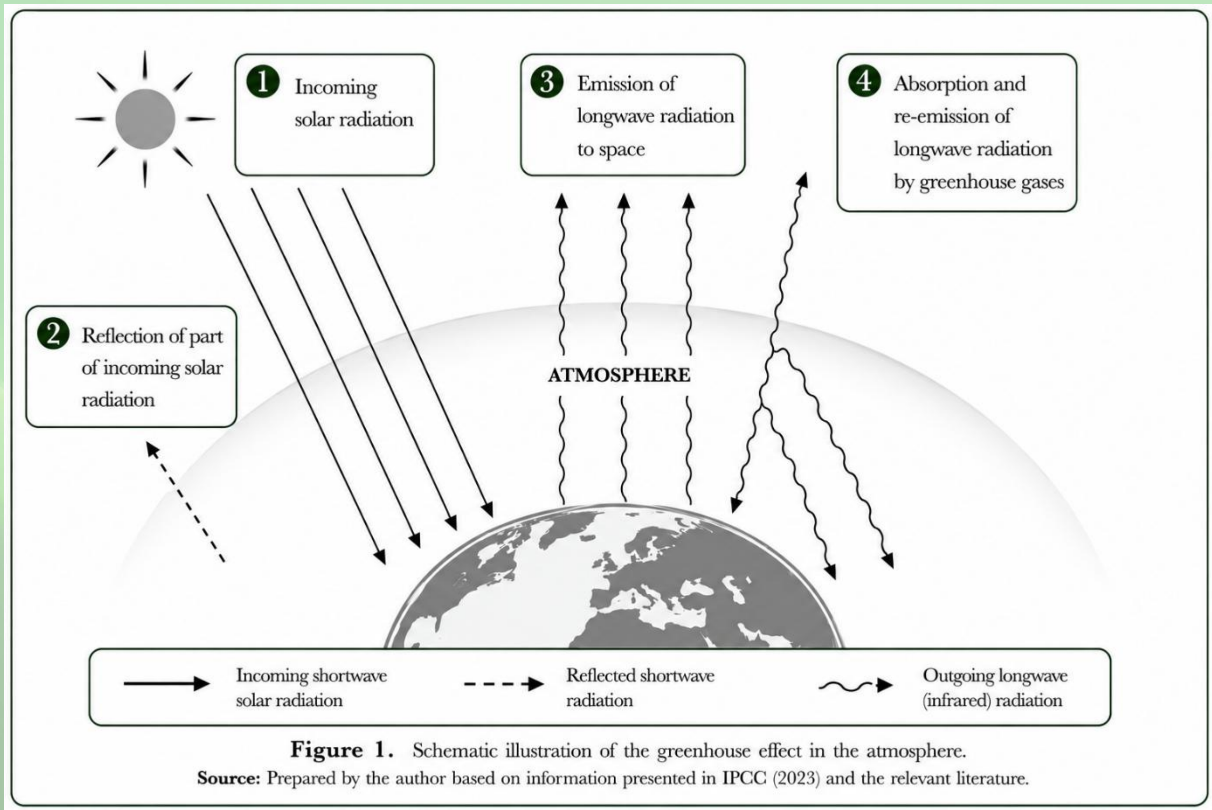


Figure 1. Schematic illustration of the greenhouse effect in the atmosphere.

Greenhouse Gases and Their Sources

Greenhouse gases differ in terms of their global warming potential, atmospheric lifetimes, and emission sources. Most greenhouse gas emissions originate from anthropogenic activities, including energy production, industrial processes, transportation, agriculture, and land-use change (FAO, 2025).

Carbon dioxide is the greenhouse gas that accounts for the largest share of global greenhouse gas emissions. The major sources of carbon dioxide emissions include fossil fuel combustion, energy production, industrial activities, and deforestation (IPCC, 2023). In particular, the increasing use of coal, oil, and natural gas in the energy sector has led to higher atmospheric carbon dioxide concentrations. In addition, land-use changes and the reduction of forest areas weaken carbon sinks.

Although its atmospheric concentration is lower than that of carbon dioxide, methane is one of the major greenhouse gases because of its high global warming potential. The main sources of methane emissions include fossil fuel production, waste management, rice cultivation, and livestock production. In the livestock sector, most methane emissions originate from enteric fermentation and manure management (Nugrahaeningtyas et al., 2024).

Nitrous oxide is one of the major greenhouse gases because of its high global warming potential and long atmospheric lifetime. A large proportion of nitrous oxide emissions originates from agricultural activities. In particular, chemical fertilizer use, manure application, and soil management practices contribute to increased nitrous oxide emissions (IPCC, 2023). Excessive nitrogen use in agriculture further increases soil-derived nitrous oxide emissions.

Contribution of Agriculture to Greenhouse Gas Emissions

Agricultural activities contribute significantly to global greenhouse gas emissions through energy use, chemical fertilizer application, irrigation, land-use change, and livestock production (IPCC, 2023). In recent years, agricultural and food systems have accounted for an increasing share of global greenhouse gas emissions. According to FAO (2025), greenhouse gas emissions from agricultural and food systems account for approximately 32% of global emissions.

Carbon dioxide emissions mainly originate from agricultural mechanization, energy use, and land-use changes. In addition, rice cultivation, livestock production, and waste management contribute to increased methane emissions, whereas chemical fertilizer use and soil management practices lead to increased nitrous oxide emissions (IPCC, 2023).

Livestock production is considered one of the major contributors to agricultural greenhouse gas emissions. In particular, livestock production accounts for a substantial share of agricultural emissions, and its environmental impacts are mainly associated with processes such as enteric fermentation, manure management, feed production, and energy use (Bellarby et al., 2012; Nugrahaeningtyas et al., 2024).

In line with global trends, the agricultural sector is an important source of greenhouse gas emissions in Türkiye. As of 2024, the agricultural sector accounted for 12.6% of the country’s total greenhouse gas emissions (TURKSTAT, 2026). Among agricultural emissions, enteric fermentation and manure management, particularly those associated with cattle production, are the major sources of emissions. This situation highlights the importance of promoting sustainable livestock practices in Türkiye.

Environmental Impacts of the Livestock Sector

Greenhouse Gas Emissions from Livestock Production

Livestock production is considered one of the major drivers of climate change because of its substantial contribution to global greenhouse gas emissions. In particular, enteric fermentation, manure management, feed production, and land-use change are among the major sources of emissions from livestock production systems (Gerber et al., 2013; Herrero et al., 2016; Nugrahaeningtyas et al., 2024). These processes result in different levels of greenhouse gas emissions depending on the characteristics of the production system and management practices.

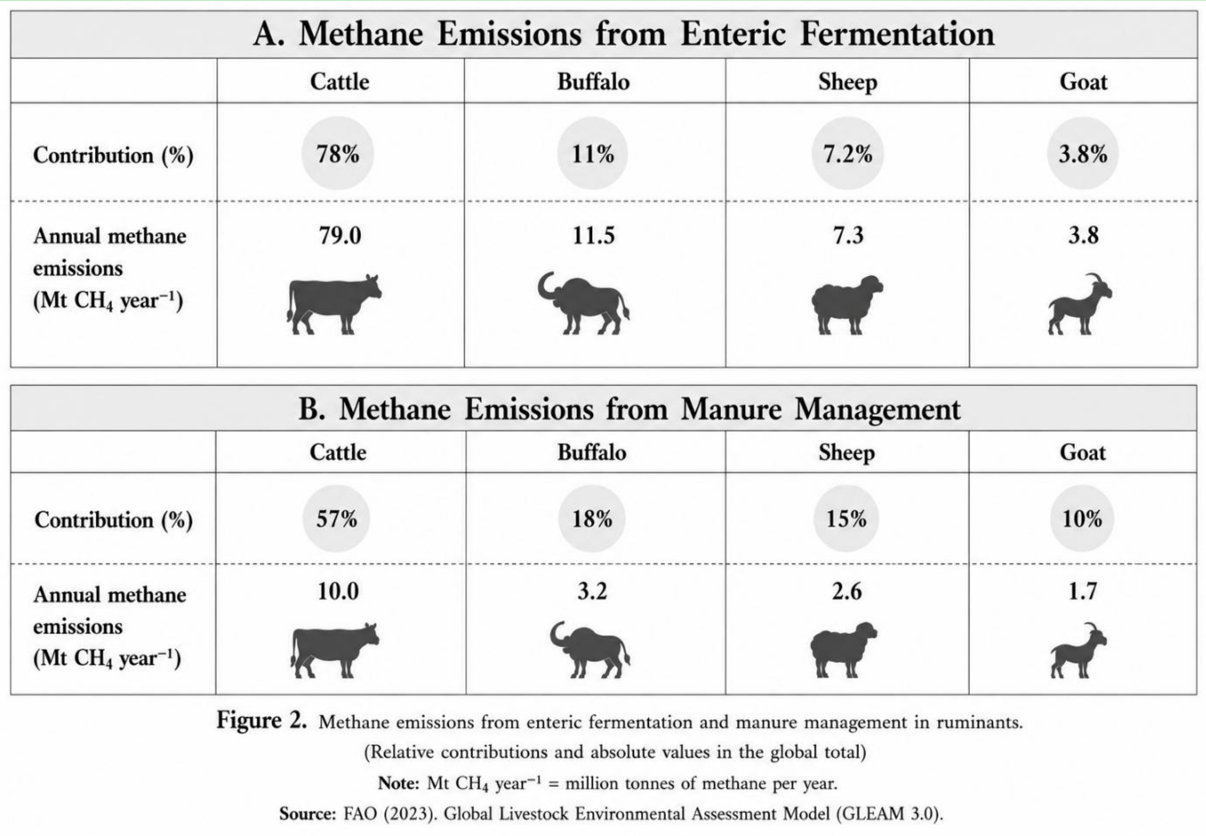
Methane accounts for a substantial proportion of greenhouse gas emissions from livestock production. Most methane emissions from livestock originate from enteric fermentation. Methanogenic microorganisms in the rumen produce methane by utilizing hydrogen and carbon dioxide generated during carbohydrate fermentation (Janssen & Kirs, 2008). Most of the methane produced is released into the atmosphere primarily through eructation. Most enteric methane is produced in the rumen (Getabalew et al., 2019). In addition, enteric fermentation accounts for a considerable proportion of global anthropogenic methane emissions (FAO, 2023).

Enteric methane production is influenced by several factors, including animal species, feed intake level, diet composition, feed digestibility, and production system (Thornton, 2010; Beauchemin et al., 2022). In particular, prolonged ruminal fermentation associated with low-quality forages may increase methane production. In contrast, highly digestible feeds, appropriate feed processing methods, and balanced diets can contribute to reducing enteric methane emissions (Beauchemin et al., 2022).

Globally, a substantial proportion of livestock-related greenhouse gas emissions originates from cattle production systems. In particular, dairy and beef cattle production systems occupy a dominant position within the sector because of methane emissions associated with enteric fermentation (FAO, 2017; Getabalew et al., 2019).

The relative contributions of ruminant species to methane emissions from enteric fermentation and manure management are presented in Figure 2. As shown in the figure, methane emissions from ruminants are predominantly derived from enteric fermentation. Total methane emissions from enteric fermentation are approximately 101.6 Mt CH_4 year^{-1}, of which 78% is attributed to cattle, 11% to buffaloes, 7.2% to sheep, and 3.8% to goats. In contrast, total methane emissions from manure management are approximately 17.5 Mt CH_4 year^{-1}, with cattle accounting for 57%, buffaloes for 18%, sheep for 15%, and goats for 10% of total emissions.

These findings indicate that approximately 85% of methane emissions from ruminants originate from enteric fermentation, whereas the remaining 15% is associated with manure management. The dominant contribution of cattle production to both emission sources suggests that methane mitigation strategies implemented in cattle production systems may provide greater emission reduction potential. The higher enteric methane production observed in cattle is associated with their larger body size, higher feed intake, and greater rumen volume (Broucek, 2014).



A. Methane Emissions from Enteric Fermentation

	Cattle	Buffalo	Sheep	Goat
Contribution (%)	78%	11%	7.2%	3.8%
Annual methane emissions (Mt CH_4 year^{-1})	79.0	11.5	7.3	3.8

B. Methane Emissions from Manure Management

	Cattle	Buffalo	Sheep	Goat
Contribution (%)	57%	18%	15%	10%
Annual methane emissions (Mt CH_4 year^{-1})	10.0	3.2	2.6	1.7

Figure 2. Methane emissions from enteric fermentation and manure management in ruminants.
(Relative contributions and absolute values in the global total)
Note: Mt CH_4 year^{-1} = million tonnes of methane per year.
Source: FAO (2023). Global Livestock Environmental Assessment Model (GLEAM 3.0).

Figure 2. Methane (CH_4) emissions from enteric fermentation and manure management in ruminants.

These results indicate that priority should be given to reducing enteric fermentation-related emissions in greenhouse gas mitigation strategies for the livestock sector. In this context, improving feed quality, optimizing diet composition, and using methane-reducing feed additives are among the most promising approaches for reducing enteric methane emissions. In addition, biogas technologies, composting practices, and advanced manure management systems can contribute to reducing manure-related methane emissions.

Another important source of emissions from livestock production is manure management. Methane is produced as a result of the anaerobic decomposition of organic matter during the storage of animal feces and urine. In addition, nitrification and denitrification processes occurring after manure application contribute significantly to nitrous oxide emissions (IPCC, 2023). In particular, liquid manure storage systems and high nitrogen contents contribute to increased greenhouse gas emissions, especially nitrous oxide emissions.

The environmental impacts of livestock production systems are not limited to direct emissions but are also influenced by indirect processes, including feed production, energy use, and land-use change (Bellarby et al., 2012; Herrero et al., 2016).

Feed Production and Resource Use

Livestock production systems exert significant environmental pressures on natural resources because of activities such as feed production, energy use, water consumption, and land use. Globally, approximately 26% of the ice-free terrestrial surface is used for grazing, while nearly one-third of cropland is devoted to feed production (Steinfeld et al., 2006). Increasing demand for animal products, increased feed production, and the widespread adoption of intensive production systems have increased pressure on natural resources (Herrero et al., 2016).

Feed production is considered one of the key factors determining the environmental impacts of livestock production systems. Chemical fertilizers, irrigation practices, and agricultural mechanization used in feed crop production result in substantial energy consumption and greenhouse gas emissions (de Vries & de Boer, 2010). In addition, the expansion of agricultural land for feed production may lead to land-use changes, resulting in ecosystem degradation, reductions in carbon sinks, and increased greenhouse gas emissions (Leip et al., 2015).

Energy use in livestock production is associated with processes related to feed production, mechanization, housing systems, and production infrastructure. In particular, increased energy use in intensive production systems contributes to greater fossil fuel consumption and associated carbon dioxide emissions. Energy requirements vary depending on the production system, farm size, and technologies used (de Vries & de Boer, 2010). Therefore, improving energy efficiency and promoting the use of renewable energy sources are considered effective strategies for reducing environmental impacts.

Water use is also one of the key factors determining the environmental sustainability of livestock production. Water use in livestock systems is not limited to drinking water requirements but also includes feed production, farm operations, and product processing, all of which contribute substantially to total water use (FAO, 2019). In particular, irrigation practices used in feed crop production account for a large proportion of total water consumption. Increasing pressure on water resources may negatively affect the sustainability of livestock production systems, especially in regions with a high risk of drought.

Land use and natural resource consumption are among the major factors affecting the environmental performance of livestock production systems. The need for extensive areas for feed production and grazing may increase pressure on land resources, thereby increasing the risk of soil degradation, erosion, and biodiversity loss (Leip et al., 2015). The intensive use of natural resources poses various environmental risks to the long-term sustainability of production systems.

Impacts of Climate Change on Livestock Production

Climate change has both direct and indirect effects on livestock production systems, with important consequences for milk and meat production, animal health, feed resources, and water availability (Cheng et al., 2022). Rising temperatures, changes in precipitation patterns, and the increasing frequency of extreme climatic events pose significant risks to the sustainability of the livestock sector (Godde et al., 2021). These effects may occur directly through impacts on animal thermoregulation, metabolism, immune function, and production performance, or indirectly through changes in feed production, water availability, and disease and parasite pressure (Cheng et al., 2022). The direct and indirect effects of climate change on livestock production systems and their consequences for production performance and sustainability are schematically illustrated in Figure 3.

One of the most evident effects of climate change on livestock production systems is heat stress. High ambient temperatures challenge the thermoregulatory mechanisms of animals, resulting in reduced feed intake. Particularly in ruminants, increasing temperatures may lead to declines in feed intake, milk yield, body weight gain, and reproductive performance. Prolonged heat stress may result in adverse consequences, including metabolic disorders, impaired immune function, and increased mortality. In addition, high-producing animals have been reported to be more susceptible to heat stress (Das et al., 2016).

Changes in precipitation patterns and drought conditions also significantly affect livestock production systems. In particular, reduced forage yield in pasture areas, declines in forage availability, and insufficient water resources may increase production costs (Thornton, 2010). Climate change may alter pasture composition, plant growth, and feed quality, while increasing temperatures and water stress may negatively affect biomass production and the digestibility of forage crops (Chapman et al., 2017). Consequently, changes in feed supply and feed quality may adversely affect livestock production performance. In addition, drought conditions have been reported to reduce pasture productivity and compromise the sustainability of grazing systems (Boone et al., 2018).

Climate change also exerts various adverse effects on animal health. High temperature and humidity conditions may weaken the immune system of animals and increase their susceptibility to disease (Naqvi & Sejian, 2011). In addition, changing environmental conditions may facilitate the spread of parasites, pathogens, and vector-borne diseases. Changes in temperature and precipitation patterns have been reported to increase disease and parasite pressure (Godde et al., 2021). Increased disease incidence and health problems may lead to production and economic losses in livestock systems.

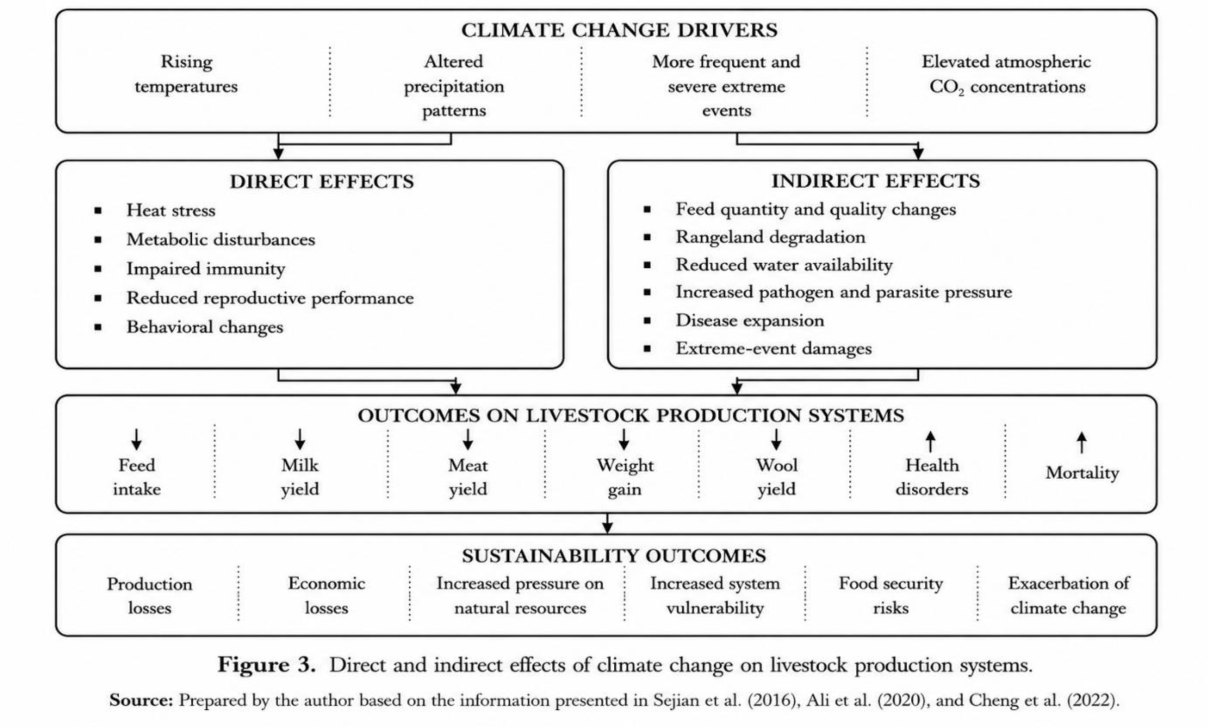


Figure 3. Direct and indirect effects of climate change on livestock production.

The increasing frequency of extreme climatic events also negatively affects livestock production systems. Events such as floods, heat waves, droughts, and wildfires may damage pasture areas, disrupt feed supply, and cause animal losses. In particular, extreme temperature conditions in intensive production systems may adversely affect animal welfare and increase productivity losses (Gaughan & Cawdell-Smith, 2015). In addition, extreme climatic events have been reported to exert significant adverse effects on feed supply chains and livestock production activities (Dellar et al., 2018).

Overall, climate change threatens the sustainability of livestock production systems by exerting multifaceted effects on production performance, feed resources, water availability, and animal health (Sejian et al., 2016; Ali et al., 2020; Godde et al., 2020). As a consequence, reductions in feed intake, milk and meat production, body weight gain, and reproductive performance may occur, whereas disease incidence, health problems, and mortality rates may increase (Figure 3). Therefore, the development of sustainable production models adapted to climate change, the use of heat-tolerant genotypes, the sustainable management of pasture and water resources, and the adoption of production systems resilient to environmental stress are considered key adaptation strategies.

European Green Deal and Livestock

The European Union (EU) has implemented the European Green Deal as a comprehensive transformation framework to address environmental challenges such as climate change, biodiversity loss, and the unsustainable use of natural resources. The main objective of the European Green Deal is to make the EU climate-neutral by 2050 and to transform it into a sustainable economy in which economic growth is decoupled from resource use (European Commission, 2019). In this context, livestock production systems are considered one of the priority areas for transformation under the European Green Deal because of their greenhouse gas emissions and pressures on land and water resources (Guyomard et al., 2020).

The Farm to Fork Strategy and the Biodiversity Strategy for 2030, developed within the framework of the European Green Deal, aim to strengthen environmental sustainability in food production systems (European Commission, 2020a; European Commission, 2020b). These strategies aim to achieve a 50% reduction in pesticide use and associated risks, a reduction in chemical fertilizer use, a 50% reduction in antimicrobial use in livestock production, and an increase in the share of organic agricultural land to 25% of total agricultural land (Jongeneel et al., 2021). In addition, the conservation of biodiversity, the reduction of natural resource use, and the promotion of sustainable production practices are among the key priorities of the European Green Deal (European Commission, 2020b).

Within the framework of the European Green Deal, the livestock sector is regarded both as a source of environmental impacts that need to be reduced and as one of the key components of the transition toward sustainability. According to the European Environment Agency, the agricultural sector accounts for approximately

10% of total greenhouse gas emissions in the EU, and a substantial proportion of these emissions originates from livestock production (EEA, 2020). According to the European Commission, 80.7% of methane emissions from livestock production originate from enteric fermentation, whereas 17.4% are associated with manure management (European Commission, 2020c). However, the environmental impacts of livestock production are not limited to methane emissions but also result from processes such as feed production, land-use change, and manure management (Gerber et al., 2013; Herrero et al., 2016).

Low-emission production practices, sustainable feeding strategies, pasture-based livestock systems, and environmentally friendly production models are among the approaches promoted under the European Green Deal. In this context, the use of alternative protein sources, the development of feeding strategies aimed at reducing enteric methane emissions, and the increased use of local feed resources are encouraged. In addition, the European Green Deal aims to reduce dependence on imported critical feed ingredients by supporting plant proteins produced within the EU and alternative feed resources such as insects, algae, and by-products derived from the processing of biological resources (European Commission, 2020a).

Improving animal welfare standards is also considered one of the priority policy areas under the European Green Deal. In particular, reducing antibiotic use, supporting pasture-based production systems, and further integrating animal welfare criteria into production systems are among the major objectives (European Commission, 2020a). In this regard, sustainable production models are emphasized not only as a means of reducing environmental impacts but also as an approach to improving animal health and welfare (Peyraud & MacLeod, 2020).

Extensive production systems based on permanent grasslands are considered production models that support environmental sustainability under the European Green Deal. These systems have been reported to contribute to soil carbon sequestration and support biodiversity conservation (EESC, 2021). Organic livestock production systems promoted under the European Green Deal are also closely associated with these production models and may contribute to reducing environmental pressures (Horrillo et al., 2020).

Jongeneel et al. (2021) reported that the implementation of the European Green Deal targets could result in an approximately 10–15% reduction in livestock production in the EU. In particular, regulations aimed at reducing greenhouse gas emissions, restrictions on fertilizer use, and stricter environmental standards may have significant effects on production levels, production costs, feed costs, farm income, and market competitiveness (Guyomard et al., 2020; Jongeneel et al., 2021). These effects are expected to be more pronounced in intensive production systems.

Within the framework of the European Green Deal, restructuring the Common Agricultural Policy (CAP) in line with environmental objectives is considered one of the key components of livestock policies. It has been suggested that the current CAP regulations are only partially aligned with the goals of the European Green Deal and that the climate and environmental dimensions of the policy need to be strengthened to achieve environmental objectives. In this regard, the expansion of performance-based support mechanisms, the promotion of practices that enhance animal welfare, and the development of policy instruments that contribute to climate and biodiversity targets have been recommended (Guyomard et al., 2020).

Nevertheless, the effects of this transition on production costs, farm income, and competitiveness should be carefully evaluated. Therefore, the development of balanced policy instruments that ensure both environmental sustainability and the economic viability of livestock production is of great importance.

Sustainable Livestock Production Approaches

Practices aimed at reducing the environmental impacts of livestock production systems include improved feeding strategies, the use of feed additives, efficient manure management, sustainable pasture management, biogas technologies, precision livestock farming applications, and the use of renewable energy sources. These practices contribute to maintaining production efficiency while also reducing greenhouse gas emissions and improving resource-use efficiency.

One of the key issues in sustainable livestock production is reducing greenhouse gas emissions. In particular, methane emissions resulting from enteric fermentation in ruminants account for a substantial proportion of emissions associated with livestock production (Herrero et al., 2016; Nugrahaeningtyas et al., 2024). Therefore, considerable research efforts have been directed in recent years toward developing nutritional and management strategies to reduce enteric methane emissions.

One of the principal approaches for reducing methane emissions is improving feed quality and optimizing diet composition. The use of highly digestible feeds, an increased proportion of high-quality forages, and the implementation of balanced diets can contribute to reducing enteric methane emissions. In addition, improving feed efficiency helps reduce greenhouse gas emissions per unit of product (Herrero et al., 2016; Beauchemin et al., 2022).

Feed additives are among the most extensively studied approaches for reducing enteric methane emissions. In particular, tannins, saponins, essential oils, and certain plant extracts can suppress methane formation by altering ruminal microbial activity (Nugrahaeningtyas et al., 2024; Türkmen, 2024). Tannins have been reported to exert inhibitory effects on methanogenic microorganisms and protozoa, whereas saponins may indirectly reduce methane production by decreasing ruminal protozoal populations. In addition, lipid supplementation has been shown to limit methane formation by altering hydrogen utilization (Beauchemin et al., 2022). However, the effectiveness of these approaches may vary depending on animal species, diet composition, and production systems.

In recent years, next-generation feed additives such as 3-nitrooxypropanol (3-NOP) and red algae have emerged as promising approaches for reducing enteric methane emissions. It has been reported that 3-NOP suppresses methane synthesis by inhibiting certain enzymes involved in methanogenesis (Türkmen, 2024). Similarly, bioactive compounds present in certain species of red algae have been shown to substantially reduce methanogenic activity in the rumen (Beauchemin et al., 2022; Nugrahaeningtyas et al., 2024). Nevertheless, the economic feasibility, long-term impacts, and efficacy of these approaches under different production systems are still being investigated.

Strategies aimed at reducing methane emissions are not limited to feed additives. Precision feeding practices, improved animal management, and increased productivity per animal can also contribute to reducing emission intensity (Beauchemin et al., 2022). In addition, studies focusing on the selection of animals with low methane production potential are considered valuable for sustainable livestock production. Genetic selection has been suggested to provide long-term and cumulative mitigation potential (Türkmen, 2024).

Manure management is one of the fundamental components of sustainable livestock production. Inadequate storage and management of animal waste may increase methane and nitrous oxide emissions. Accordingly, improved manure management systems, composting practices, and the widespread adoption of biogas technologies are important sustainable production approaches (Herrero et al., 2016; Nugrahaeningtyas et al., 2024). In particular, biogas systems contribute to renewable energy production while reducing greenhouse gas emissions associated with animal waste. Furthermore, recycling animal waste as compost and organic fertilizer supports circular production systems by enabling nutrient reuse.

Pasture management and pasture-based production systems are among the principal approaches supporting the environmental dimension of sustainable livestock production. Sustainable management of pasture resources can contribute to reducing erosion, conserving biodiversity, and enhancing soil carbon sequestration (Bellarby et al., 2012). In addition, appropriate grazing management practices have been reported to improve pasture productivity and help preserve soil carbon. Moreover, pasture-based production systems may provide several environmental advantages compared with systems relying on intensive feed inputs.

Organic livestock production systems are considered important components of sustainable production approaches. These systems may reduce environmental impacts because of their greater reliance on pasture resources, limited use of synthetic inputs, and stronger emphasis on animal welfare (Horrillo et al., 2020). Furthermore, this production approach may contribute to biodiversity conservation and environmental sustainability. However, their economic sustainability should be carefully evaluated, as productivity levels may be lower under certain conditions.

Technological developments play a critical role in the advancement of sustainable livestock production systems. Precision livestock farming technologies enable real-time monitoring of feed intake, animal behavior, health status, and environmental conditions. Sensor systems, automated monitoring technologies, and data-driven management practices have been reported to improve productivity, optimize resource use, and help reduce environmental impacts (Herrero et al., 2016). In addition, the use of renewable energy systems in livestock farms may contribute to reducing energy costs and greenhouse gas emissions associated with fossil fuel use.

Climate change adaptation strategies are also important components of sustainable livestock production systems. Practices such as the use of heat-tolerant genotypes, appropriate housing designs, improved ventilation systems, and efficient water management can help mitigate the adverse effects of climate change on animals. In particular, the development of production systems resilient to environmental stress conditions is important for maintaining production continuity and animal health (Türkmen, 2024). In addition, practices aimed at improving animal welfare have been reported to have positive effects on productivity and animal health.

Conclusions

Climate change poses increasing environmental, economic, and social challenges to livestock production systems. Methane and nitrous oxide emissions associated with livestock production, together with natural resource use, pressures on land resources, and water consumption, represent some of the major challenges to the environmental sustainability of the sector. Nevertheless, livestock production systems remain strategically important because of their contributions to food security, support for rural livelihoods, and their role in human nutrition.

The European Green Deal and related policy frameworks aim to promote the adoption of more sustainable livestock production models. Achieving these objectives requires stronger integration of environmental criteria into agricultural support policies, along with effective policy instruments that encourage sustainable production practices.

Practices aimed at reducing the environmental impacts of livestock production offer considerable mitigation and adaptation potential. However, drought, rising temperatures, declining pasture productivity, and increasing pressure on water resources are expected to pose greater risks to the sustainability of livestock production systems in the future.

The transition to sustainable production systems should be implemented not only in accordance with environmental objectives but also while taking into account economic feasibility, farm income, production costs, and food security. Measures aimed at reducing greenhouse gas emissions and changes in production systems may have significant effects on production costs and market competitiveness. Therefore, sustainability policies should be supported through producer incentives, investments in technical infrastructure, educational activities, and scientific research.

In conclusion, the widespread adoption of practices aimed at reducing greenhouse gas emissions and conserving natural resources in livestock production systems is important for mitigating the environmental impacts of the sector. At the same time, considering the importance of livestock production for food security, rural development, and economic productivity, a balanced approach should be adopted to align environmental objectives with production continuity. In this context, holistic policies that simultaneously address environmental, economic, and social dimensions will play a decisive role in ensuring the long-term sustainability of livestock production systems.

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