

Methane Abatement in Brazilian Cattle

Financial Opportunities and Challenges



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List of acronyms

3-NOP: 3-Nitrooxypropanol

AD: Anaerobic digestion

Avg.: Average

BAU: Business as usual

CH₄: Methane

CO₂e: Carbon dioxide equivalent

CT: Condensed tannins

DM: Dry matter

EUDR: European Union Deforestation Regulation

GHG: Greenhouse gas

Gt: Gigatonne

Ha: Hectare

ILO: International Labour Organization

IPR: Inevitable policy response

Kg: Kilogramme

Mt: Megatonne

R&D: Research and development

USD: United States dollar

Summary



Brazil's cattle sector: a methane challenge and transition opportunity

The Brazilian cattle sector, central to the Brazilian economy, is at a critical juncture. It emits 71% of national methane output (approx. 416 Mt CO₂e/year) so has become a critical focus for the country's GHG emissions. Yet, ambitious climate scenarios predict a shift in global trends with a reduction of up to 52% in beef demand by 2050. Additionally, financial institutions managing over USD121tn are screening supply chains for deforestation and emissions risk. Without strategic diversification and optimisation, low-efficiency producers, especially in North and Northeast Brazil, face growing financial, regulatory, and reputational exposure.

This report outlines risks and opportunities for three strategic pathways for methane abatement and economic resilience:

- Diversification away from cattle into poultry, pork, plant-based and alternative proteins, and reforestation.
- Optimisation of Brazilian pasture cattle systems through improved forage, and silvopasture.
- Direct methane abatement via breeding, feed additives, and manure management.

Main findings

Long term (to 2050), diversification away from cattle offers the highest methane reduction potential with a 40% reduction in herd size resulting in up to 163.4 Mt CO₂e/year of avoided emissions. Plant-based and alternative proteins deliver a 100% reduction, while poultry and pork offer 96–99% with existing market demand. Reforestation adds carbon sequestration benefits.

Near term (to 2030), optimisation of Brazilian pasture cattle systems is faster to implement. Enhanced cattle intensification can reduce methane emissions from pasture-raised cattle (90–87% of Brazil's herd) by up to 30%. Silvopasture and improved forage reduce enteric methane emissions by 6–25% and improve soil, water, and farm income. Feed additives can cut enteric emissions by up to 30%, but are limited to feedlot systems (10–13% of Brazilian herds). Reduction in absolute methane emissions requires limiting animal numbers.

Brazil is well-positioned to lead this transition, with the world's second-largest cattle herd, vast degraded pastureland, strong research institutions, and infrastructure for poultry and soy. Its natural capital also positions it to benefit from biodiversity finance.

More granular assessments of context-specific potential and on-the-ground needs are essential to building investor confidence. Implementing these methane abatement measures requires significant effort from multiple stakeholders so the development of case studies demonstrates application in the real world. This report encapsulates the reach of technical possibilities to provide a bridge between investigation and the real economy.

Recommendations for investors

- **Integrate methane metrics into environmental, social, and governance (ESG) frameworks** and engage portfolio companies on credible transition plans aligned with Brazil's climate goals and international regulations (e.g., EU Deforestation Regulation).
- **Support a dual-track transition** by funding short-term optimisation (e.g., silvopasture, improved forage) while investing in long-term diversification (e.g., non-ruminant meat, plant-based proteins, and reforestation).
- **Prioritise nature-positive strategies** by investing in silvopasture, pasture restoration, and reforestation to unlock methane reductions, biodiversity gains, and carbon-credit revenue.
- **Support high-impact innovation** through emerging technologies such as alternative proteins and genetic improvements to capture climate return on investment (ROI) and future market value.

1. Introduction: Brazilian methane emissions



Brazil accounted for approximately 2.0 Gt CO₂e net emissions per year in 2022, representing 3% of global greenhouse gas (GHG) emissions.^{1,2} The agriculture sector was the largest driver of Brazil's emissions profile with 50% (622.0 Mt CO₂e) of which methane was a leading contributor.³

In 2022, total national methane (CH₄) emissions reached 589.7 Mt CO₂e, of which 75% (441.1 Mt CO₂e) originated from agriculture. Within agriculture, enteric fermentation was the dominant source, generating 404.0 Mt CO₂e, while cattle manure management contributed 12.8 Mt CO₂e. In total, cattle emissions accounted for 416.8 Mt CO₂e, 71 % of Brazil's total methane emissions.⁴

Cattle systems are particularly emissions intensive with production accounting for:

- 20% of Brazil's total GHG emissions,
- 67% of agricultural GHG emissions,
- 71% of Brazil's total methane emissions, and
- 94% of agricultural methane emissions.⁵

This makes the sector a major contributor to Brazil's climate vulnerability, and a target for immediate transition, given the importance of methane emissions in short-term climate warming.

The crucial role of beef cattle in the Brazilian economy

With over 230 million head of cattle, the second-largest herd in the world, Brazil is both a leading producer and the largest exporter of beef globally, supplying over 3 million tonnes of beef in 2023 alone.⁶ Beef cattle accounted for approximately 9% of national GDP in 2020, with some estimates placing the broader cattle sector contribution closer to 10% once value chains such as retail, feed, processing, and logistics are included.⁷ The industry supports around 3.3 million jobs, predominantly in rural areas, and remains a key source of income and identity for many agricultural communities.⁸

2. Risks of business as usual



Box 1. Brazil and the world are moving away from beef

According to the UN Food and Agriculture Organisation (FAO) and Organisation for Economic Co-operation and Development (OECD) data, per capita beef consumption globally has declined steadily since 2007, aligning with a long-term global shift in meat consumption towards poultry and pork. This trend is set to continue with beef projected to decrease by a further 2% both domestically within Brazil and globally by 2031. Other high-consuming nations are predicted to register declines of between 2–15% over the same period. While Asia-Pacific is the only region where per capita beef consumption is projected to increase, countries in this region are currently very low consumers.⁹

In 2022, Brazilian per capita beef consumption fell to its lowest level since 2004, driven by shrinking disposable income, price instability, and consumer preference shifts toward poultry and plant-rich diets. Despite this, Brazil is the second-highest consumer of beef per capita, after the USA (34.5 kg/cap/yr).¹⁰ In contrast to these business-as-usual (BAU) projections, estimations based on likely climate policy scenarios predict steeper declines over the same period. A model based on the Principles for Responsible Investment's Inevitable Policy Response Forecast, targeting warming at below 2°C, projects a decline of 9% in domestic beef demand by 2030, and 38% by 2050 compared to 2020. These declines in domestic beef demand increase further under more ambitious climate transitions expected in a world that acts to restrict warming to 1.5°C above pre-industrial levels, with reductions of up to 15% by 2030, and 52% by 2050 which is when these models also predict global ruminant meat demand to fall by 5–22%.¹¹

Volatile demand, shifting investor sentiment, and emerging regulation are converging to make the traditional cattle production model increasingly precarious, particularly for low-margin operators. While Brazil's exports currently remain strong, international buyers are under increasing pressure to demonstrate deforestation-free, low-emission sourcing. In parallel, food manufacturers and retailers are recognising the interconnectedness of protein diversification in achieving climate, nature, and health goals.¹² Reputational risk now extends beyond producers to the financiers and insurers that support them, with investors threatening divestment and civil society applying scrutiny to sustainability claims.^{13,14} With a growing share of Brazilian production destined for international markets, Brazilian cattle value chains are progressively exposed to these shifts in global consumer preferences and regulations.¹⁵

Moreover, policy shifts have already taken place: Denmark has launched the world's first livestock methane tax, with climate disclosure frameworks in Europe and the USA, among others, beginning to reshape global market access.^{16,17} As investor, consumer, and regulatory priorities change, suppliers which cannot meet new standards risk losing contracts.¹⁸

For many Brazilian producers, the margins are already razor-thin. Analysis from the Orbitas climate transition scenarios predicts that:

- under a BAU scenario, remote and low-efficiency cattle farms in Brazil's northeast region face up to a 90% probability of financial loss by 2050;
- a 30% drop in beef prices would trigger losses for nearly every producer outside the most efficient regions, such as Mato Grosso; and
- under BAU, a reduction of 53% in beef prices is projected by 2050 compared to 2020, deepening losses across the sector.¹⁹

‘If buyers are unable to distinguish between high- and low-risk suppliers, the entire Brazilian cattle sector may experience financial pressure due to the actions of a portion of the producers.’ - [Orbitas, 2025](#)

Summary table: economic risks

Market risk	Domestic beef consumption declining; global shifts away from ruminants
Price risk	A reduction of 53% in beef prices projected by 2050 under BAU
Production risk	Prospect of financial loss in some regions of up to 90%
Reputational risk	Investors and buyers distancing themselves from high-emitting and deforestation-linked suppliers
Regulatory risk	Methane taxes and climate compliance costs already emerging in EU and beyond, i.e., EUDR (EU Deforestation Regulation, 2025) banning imports from deforested land after 2020
Capital access risk	Companies unable to meet sustainability benchmarks may lose finance

Even under modest climate policy scenarios aiming to keep warming below 2°C (via carbon prices of USD87–100/tCO₂, reduced livestock demand to >600 kcal/cap/day, expanded protected areas, moderate yield gains, and strong forest pledges) low- and medium-tech operations may become unprofitable by 2050. Meanwhile, those failing to diversify or adopt sustainable intensification practices could lose USD155–88 per hectare due to higher production costs and lower demand.²⁰ However, it is worth noting that this remains a more favourable outcome for beef producers than a BAU trajectory, where pricing shocks are likely to drive even steeper declines in profitability.

Biophysical risks to cattle farming

Cattle farming in Brazil is increasingly vulnerable to climate and ecological disruption, which are risks that threaten the physical viability of production systems and the wider economy. From water scarcity to pasture collapse, the sector faces direct operational stress as temperatures rise, weather extremes intensify, and biodiversity declines, all of which disrupt feed supply, reduce animal health, and degrade pasture.²¹

In July 2023, 3,000 cattle died of hypothermia in Mato Grosso do Sul, as temperatures plunged from 30°C to 4°C in just nine hours. The losses affected 90 producers across 18 cities and cost over USD800,000 in damages.

Cattle are heavily reliant on pasture, yet 37% of grazing land could be lost by 2050 due to land competition, reforestation, and ecosystem restoration efforts. In addition, pasture quality is already under pressure with studies warning that water insecurity will reduce the nutritional quality of feed, requiring costly supplements to maintain weight gain.

The direct risks of water insecurity to Brazil’s cattle sector are estimated at USD8.92bn by 2030 and could also lead to higher methane emissions due to less efficient digestion.²²

Summary table: biophysical risks to cattle farming

Extreme weather	Rising frequency of heat waves, cold snaps, droughts, and flooding reducing livestock survival and productivity
Feed-quality decline	Climate-driven water stress and degraded pasture reduce feed quality and increase methane emissions
Land competition	Land competition provokes a decrease of 37% in pasture area by 2050 compared to 2020

Social risks to cattle farming

Box 2. Social risks from cattle farming

While not in the main scope of this analysis, there are also social risks from cattle farming. These include health conditions linked to overconsumption of red meat, land and water conflicts, and the exposure of rural workers to environmental hazards.

Brazil's high consumption of red and processed meats contributes directly to the country's non-communicable disease burden. In 2018, 8.4% of Brazil's direct healthcare costs were attributed to the consumption of red and processed meats, including elevated risks of cancer, coronary heart disease, and type-II diabetes.²⁶

Agriculture and livestock workers are among the most exposed to climate stress, especially women, informal labourers, and children who are already under-protected. By 2030, Latin America is projected to lose the equivalent of 2.5 million full-time jobs due to heat stress alone, with 1.6 million of these losses occurring in South America. Outdoor workers, particularly those in informal rural employment, face increasing risks from dehydration, fatigue, and lost working hours during extreme heat events.²⁷

Socio-environmental conflicts are being documented more often in relation to land and water seizure, as well as 'green grabbing'.²⁸ Expansion of agricultural frontiers in Brazil's MATOPIBA region has been linked not only to deforestation but also to land conflicts, displacement of traditional land users, and water disputes, all of which have had severe consequences for smallholder livelihoods.²⁹ This growth has often favoured large-scale, capital-intensive operations, deepening existing inequalities and marginalising local communities.³⁰

Without managed transition planning, BAU conditions could amplify inequality, displace producers and local land users, and trap low-productivity farmers in deepening economic and social insecurity.

Even under a conservative emissions reduction pathway, the sector is projected to undergo major changes by 2050, compared to 2020:

- 38% drop in domestic beef demand,
- 25% drop in ruminant meat production,
- 37% loss of pastureland due to land competition and forest restoration, and
- 80%+ probability of financial loss from climate-induced economic shocks.

These changes will not affect producers equally. Earnings of low-efficiency cattle farms in northern Brazil are already only around 8% of those of their high-efficiency counterparts in the south, due to limited access to finance, infrastructure, and slaughterhouses.²³ Without deliberate transition support, these farmers face the greatest risk of displacement.

As the food system decarbonises and diets shift, livestock-linked jobs are projected to decline sharply, especially in traditional animal-based production. Based on modelling aligned with a decarbonisation pathway consistent with the Paris Agreement long-term objective of limiting global temperature rise to 'well below 2°C above preindustrial levels', the International Labour Organization (ILO) projects:

- 4.3 million fewer jobs across livestock, poultry, dairy, and fishing in Latin America by 2030 compared to a high-emissions scenario that corresponds to current trends and culminating in a 3°C world,
- which represents 29% of projected sectoral employment losses under net-zero pathways,
- with Brazil's livestock sector alone losing up to 500,000 jobs (5% of current employment) without transition policies.²⁴

Brazil is uniquely positioned to lead in agrifood methane abatement and protein transition, but without an explicit strategy to protect livelihoods, the social cost could be high.

‘Climate transitions will create winners and losers in the global cattle sector. The only unknown is the speed and scale.’ - **Orbitas, 2025**

Summary table: social risks

Job loss in livestock	Up to 4.3 million jobs lost in Latin America; 500,000 in Brazil’s livestock sector alone in a ‘well below 2°C’ transition scenario by 2030
Informal labour exposure	Agricultural workers (especially women and children) highly vulnerable to climate shocks and economic exclusion
Widening inequality	Without transition planning, low-skilled, low-income rural workers will face the brunt of climate and market shocks, particularly in the north

Climate transition risks

Transition risks (arising from the global response to climate change) are no longer theoretical but are predicted, material, and accelerating.

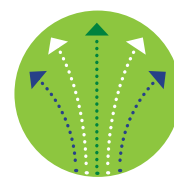
Climate transition modelling from Orbitas under the Forecast Policy Scenario (a plausible, policy-driven pathway aligned with limiting global warming to 2°C above pre-industrial levels) presents a more than 80% probability of financial loss across Brazil’s cattle sector by 2050, particularly for producers which fail to invest in efficiency or diversification. Those producers operating business models based on land expansion or low technology use are at the greatest risk of being stranded. In contrast, producers which adopt pasture intensification, low-emissions practices, and diversified revenue streams are better positioned to withstand policy and price shocks.

The Inevitable Policy Response (IPR), developed by the UN-supported Principles for Responsible Investment, is already being used to assess corporate transition risk. With over USD121tn assets under management subject to these principles, financial institutions are increasingly screening for exposure to deforestation, emissions intensity, and transition readiness.²⁵ Cattle supply chains not aligned with global transition pathways limiting warming to 1.5°C or 2°C risk exclusion from future markets and capital flows.

Summary table: transition risks

Stranded producer risk	Low-tech, extensive systems face 80–100% probability of financial loss by 2050. Producers which fail to adopt emissions-reducing technologies risk being priced out of supply chains
Investor risk	IPR-aligned investors (USD121tn) using transition forecasts to guide asset screening

3. Opportunities to maximise methane reduction in Brazilian cattle



To identify opportunities for mitigation, the theoretical maximum methane reduction achievable in Brazil's cattle sector was estimated using scientifically validated strategies. The approach is based on best available science and adapted to Brazil's production context, which is predominantly pasture-based. Three categories of interventions were assessed:

- 1. Diversification** away from cattle via 11 potential measures, including a shift to non-ruminant livestock, alternative proteins, or other land uses.
- 2. Improving production** systems using three potential measures, including enhanced productivity through better forage quality and silvopasture.
- 3. Direct methane reduction** using seven potential measures, including the application of feed additives, improved manure management, and low-emission cattle breeding.

Diversification scenarios were modelled in line with the EAT-Lancet pathway for global food system transformation, devised by the EAT-Lancet Commission, which identifies the need for a sustained reduction of approximately 5% per year in global red meat production from 2025–2050. This is the reduction required to remain within climate, biodiversity, and health boundaries, which corresponds to an approximate 40% reduction per decade when compounded, and a decline to below 50 Mt per year by mid-century. Conforming to this pathway, a 40% reduction in Brazil's cattle herd size was applied as the basis for modelling diversification away from cattle, which aligns with the EAT-Lancet recommendation for the reduction in cattle production over the next decade.

For each of the 21 mitigation measures assessed, the maximum mitigation potential was attained under full implementation in Brazil following three steps:

1. Identifying from the scientific literature the maximum mitigation factor for Brazil if available or the closest regional or global estimate.
2. Applying the mitigation factor to Brazil cattle emissions sources, either enteric fermentation, manure or both.
3. Applying the mitigation factor to the share of cattle replaced (40%) in pasture (88.5%), in feedlot (11.5%), or in both pasture and feedlot (100%), depending on each measure's applicability.

Main strategies to maximise methane reduction

In line with current scientific studies, the highest methane abatement arises from diversification away from cattle.^{31,32} A reduction of 40% in the national herd size with a transition to non-ruminant meats, plant-based proteins, alternative proteins, or non-agricultural land uses such as reforestation, offer the highest methane abatement potential: 160.1 to 166.7 Mt CO₂e per year by eliminating methane emissions from enteric fermentation and manure (Figure 1).

While these strategies present the greatest impact, short-term implementation may be challenging. However, initiating supportive diversification measures and investments early lays the foundation for a long-term transition strategy, positioning Brazil for sustained climate and economic benefits.

These estimates focus solely on methane and exclude other GHGs such as nitrous oxide or carbon dioxide. For example, diversifying into pigs or poultry accounts for methane from manure in substituted systems, but not emissions from feed production, housing, or land-use change (See Appendix 3). These figures are intended to inform investment decisions in effective agrifood methane abatement.

The second most impactful strategy is genetic improvement, with a projected methane reduction of 24% of methane emissions per year (97.0 Mt CO₂e per year); although, full benefits are expected only by 2050.

Among interventions targeting existing cattle systems, pasture-based strategies, such as improved forage and silvopasture, have the highest potential, reducing methane emissions by 11-15% per year (46.5 to 62.6 Mt CO₂e per year). This is particularly relevant in Brazil where 87-90% of cattle are pasture-raised.³³ However, this strategy could induce the Jevons effect whereby the productivity gains result in lower prices and higher consumption, leading to herd expansion so that total emissions remain constant or increase.³⁴

Grazing practices, animal health, and fertility management are also important measures to improve pasture-based cattle systems which can increase productivity and reduce methane emissions per unit of production. Improved health, better-quality diets, and higher feed intake not only increase growth and hence methane production per animal, but also improve yield which reduces methane emission intensity. Farms pursuing this strategy can reach a productivity target with fewer animals than farms with lower productivity, allowing farmers to reduce herd sizes and absolute methane emissions.³⁵ Implementing enhanced intensification of pasture-based beef production in South America could reduce methane emissions by up to 30.5% per kilogramme of beef, which if implemented by all pasture-fed cattle systems, could mitigate up to 27% of Brazil's cattle-related methane emissions (112 Mt CO₂e per year).³⁶

While feed additives (e.g., 3-NOP, red seaweed) can achieve higher unit reductions they are limited to feedlot systems, which represent 10-13% of Brazil's herd so their national mitigation potential is lower at 2-6% (8.1 to 24.9 Mt CO₂e per year).

Finally, manure management offers the smallest impact, 0.2-0.3% (1.0 to 1.2 Mt CO₂e per year), as manure accounts for just 3.1% of cattle-related methane emissions, compared to 96.9% from enteric fermentation. These interventions are also only feasible in intensive systems with controlled waste handling.³⁷

Figure 1. Maximum methane mitigation potential per year estimated for all measures if applied fully in Brazilian cattle systems, based on available mitigation emission factors derived from recent scientific literature (see methodology in Appendix 2).

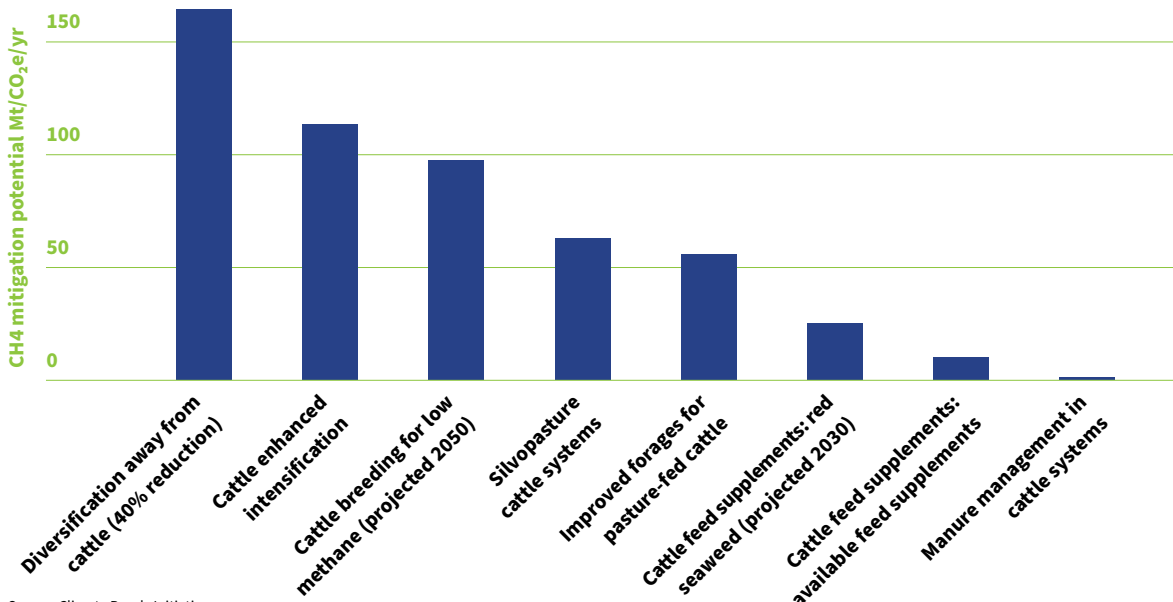


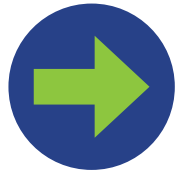
Figure 2. Main methane abatement measures mapped to their costs and risks, based on the analysis and review of existing scientific evidence.

Pathway	Max. methane reduction (%)	Cost effectiveness	Key risks
Diversification	96-100	High	Social, behavioural, market, biophysical (unquantified)
Cattle enhanced intensification	30.5	Unquantified	Upfront cost, biodiversity, long-term returns
Improved forage and silvopasture	11-18	Very high	Works best in concentrate-supplemented systems
Feed additives	2-6 (*by 2050)	Moderate-low	High cost, limited scalability, only feedlot, long-term effectiveness
Breeding	23 (*by 2050)	Very high*	Delayed payoff, risks of trade-offs with productivity
Manure management	0.2-0.3	Moderate	High capex, lock-in risk

Colour-coded assessment of qualification from dark green: very positive, light green: positive, light orange: negative, orange: deeply negative. Grey indicates insufficient evidence available to qualify.

A detailed analysis of potential methane mitigation with economic and risk considerations in Appendix 1 presents the available evidence for each intervention contextualised for Brazil.

4. Conclusion and recommendations for investors



Investors play a pivotal role in accelerating Brazil's low-methane transition. Strategic capital allocation can both mitigate climate risk and capture long-term value as the agrifood sector evolves. The following recommendations outline how investors can align portfolios with national and international climate objectives while supporting a just and profitable transition away from high-emission systems.

Recommendations:

- Integrate methane metrics into ESG frameworks and engage portfolio companies on credible transition plans aligned with Brazil's climate goals and international regulations (e.g., EUDR).
- Support a dual-track transition by funding short-term optimisation (e.g., silvopasture, improved forage) while investing in long-term diversification (e.g., non-ruminant meat, plant-based proteins, and reforestation).
- Prioritise nature-positive strategies by investing in silvopasture, pasture restoration, and reforestation to unlock methane reductions, biodiversity gains, and carbon-credit revenue.
- Support high-impact innovation through emerging technologies such as alternative proteins and genetic improvements to capture climate ROI and future market value.

Appendix 1. Methane mitigation potential, economic opportunity, and risks associated with the implementation of methane abatement interventions in Brazilian cattle systems

Diversification away from cattle

This methane mitigation strategy involves repurposing land and infrastructure used for 40% of cattle production towards alternative activities, such as non-ruminant meat, protein crops, reforestation or ecosystem restoration. These options are highly context dependent. The following provides an initial estimate of their methane mitigation potential, economic opportunities, and associated risks based on available data for Brazil and globally. A more detailed analysis and modelling could refine these estimates in a future second phase of this assessment.

Shift to non-ruminant meat (pork and poultry)

Lower emissions profiles, faster turnover, and strong consumer demand, both domestic and global, make pork and poultry production a practical alternative for investors and producers navigating the decline of ruminant meat.

For cattle-dependent operations at risk of market exit, non-ruminant meat offers a commercially viable pivot, leveraging existing expertise while aligning with climate goals. For investors and policymakers, this represents a ready-made market for targeted support, enabling a shift away from ruminant livestock without taking a risk on emerging technologies or uncertain markets.

Poultry and pork already account for a growing share of Brazil’s meat market. In 2020, poultry represented 29% of domestic livestock product demand, nearly matching ruminant meat at 32%. In contrast to the projected decline in ruminant meat, demand for poultry and pork is forecast to rise (22% in Brazil and 51% globally by 2050 under BAU) highlighting clear growth potential.³⁸

Brazil is well-positioned to scale these sectors, benefiting from established export infrastructure, consumer trust, and rising demand in middle-income markets.³⁹ Diversifying into poultry and pork enables immediate methane reduction, leverages existing supply chains, and offers a financially viable alternative to cattle.

Among methane mitigation strategies, transitioning to non-ruminant meats ranks just behind plant-based and alternative proteins, and significantly outperforms direct methane abatement in cattle systems. Pork and poultry benefit from strong market demand and infrastructure, making them more immediately actionable, unlike alternative proteins, plant-based, or reforestation approaches. However, their feed dependency poses economic and environmental considerations, including cost and impact on other GHG emissions.

Methane mitigation potential

Intensity
Switching from beef reduces methane emissions per kg by 99% with poultry, and 96% with pork.

Absolute
Replacing 40% of Brazilian cattle production with pork or poultry could reduce methane emissions by 160.1 to 164.6 Mt/CO₂e per year by 2025 (excluding other GHG and deforestation impacts).

Protein type	GHG emissions intensity (kg CO ₂ e/kg) ⁴⁰	Methane emissions (kg CO ₂ e/kg) ⁴¹
Beef	99.5	49.0
Pork	12.3	2.0
Chicken	9.9	0.6 ⁴²

Economic opportunity

Cost-effectiveness
Poultry and pigs convert feed more efficiently, grow faster, and require less land than cattle, lowering both emissions and production costs. In 2025, average production costs per kg in Brazil were USD1.51 for chilled chicken and USD1.56 for live swine, compared to USD4.05 for beef (carcass weight).^{43,44}

Future performance
Globally, poultry is expected to constitute 47% of meat protein consumption by 2031, according to the OECD-FAO Agricultural Outlook for 2022–2031.⁴⁵ In Brazil, livestock demand is expected to grow 22% by 2050, while ruminant meat demand declines by 2% by 2031 and 9% by 2050 under BAU.^{46,47}

Risks of diversifying into non-ruminant meat

Financial risks
Transitioning from extensive cattle ranching to poultry or pig farming requires a significant outlay of capital investment and increases reliance on concentrated feed inputs. This exposes producers to global commodity price volatility and potential grain market shocks, especially during extreme weather or geopolitical disruptions. Feed dependency may also raise production costs and deforestation risks in some regions.

Biophysical risks
Pigs and poultry are highly sensitive to thermal stress. Without sufficient ventilation or cooling infrastructure, heat waves can reduce feed intake and weight gain, impact reproductive efficiency, and increase mortality.⁴⁸ Climate change is expected to intensify these risks through more frequent heat extremes.

Shift to plant-based proteins

Transitioning from beef production to plant-based protein crops, such as beans, lentils, chickpeas, and soy, offers one of the most effective climate mitigation strategies in Brazilian agriculture. These crops do not emit methane, require less land and water, and align with evolving nutrition policies and consumer preferences.

Brazil is already the global leader in soy production (mostly for animal consumption) and the world’s second largest producer of beans after India.⁴⁹ Redirecting part of this capacity toward human consumption through policy, investment, and behaviour change can enhance public health, advance sustainability, strengthen farmer resilience, and open new domestic and international markets.

Beyond climate benefits, plant-based protein cultivation offers a clear labour transition strategy. ILO modelling aligned with a Paris Agreement decarbonisation scenario (well below 2°C) projects a loss of 4.3 million jobs in Latin America’s livestock, poultry, dairy, and fishing sectors by 2030, including up to 500,000 in Brazil’s livestock industry. However, the same modelling shows that shifting to sustainable, plant-rich food systems could create 19 million new full-time jobs in the region’s agrifood sector, more than offsetting job losses in livestock.⁵⁰ This presents a major opportunity for Brazil to boost rural employment and support a just transition.

Shifting towards plant-based protein production outperforms all other methane mitigation strategies, slightly ahead of non-ruminant meat and far beyond on-farm measures such as manure management or pasture improvements. However, scaling this transition will require coordinated efforts to increase consumer demand, supported by public policy, dietary shifts, and targeted investment across the value chain.

Methane mitigation potential



Unlike livestock, plant-based proteins produce no methane, have much lower GHG emissions, and can restore degraded soils. For example, there is a tenfold decrease in GHG emissions for peas compared to chicken, twelvefold decrease compared to pork, and 98 times less than beef.⁵³

Intensity

Switching from cattle to legume production (e.g., soy) eliminates methane emissions and cuts total GHG emissions per kg by 98%.⁵⁴

Absolute

Replacing 40% of Brazilian cattle production with legumes or nuts could reduce methane emissions by up to 166.7 Mt/CO₂e per year by 2025.

Protein type	GHG emissions (kg CO ₂ e/kg) ⁵¹	Methane emissions (kg CO ₂ e./kg) ⁵²
Beef	99.5	49.0
Beans	1.8	0.0
Nuts	0.4	0.0
Peas	0.9	0.0

Methodological note: Emissions intensity comparisons are based on global average lifecycle GHG emissions per kg of food product, drawn from Our World in Data, which compiles data from *Reducing Food’s Environmental Impacts Through Producers and Consumers* (Poore & Nemecek, 2018). Reported median values indicate that peas emit approximately 1 kg CO₂e per kg of product (with none attributable to methane), poultry meat approximately 10 kgCO₂e/kg (with less than 1 kg from methane), pork approximately 12 kg CO₂e/kg (with just under 2 kg from methane), and beef approximately 100 kg CO₂e/kg (of which roughly 49 kg is methane). Relative differences between peas and other proteins (tenfold versus poultry, twelvefold versus pork, and ninety-eightfold versus beef) were calculated by dividing total emissions intensity per kilogram of product. Values reflect global average production systems and lifecycle boundaries as defined in Poore & Nemecek (2018).

Economic opportunity



Cost-effectiveness

Pulses (beans, lentils, peas, chickpeas) are among the lowest-cost protein sources per gram with minimal GHG emissions and energy use per nutritional unit.⁵⁵

Future performance

The plant-based protein industry is projected to exceed USD27bn globally by 2030.⁵⁶

Risks of diversifying into plant-based protein crops



Financial risks

Crops such as soy are tied to volatile global commodity markets, exposing producers to price fluctuations, input cost inflation, and policy changes. Smallholders may face greater uncertainty without access to risk management tools.

Biophysical risks

In degraded or marginal lands, crop failure due to drought, floods, pests, or disease can result in full-season losses, particularly for monoculture systems without crop insurance.

Shift to alternative proteins

Alternative proteins, ranging from plant-based meat substitutes to microbial fermentation and cultivated meats, offer a novel, low impact, methane-free source of nutrition and a growing economic opportunity for Brazilian agriculture. These innovations require less land and water and decouple protein production from livestock-intensive supply chains.

While the sector is still maturing, its trajectory is clear. Forecasts from Kearney Consulting, Boston Consulting Group, FAIRR, the World Bank and the UN estimate that alternative proteins could account for 10%-45% of the total protein market by 2035 and 25%-60% by 2050, creating new opportunities in trade, technology, and agriculture transition, especially for cattle-dependent regions.^{57,58,59}

Importantly, diversification into alternative proteins does not require direct involvement in manufacturing. Upstream opportunities exist in supplying essential inputs such as soy, sugars, and other agricultural commodities to support production.⁶⁰

Diversification into alternative proteins ranks among the most effective methane mitigation strategies, slightly outperforming non-ruminant livestock strategies and far exceeding on-farm interventions in cattle systems. However, widespread adoption is constrained by technological maturity, market development, consumer acceptance, and, in some cases, regulatory approval. Realising its full potential will require sustained innovation, supportive policy, and long-term investment.

Methane mitigation potential

Intensity
Alternative proteins emit up to 94% less GHGs than beef and produce no methane.⁶⁷

Absolute
Replacing 40% of Brazilian cattle production with alternative proteins could reduce methane emissions by 166.4 to 166.7 Mt/CO₂e per year by 2050.

Product type	GHG emissions (kg CO ₂ e/kg)	Methane emissions (kg CO ₂ e/kg)
Beef ⁶¹	99.5	49.0
Soy milk ⁶²	0.9	0.0
Tofu ⁶³	3.2	0.0
Plant-based meat ⁶⁴	0.9	0.1
Fermentation-based (avg.) ⁶⁵	1.0	0.0
Cultivated meat (with renewable energy) ⁶⁶	2.8	0.1

Economic opportunity

Cost-effectiveness
Plant-based alternative proteins deliver the highest GHG savings per-dollar-invested of any mitigation strategy, 4.4 Mt of CO₂e per US1bn: three times greater than investing in transportation or buildings.⁶⁸

Future performance
Boston Consulting Group projects that by 2035, alternative proteins could replace 11-22% of traditionally animal-sourced foods globally, driven by improvements in taste, texture, price, and supportive regulation.⁶⁹ As Europe and North America approach 'peak meat', demand for conventional animal proteins is expected to decline.⁷⁰

Risks of diversifying into alternative proteins

Financial
The alternative proteins market is still maturing, especially in middle-income countries such as Brazil. Growth is inconsistent and sensitive to consumer trends, requiring continued investment, technological progress, and regulatory clarity.⁷¹

Biophysical
Cultivated meat and some fermentation processes are energy intensive and require controlled environments. Their GHG emissions depend heavily on the energy mix (i.e., less advantageous if based on fossil energy). In Brazil, where the grid includes both renewables and fossil fuels, emissions impact varies by location.

Shifting to non-agricultural land uses (e.g., reforestation)

Brazil holds exceptional potential for carbon sequestration through natural climate solutions, especially reforestation and ecosystem restoration. For cattle producers on marginal or degraded land facing transition risks, shifting to non-agricultural land uses might offer a viable, climate-aligned income strategy.

As Brazil's regulated carbon market develops and voluntary carbon and biodiversity credit markets expand, land value is increasingly tied to what it protects rather than to what it produces. Diversifying into nature-based solutions can unlock new revenue streams, reduce climate exposure, and safeguard long-term land value.

What was once considered 'unproductive' land can now generate revenue through high-integrity carbon sequestration, biodiversity services, and nature-based finance. These zero-methane, zero-GHG strategies align with investor trends, national climate commitments, and resilience priorities.

Modelling outputs suggest that Brazil has the potential to liberate up to 32.3 Mha of agricultural land by 2035, reaching 68.4 Mha by 2050. If dedicated to reforestation, the model projects that by 2050 the country's land carbon stock could increase by ~ 3200 MtC, mainly supported by natural vegetation regeneration in the Cerrado biome.⁷²

With emerging carbon markets and rising penalties for high-emission production, investing in nature is becoming a pragmatic financial decision, not just an environmental one.⁷³

Reforestation ranks among the most effective methane mitigation strategies, outperforming on-farm interventions, and slightly exceeding diversification into plant-based and alternative proteins, and non-ruminant meats. However, financial viability remains constrained by underdeveloped and volatile carbon and biodiversity markets, creating uncertainty for landholders in the near term.

Methane mitigation potential



Intensity

Reforestation eliminates methane and other GHG livestock emissions and actively removes atmospheric CO₂ under suitable conditions.⁷⁴

Absolute

Replacing 40% of Brazilian cattle production with nature restoration could reduce methane emissions by up to 166.7 Mt CO₂e per year by 2025, alongside biodiversity and carbon sequestration benefits.

Economic opportunity



Cost-effectiveness

OECD estimates land conversion from grassland to forest costs USD4–59 per tonne of tCO₂e, with potential earnings of USD87/tCO₂e under a forecast scenario.⁷⁵

Future performance

The voluntary carbon market grew from USD200mn to USD2bn between 2016 and 2021. Brazil is well-positioned to lead in jurisdictional and project-based carbon credits, with emerging biodiversity markets offering additional revenue through ecosystem protection.⁷⁶

'Some estimates suggest that 15% of the world's entire carbon offset potential lies within Brazil, 80% of which is associated with pasture restoration and reforestation projects.' - **Orbitas, 2025**

Risks of diversifying into non-agricultural land uses



Financial risks

Reforestation involves high upfront costs and delayed returns, making it challenging for producers with limited cash flow. Unlike cattle, which provides regular income, nature-based projects are backloaded and subject to verification cycles.⁷⁷

Biophysical risks

Afforesting natural grasslands and savannas, such as parts of the Cerrado, can cause ecological harm. Poorly implemented afforestation disrupts water cycles, increases fire risk, and reduces biodiversity and resilience, according to the IPCC. Restoration must prioritise native species and ecosystem function over simplistic tree planting.⁷⁸

Sustainable intensification of cattle in pasture

Enhanced intensification

Large scale enhanced intensification of pasture-based beef production in South America holds the potential to reduce emissions by increasing efficiency and productivity. In the enhanced scenarios, the primary emissions reductions could be achieved through improvements in feed digestibility, feed conversion efficiency, and reduced time to slaughter, with outcomes linked to production efficiency resulting from pasture improvement, supplementation, and better animal performance. These practices are currently deployable in pasture-based systems across South America and align sustainable beef production approaches that prioritise pasture management and supplementary nutrition as an essential first step in pasture intensification.⁷⁹

Intervention	Methane reduction	Methane intensity (kg CO ₂ e/kg beef – carcass weight)	Methane intensity (kg CO ₂ e/kg beef – retail weight)
Enhanced intensification	~30.5%	23.5 tCO ₂ e/t cw	31.3 tCO ₂ e/t rw

Improved forage

Improved forage, particularly tropical legumes with condensed tannins (CT), offer a promising methane mitigation strategy for extensive cattle systems. This forage alters rumen microbial activity, reducing methanogenesis while supporting productivity, disease resistance, and reproductive performance. While some tannin rich species lower fibre digestibility, others, such as *Lotus corniculatus* and *L. sulla*, have shown net gains in both production and methane reduction.⁸⁰

Other forage enhancements, such as incorporating tree leaves, ground pods, shrubs, nitrates, and oils can reduce methane emissions by 10–25% per kg of dry matter intake.⁸¹ When combined with pasture restoration, improved forage

provides a low-cost, scalable solution that aligns with traditional grazing and delivers co-benefits (for producers, animal health, and ecosystems among others).

When combined with the land-sparing and potential carbon sequestration benefits of improved pasture, the emissions level of these improved systems could reduce total emissions in 2050 by 40% compared to 2020 levels. However, these benefits are likely to plateau over time as soils approach new equilibrium levels.⁸²

While their methane abatement potential is modest compared to shifting away from cattle, improved forage outperforms feed additives and manure management in overall impact.

Methane mitigation potential



Intensity

Enteric methane emissions can be reduced by 6-25% depending on forage type and quantity.

Absolute

If 100% Brazilian pastures adopted improved forage (inclusion of tannin-rich species, tree leaves, ground pods, shrubs, nitrates, and oils), methane emissions could fall by between 46.5-62.6 Mt/CO₂e per year by 2025.

Economic opportunity



Cost-effectiveness

Improved pasture management is among the most cost-effective strategies. A Tier 3 study in Colombia found that adaptive grazing reduced enteric methane at a net negative marginal cost of USD99.70/tCO₂e, requiring no capital investment, only changed practices.⁸⁴

Future performance

Improving pasture quality improves farm profitability and resilience. In Brazil, pasture and soil fertility improvements are projected to support stable profits, even under climate transition scenarios that increase production costs. These low-cost interventions also could benefit producers with access to growing markets for low-emission and deforestation-free products.⁸⁵

Intervention	Methane yield reduction (g CH ₄ /kg DM intake) ⁸³	Methane intensity (kg CO ₂ e/kg beef)
CT-rich forage (e.g. <i>L. corniculatus</i>)	~10–25%	40.7
Inclusion of trees, oils, nitrates	~6–20%	42.8

Risks of improved forage



Financial risks

Restoring degraded pasture and introducing improved forage can incur an initial outlay of USD200–400/ha, which could be unaffordable for low-income producers without access to credit. Short-term income may decline during the transition, increasing financial vulnerability.⁸⁶

Biophysical risks

Poorly managed forage systems, particularly those using non-native species, can disrupt local ecosystems. Traits like drought resistance and rapid growth may resemble invasive species, risking biodiversity loss and ecological imbalance. Restoration efforts must be ecologically aligned and monitored to avoid unintended consequences.⁸⁷

Silvopasture

Silvopastoral systems, integrating trees, shrubs, pasture, and livestock, offer a climate and land-efficient alternative to conventional cattle grazing. In Brazil, intensive silvopastoral systems use fodder trees, legumes, and live fences to improve soil, reduce runoff, store carbon, and enhance biodiversity.⁸⁸

In contrast to feed additives, silvopasture reduces methane while increasing productivity per hectare. It shares similarities with improved forage systems due to the use of nutrient-rich, methane-suppressing legumes, but adds value through the integration of trees. Trees provide shade, reduce heat

stress, and create new revenue streams, improving animal welfare and land productivity.⁸⁹ Due to these overlaps, silvopasture should not be considered additive to other pasture improvements, such as improved forage, when calculating methane mitigation outcomes.

While methane abatement is modest, silvopasture delivers strong co-benefits and outperforms feed additives and manure management in overall impact.

Methane mitigation potential



Intensity

Enteric methane emissions decline 15–20% per animal, with additional carbon sequestration from trees and soil improvement.

Absolute

If adopted across 100% Brazilian pastures, silvopasture could reduce 62.6 Mt/CO₂e per year by 2025, with sequestration benefits.

Economic opportunity



Cost-effectiveness

Silvopasture systems deliver up to 4 times higher net present value and significantly improved internal rate of return (22–30%) compared to monoculture systems. The payback period shortens from 6–8 years to 4–6 years, and land required to earn two minimum salaries drops from 6.5 to 3.8 hectares. Silvopasture provides a secure and profitable path for farmers in the long term.^{91,92}

Future performance

Silvopasture is increasingly seen as a strategic investment. As carbon markets mature, tree-based systems can generate dual income from both productive outputs (e.g., beef, milk, timber) and ecosystem services (e.g., carbon and biodiversity credits).⁹³ Research in Latin America demonstrates that silvopasture is more profitable and resilient than conventional pasture under climate stress, with growing demand for low-emission, deforestation-free products likely to attract preferential financing and market access.⁹⁴ Widespread adoption will depend on technical assistance, upfront finance, and policy support to make it viable for small- and medium-scale producers.^{95,96}

Practice	Estimated CH ₄ reduction	Methane intensity (kg CO ₂ e/kg beef)
Silvopasture with legumes	~15–20% vs. grass monocultures ⁹⁰	40.7

Risks of silvopasture



Financial risks

High upfront costs for tree planting, fencing, and system redesign pose challenges, especially for producers without subsidies or access to credit. Complexity in management and delayed profitability can strain cash flow, making public support essential for broader adoption.⁹⁷

Biophysical risks

Trees and forage crops may compete for light, water and nutrients. While shading from tree canopies can reduce the yield of sun-dependent grasses, shade-tolerant species may still perform well. Careful species selection and system design are critical to avoid productivity losses.⁹⁸

Direct methane abatement in cattle systems

Feed supplementation and inhibitors

Despite significantly lower methane mitigation potential than diversification or improved pastures, modifying cattle diets through supplementation and methane-inhibiting additives offers one of the most immediately deployable solutions to reduce enteric methane emissions.⁹⁹ Whether through high-fat diets, next-generation feed additives such as 3-NOP (Bovaer®), or red seaweed, these interventions target methane production at the microbial level. Some products, such as 3-NOP, are already approved in over 65 countries, including Brazil, and have been shown to reduce methane by 13-30% in high concentrate systems.¹⁰⁰ Others, such as seaweed-based inhibitors, are rapidly developing but face challenges around cost, palatability, scalability, and public acceptance.¹⁰¹

However, the majority of studies rely on additives mixed into a total mixed ration and there is very little evidence of the mitigation benefits achieved if the additive is provided in a supplement consumed infrequently, as in pasture systems.¹⁰² Thus, feed supplementation and inhibitors are most effective in feedlot systems which only accounts for 10-13% of Brazil's beef production, as the majority (87-90%) of cattle are finished on pasture.¹⁰³

Despite higher per cow reductions, the total potential emissions reductions compared to diversification away from cattle or pasture improvements are low due to limited applicability in pasture-based systems. However, feed supplementation still significantly outperforms manure management systems as a mitigation strategy.

‘The use of methane inhibitor feed additives has the potential to lower methane emissions from livestock and is thus one tool to slow the progression of climate change in the short term.’ - CGIAR, 2024

Methane mitigation potential



Intensity

The feed supplements that are market-ready can reduce emissions 12-30%. However, this higher figure can only be realised in high-intensity indoor systems.

Absolute

The maximum methane mitigation potential of market-ready feed additives (currently deployable) is 8.1-10.2 Mt/CO₂e per year if 100% Brazilian feedlot cattle were fed effective feed supplements. While the mitigation potential of interventions such as red seaweed rises to 24.9 Mt/CO₂e, this is only likely to be fully realisable by 2030,¹⁰⁹ reflecting scale-up timelines and commercial readiness. More broadly, the mitigation performance of both process- and technology-based interventions may improve as practices are refined and delivery mechanisms optimised.

Economic opportunity



Cost-effectiveness

With an estimated cost of Bovaer® of less than USD0.5 per pint of milk, McKinsey and Co. estimate the cost of using advanced feed additives for methane emissions abatement is USD99 per tCO₂e.^{110,111} Whereas the OECD estimates cost-effectiveness of fat supplementation to range from a net saving of USD82 to a cost of ~587/t CO₂e.^{112,113} Co-benefits can sometimes include higher milk yields and carcass weight due to energy saved from CH₄ synthesis being redirected to protein/fat storage.¹¹⁴

Future performance

Brazil is an early adopter, offering potential for leadership in lower-methane livestock exports.¹¹⁵ The market for methane-reducing seaweed additives is projected to grow 57%, from USD47mn (2022) to USD306mn by 2030.¹¹⁶

Intervention	CH ₄ reduction potential	Methane intensity (kg CO ₂ e/kg beef)	Notes
3-NOP (Bovaer®) ¹⁰⁴	14–30% (context dependent)	38.6	Effective in indoor systems; reduced impact for grazing. ¹⁰⁵ Potential reduction in the efficacy over time due to microbial adaption.
Red seaweed (Asparagopsis) ^{106,107}	9-98% up to a maximum of 55% for dairy and up to 98% for beef	23.6	Small market share, scaling expected but not yet ready.
High-fat diets/oils (e.g., palm, sunflower) ¹⁰⁸	12–23%	40.7	Works best in concentrate-supplemented systems

Risks of feed supplementation



Financial risks

The use of additives, while effective in lowering emissions, incurs additional costs while doing little to increase productivity.¹¹⁷ The 3-NOP based feed additives typically cost about USD100-150 per cow per year while red seaweed-based additives are still emerging in the market and are generally more expensive than 3-NOP due to limited supply and scalability challenges.¹¹⁸ However, unless farmers can command a higher price for low-emission beef, they are unlikely to recoup these additional costs. Hence, funding support is likely required for widespread adoption.

Biophysical risks

There is emerging evidence that the rumen microbiome may adapt over time to some additives, potentially reducing their long-term efficacy. This raises concerns about the durability of mitigation impacts without continuous innovation or rotation of strategies.¹¹⁹

Methodological note: Maximum mitigation potential was estimated under an assumption of full implementation in Brazil. Firstly, maximum methane reduction factors for market-ready feed additives were identified from the scientific literature, including CGIAR (2024) for 3-NOP (Bovaer) and Ku-Vera et al. (2020) for high-fat/oil supplementation strategies in tropical forage systems. Secondly, these mitigation factors were applied to Brazil's enteric fermentation emissions, which account for 88.5% of national cattle methane emissions. Finally, the adjusted mitigation potential was scaled to the proportion of cattle in feedlot systems (11.5% of the national herd), reflecting the practical maximum applicability of feed-based interventions. The resulting range (8.1–10.2 MtCO₂e per year) represents a technical maximum under full uptake among feedlot cattle and does not account for economic, behavioural, or logistical constraints.

Breeding cattle for low emissions

Selective breeding for lower methane emissions is an emerging strategy that alters the gut microbiome of cattle and digestive efficiency over time. By favouring animals with naturally lower enteric fermentation, producers can gradually reduce herd-level emissions without the need for gene editing.¹²⁰

While this strategy will not deliver immediate gains toward the Global Methane Pledge 2030 targets, it may be one of the most cost-effective, long-term tools available. There are economic benefits which could occur from improved efficiency (higher yield and/or less resource used). Therefore, many of the cost-effectiveness estimates are net negative.¹²¹ This is particularly beneficial in pasture-based systems where feed additives are harder to implement.¹²²

Genetic improvements have the potential to out-perform the other methane mitigation strategies that target changes within cattle systems; however, they still fall far behind diversification options and are not predicted to be scalable until 2050, unlike improvements in pasture which can be rolled out immediately.

Methane mitigation potential



Intensity

Selective breeding could reduce livestock CH₄ by 24% by 2050.¹²³

Absolute

The maximum methane mitigation potential of improved genetics is 97.0 Mt/CO₂e per year if 100% Brazilian cattle were from low emitting stock. However, this level of reduction is not predicted until 2050.¹²⁴ World Bank estimates find that breeding cattle for low enteric fermentation would reduce global emissions by 506 Mt/CO₂e by 2050.¹²⁵

Economic opportunity



Cost-effectiveness

The OECD estimates that the cost-effectiveness could be between USD-5,279 to USD20 per tCO₂e, making it one of the most cost-effective measures. The on-farm cost of this measure is usually assumed to be zero. It is likely that even if there is a need to switch from natural service to artificial insemination for genetic improvement, there is likely to be no significant cost increase. Additionally, economic benefits will occur because of improved efficiency (higher yield and/or less resource used). Therefore, most of the cost-effectiveness estimates are negative.^{126,127} Support for R&D now could avoid the need to buy feed additives in the future.¹²⁸

Future performance

Breeding for lower methane emissions is one of the most promising long-term solutions for reducing enteric methane within pasture-based systems, particularly in Brazil where feed additives are less applicable. Advances in genetic selection now allow breeders to target traits linked to lower methane yield without compromising productivity. The overall mitigation impact is gradual, but cumulative, with reductions of up to 24% expected by 2050 if adopted at scale.¹²⁹ Importantly, breeding is a permanent and inheritable solution: once embedded in national herds, benefits persist without the need for ongoing investment, additives, or infrastructure.¹³⁰ The strategy is highly cost-effective, with OECD estimating negative costs per tCO₂e, making it one of the few interventions with net negative abatement costs over time.¹³¹

Risks of breeding for lower methane



Financial risks

Payoff is delayed; farmers and breeders may need incentives to adopt selection protocols today to deliver mitigation benefits in 2050.

Biophysical risks

Breeding cattle for lower methane production is predicted to be one of the most impactful interventions within cattle systems by 2050.¹³² However, breeding for low methane emissions may inadvertently affect other desirable traits affecting growth rate, fertility, or milk yield. These trade-offs are not yet fully understood and could reduce overall productivity if not carefully managed, which could have knock-on effects with productivity and thus other GHG emissions.¹³³

Manure management

While cattle manure is a major source of methane and ammonia emissions, accounting for approximately 3% of agricultural methane emissions, it is also an untapped source of value. Improved manure management, such as slurry acidification, pit covering or anaerobic digestion, can reduce emissions, generate energy, and transform waste into productive inputs.¹³⁴

These options are particularly relevant for intensive or semi-intensive cattle operations. While less transformative than diversification or pasture improvements, they offer methane savings for farms where animal numbers and capturable waste volumes are already high. However, there is a risk that investing in manure management infrastructure may reinforce or lock in intensive, high-emitting production models, potentially slowing a broader shift toward more sustainable, low-emission protein systems.

Manure management is the least effective methane mitigation strategy for Brazil, falling well behind pasture improvements and diversification. This is due to the fact that the reduced emissions from manure compared to enteric fermentation are only applicable in feedlot systems which make up only small fraction of Brazil’s cattle production.

Methane mitigation potential



Intensity

Biogas digesters, which convert methane and carbon dioxide into energy, can capture up to 80% of the methane from manure.¹³⁹

Absolute

The maximum methane mitigation potential of cattle manure management is 1.0-1.2 Mt/CO₂e per year by 2025 if 100% of manure from Brazilian feedlot cattle were effectively managed. The World Bank estimates that expanding anaerobic manure digestion globally has the potential to save 260 MtCO₂e by 2050.¹⁴⁰

Economic opportunity



Cost-effectiveness

McKinsey & Co. estimate the abatement cost of anaerobic digestion at approximately USD92 per tonne of CO₂e.¹⁴¹ Slurry acidification, while less capital-intensive, still costs around USD55 per cow per year, though it also improves the slurry’s fertiliser value. Direct methane capture systems can generate new revenue streams from on-farm energy or biogas sales, with methane valued at roughly 10 pence per kilogramme.¹⁴²

Future performance

High-quality digesters or covered slurry pits can generate heat, electricity, or fuel, reduce on-farm energy bills and decarbonise agricultural operations.

Practice	CH ₄ reduction potential	Methane intensity after implementation (kg CO ₂ e eq./kg beef)	Notes
Anaerobic digestion (AD) ¹³⁵	Up to 80% of manure CH ₄ .	47.8	Captures methane for energy; offsets fossil use.
Slurry acidification (e.g. H₂SO₄) ¹³⁶	50–90% of manure CH ₄ & NH ₃ .	47.9	Used in Denmark on 20% of slurry; strong air and river pollution reduction co-benefits.
Direct slurry capture ^{137,138}	Up to 80% of manure CH ₄ .	47.8	Emerging tech does not require AD plant.

Risks of manure management systems



Financial risks

High upfront capital costs for installation, particularly for digesters and direct capture equipment; public or retailer support may be needed.

Biophysical risks

Manure management systems such as digesters and acidification require chemical handling, and ongoing maintenance to avoid leaks or accidents. There is also a risk of locking in fossil fuel gas infrastructure and reinforcing intensive, high-emitting livestock systems, which could delay broader transitions to low-emission protein production.

Table 1. Summary table methane mitigation potential, economic opportunity, and risks associated with the implementation of methane abatement interventions in Brazilian cattle systems.

Note improved forage and silvopasture overlap thus these are not additional.

		Methane mitigation potential			Economic opportunity		Risks	
		Methane emissions reduction (range)	Methane emission intensity (t CH ₄ /t food product, global avg)	Brazil maximum methane mitigation potential (Mt/CO ₂ e)	Cost-effectiveness	Future performance	Financial	Biophysical
Diversification away from cattle (40% herd size reduction)	Non-ruminant meats (e.g., poultry and pork).	96-99% of enteric fermentation and manure emissions.	0.6-2	160.1-164.6	2025 Production costs: Poultry: 1.51 USD/kg Pork: 1.56 USD/kg Beef (carcass weight) (2021): 4.05 USD/kg	Lower input costs and potential strong demand for poultry and pork make this a financially viable alternative.	High capex and lack of dedicated infrastructure. Increased reliance on external feed inputs compared to pasture.	Thermal stress
	Unprocessed plant-based proteins (e.g., soy grain).	100% of enteric fermentation and manure emissions.	0	166.7	Pulses are among the cheapest protein to produce (per g of protein).	Low production costs, offering strong economic returns when prices and demand are high.	Increased export compared to beef means higher exposure to global commodity markets.	Some regions may not be suitable for such production.
	Processed alternative proteins (e.g., tofu to cultivate meat).	100% of enteric fermentation and manure emissions.	0-0.1	166.4-166.7	Alternative proteins offer highest emissions savings per dollar invested, 3x higher than investing in green buildings or transport. USD1trn investment = 4.4 Gt CO ₂ e saved.	Good long-term investment but capital intensive and requires market maturity on demand and supply sides.	Consumer demand is volatile and maturing. Requires sustained investment and regulatory support.	Emissions profile can be highly sensitive to the energy mix.
	Non-agricultural land use.	100% of enteric fermentation and manure emissions.	N/A	166.7 (plus carbon sequestration)	OECD estimate: USD4-59/tCO ₂ e sequestered.	Potential high return at low upfront cost (dependent on carbon market evolution).	Potential returns are only long term.	Misaligned afforestation can cause biodiversity loss, fire risk, and maladaptation.

Table 1: continued

		Methane mitigation potential			Economic opportunity		Risks	
		Methane emissions reduction (range)	Methane emission intensity (t CH ₄ /t food product, global avg)	Brazil maximum methane mitigation potential (Mt/CO ₂ e)	Cost-effectiveness	Future performance	Financial	Biophysical
Sustainable intensification of cattle in pasture	Improved forage.	6-25% of enteric fermentation emissions.	40.7-42.8	46.5-62.6	Savings (net negative cost) of USD99.7 per tCO ₂ e.	Among the most accessible and low-cost strategies for reducing methane in pasture-based systems		Can disrupt biodiversity and alter plant communities.
	Silvopasture.	15-20% enteric fermentation emissions.	40.7	62.6 (plus sequestration)	USD3,154/ha profit over 20 years. ROI: 15.6% vs. 8.7% for traditional pasture.	Strong long-term economics, particularly where labour and infrastructure support is available.	High start-up costs, requires ongoing technical support, and delayed returns (4-6 years).	Competition for light, water, nutrients between trees and pasture.
Direct methane abatement in cattle systems	Feed supplementation and inhibitors.	12-30% of enteric fermentation emissions.	23.6-40.7	8.1-24.9	3-NOP (Bovaer®): ~USD100-150/cow/year; ~USD99/tCO ₂ e. Red seaweed costs more, scaling, not yet mature.	Only economically viable in feedlot systems.	Farmers may not recoup costs without price premiums.	Possible microbial adaptation over time may reduce effectiveness.
	Breeding for low emission.	24% of enteric fermentation emissions.	37.6	97	OECD estimate: USD128 to 18/tCO ₂ e net savings over time.	One of the cheapest long-term solutions. Delayed returns (by 2050), but highly cost-effective with early investment.	Delayed payoff, farmers need incentives to adopt breeding protocols now.	Risk of trade-offs with productivity traits.
	Manure management.	50-90% of manure emissions.	47.8-47.9	1.0-1.2	AD: €48 to €130/tCO ₂ e. Slurry acidification: ~USD55/cow/year.	Capital-intensive but creates new revenue streams (e.g., biogas sales). Most viable in intensive indoor operations which limits scalability in Brazil.	High capex for digesters and direct capture systems.	Risks of leaks or accidents if poorly maintained.

Appendix 2. Further information on methane mitigation potential

Methodological consideration and references

Tables below provide additional information relating to the methodological approach and resources used to calculate theoretical maximum mitigation potentials of 21 methane mitigation measures.

Table 2. Methane mitigation measures analysed, and parameters used for maximum mitigation potential calculation									
Mitigation strategy		Subcategory	Assumed CH ₄ intensity reduction %	Reduces enteric ferm. (96.9% of cattle emissions)	Reduces manure (3.1% of cattle emissions)	Feedlot cattle only (11.5% of cattle)	Pasture only (88.5% of cattle)	Max CH ₄ mitigation potential Mt/CO ₂ e/yr	Max CH ₄ mitigation potential (%)
BAU	No change	Beef	0.0%	Y	Y	Y	Y	0.0	0.0
	Diversification	Non-ruminant meat	Chicken	98.7%	Y	Y	Y	Y	411.4
Pork			96.0%	Y	Y	Y	Y	400.2	96.0
Plants		Nuts	100.0%	Y	Y	Y	Y	416.8	100.0
		Peas	100.0%	Y	Y	Y	Y	416.8	100.0
		Beans	100.0%	Y	Y	Y	Y	416.8	100.0
Alt proteins		Plant-based meat	99.9%	Y	Y	Y	Y	416.4	99.9
		Soymilk	100.0%	Y	Y	Y	Y	416.8	100.0
		Tofu	100.0%	Y	Y	Y	Y	416.8	100.0
		Fermentation derived	100.0%	Y	Y	Y	Y	416.8	100.0
		Cultivated	99.8%	Y	Y	Y	Y	416.0	99.8
Non-agricultural		Non-agri land use	100.0%	Y	Y	Y	Y	416.8	100.0
Sust. Intensification in pastures	Enhanced intensification	Improved management in pastures	30.5%	Y	Y	N	Y	112.0	26.9
	Improved forages	CT-rich forages (e.g. <i>L. corniculatus</i>)	17.5%	Y	N	N	Y	62.6	15.0
		Inclusion of trees, oils, nitrates	13.0%	Y	N	N	Y	46.5	11.2
	Silvopasture	With legumes	17.5%	Y	N	N	Y	62.6	15.0
Direct methane abatement in cattle herds	Feed supplementation & inhibitors	3-NOP (Bovaer®)	22.0%	Y	N	Y	N	10.2	2.5
		Red seaweed*	53.5%	Y	N	Y	N	24.9	6.0
		High fat diets / oils (e.g. palm, sunflower)	17.5%	Y	N	Y	N	8.1	2.0
	Genetics	Breeding for low methane	24.0%	Y	N	Y	Y	97.0	23.3
	Manure management	Aerobic digestion	80.0%	N	Y	Y	N	1.2	0.3
		Slurry acidification	70.0%	N	Y	Y	N	1.0	0.2
		Direct slurry capture	80.0%	N	Y	Y	N	1.2	0.3

*technology not scalable yet

Table 3. References for CH₄ reduction factors

Note: Reduction factors for diversification away from cattle were derived by comparing the absolute methane (CH₄) emission intensities of different protein sources with those of beef. The relative difference between these values was then expressed as a percentage reduction, to allow comparison with other mitigation strategies reported in the literature.

Reference	Source
CH ₄ accounts for 49 kg CO ₂ e/kg of beef emissions (the baseline)	Our World in Data (2020) The carbon footprint of foods: are differences explained by the impacts of methane? Available at: https://ourworldindata.org/carbon-footprint-food-methane
CH ₄ represents 6.25% of chicken CO ₂ e (0.6 kg CO ₂ e/kg)	Climate Bonds Initiative (2024) Agriculture Production Excel Tool. Available at: https://www.climatebonds.net/our-expertise/climate-bonds-standard-and-certification-scheme/sector-criteria/agriculture-production
CH ₄ accounts for 2 kg CO ₂ e/kg of pork emissions	Our World in Data (2020) The carbon footprint of foods: are differences explained by the impacts of methane? Available at: https://ourworldindata.org/carbon-footprint-food-methane
CH ₄ represents 0% of bean CO ₂ e (0 kg CO ₂ e/kg)	Our World in Data (2020) The carbon footprint of foods: are differences explained by the impacts of methane? Available at: https://ourworldindata.org/carbon-footprint-food-methane
CH ₄ represents 5% of plant-based meat CO ₂ e (0.1 kg CO ₂ e/kg)	Keoleian, G. A., & Heller, M. C. (2018). Beyond Meat's beyond burger life cycle assessment: a detailed comparison between a plant-based and an animal-based protein source.
CH ₄ represents <0% of fermentation derived protein CO ₂ e (methanotrophic consume CH ₄)	Sillman, J., Uusitalo, V., Ruuskanen, V., Ojala, L., Kahiluoto, H., Soukka, R., & Ahola, J. (2020). A life cycle environmental sustainability analysis of microbial protein production via power-to-food approaches. The International Journal of Life Cycle Assessment, 25, 2190-2203.
CH ₄ represents 9% of cultivated meat's CO ₂ e in a renewable energy scenario (0.1 kg CO ₂ e/kg)	Sinke, P., Swartz, E., Sanctorum, H., van der Giesen, C., & Odegard, I. (2023). Correction: Ex-ante life cycle assessment of commercial-scale cultivated meat production in 2030. The International Journal of Life Cycle Assessment, 28(9), 1225-1228.
CT-rich forages (e.g., <i>L. corniculatus</i>) reduces enteric CH ₄ ~10–25%	Ku-Vera, J., Castelań-Ortega, O. A., Galindo-Maldonado, F. A., Arango, J., Chirinda, N., Jiménez-Ocampo, R., ... & Solorio-Sánchez, F. J. (2020). Review: strategies for enteric methane mitigation in cattle fed tropical forages. Animal 14 (3), s453–s463.
Enhanced intensification in pasture systems can reduce CH ₄ by 30.5%	Costa Jr, C., Tedeschi, L. O., Gonzalez-Quintero, R., Arango, J., Burkart, S., Grosjean, G., ... & Rao, I. M. (2025). South America's pasture intensification can increase beef production, reduce emissions by 30% and mitigate warming from methane by 2050. Scientific Reports, 15(1), 35734.
Inclusion of trees, oils, nitrates reduces enteric CH ₄ ~6–20%	Ku-Vera, J., Castelań-Ortega, O. A., Galindo-Maldonado, F. A., Arango, J., Chirinda, N., Jiménez-Ocampo, R., ... & Solorio-Sánchez, F. J. (2020). Review: strategies for enteric methane mitigation in cattle fed tropical forages. Animal 14 (3), s453–s463
Silvo pasture with legumes reduces enteric CH ₄ ~15–20%	Ku-Vera, J., Castelań-Ortega, O. A., Galindo-Maldonado, F. A., Arango, J., Chirinda, N., Jiménez-Ocampo, R., ... & Solorio-Sánchez, F. J. (2020). Review: strategies for enteric methane mitigation in cattle fed tropical forages. Animal 14 (3), s453–s463.
3-NOP (Bovaer®) reduces enteric CH ₄ ~13.7–30%	CGIAR (2024) 2024: Break Through Agenda Report Agriculture. Available at: https://www.cgiar.org/2024-breakthrough-agenda-report-agriculture/
Red seaweed reduces enteric CH ₄ ~9-98%	Kinley, R. D., G. Martinez-Fernandez, M. K. Matthews, R. de Nys, M. Magnusson, and N. W. Tomkins. 2020. "Mitigating the Carbon Footprint and Improving Productivity of Ruminant Livestock Agriculture Using a Red Seaweed." Journal of Cleaner Production 259: 120836. https://doi.org/10.1016/j.jclepro.2020.120836 .
High fat diets / oils (e.g. palm, sunflower) reduces enteric CH ₄ ~12-23%	Ku-Vera, J., Castelań-Ortega, O. A., Galindo-Maldonado, F. A., Arango, J., Chirinda, N., Jiménez-Ocampo, R., ... & Solorio-Sánchez, F. J. (2020). Review: strategies for enteric methane mitigation in cattle fed tropical forages. Animal 14 (3), s453–s463.
Breeding for low methane reduces enteric CH ₄ emissions 24%	Green Alliance (2025) The climate emergency brake: an ambitious plan to cut UK methane emissions. Available at: https://methanematters.eu/wp-content/uploads/2025/05/The-climate-emergency-brake.pdf
Anaerobic digestion reduces manure emission up to 80%	World Bank (2024) Recipe for a Liveable Planet: Achieving Net Zero Emissions in the Agrifood System. Available at: https://www.worldbank.org/en/topic/agriculture/publication/recipe-for-livable-planet
Slurry acidification reduces manure emissions 50-90%	Green Alliance (2025) The climate emergency brake: an ambitious plan to cut UK methane emissions. Available at: https://methanematters.eu/wp-content/uploads/2025/05/The-climate-emergency-brake.pdf
Direct slurry capture reduces manure emissions up to 80%	World Bank (2024) Recipe for a Liveable Planet: Achieving Net Zero Emissions in the Agrifood System. Available at: https://www.worldbank.org/en/topic/agriculture/publication/recipe-for-livable-planet

Appendix 3. Methane intensity per kilogramme of food

Methane intensity helps assess the climate impact of food production. Conventional beef, without interventions, emits ~49 t CO₂e/t, making it one of the highest methane-emitting foods. In contrast, foods excluding beef have the lowest intensities.

- Plant-based proteins (beans, nuts, peas): 0 t CO₂e/t - most effective for methane mitigation.
- Alternative proteins (soy milk, tofu, plant-based meat, fermentation derived, cultivated meat): 0–0.1 t CO₂e/t - very low emissions.
- Non-ruminant meats (poultry, pork): 0.6–2 t CO₂e/t - low emissions due to lack of enteric fermentation; methane comes only from manure.

While diversifying away from beef offers the greatest impact, several interventions within beef production can substantially lower methane intensity. These strategies vary in effectiveness, scalability, and readiness, but together they offer a pathway to more sustainable beef.

Beef system interventions:

- Feed additives/inhibitors: 23.6–40.7 t CO₂e/t - lowest with red seaweed (not yet scalable).
- Selective breeding: ~37.6 t CO₂e/t - full potential expected by 2050.
- Improved forage (e.g., silvopasture, tannin-rich species): 40.7–42.8 t CO₂e/t.
- Manure management (anaerobic digestion, slurry acidification): 47.8–47.9 t CO₂e/t.

Major methane reductions are achievable through dietary shifts and targeted cattle system interventions, especially those focused on cattle diets and genetics.

Beyond methane: understanding the full emissions profile of protein production

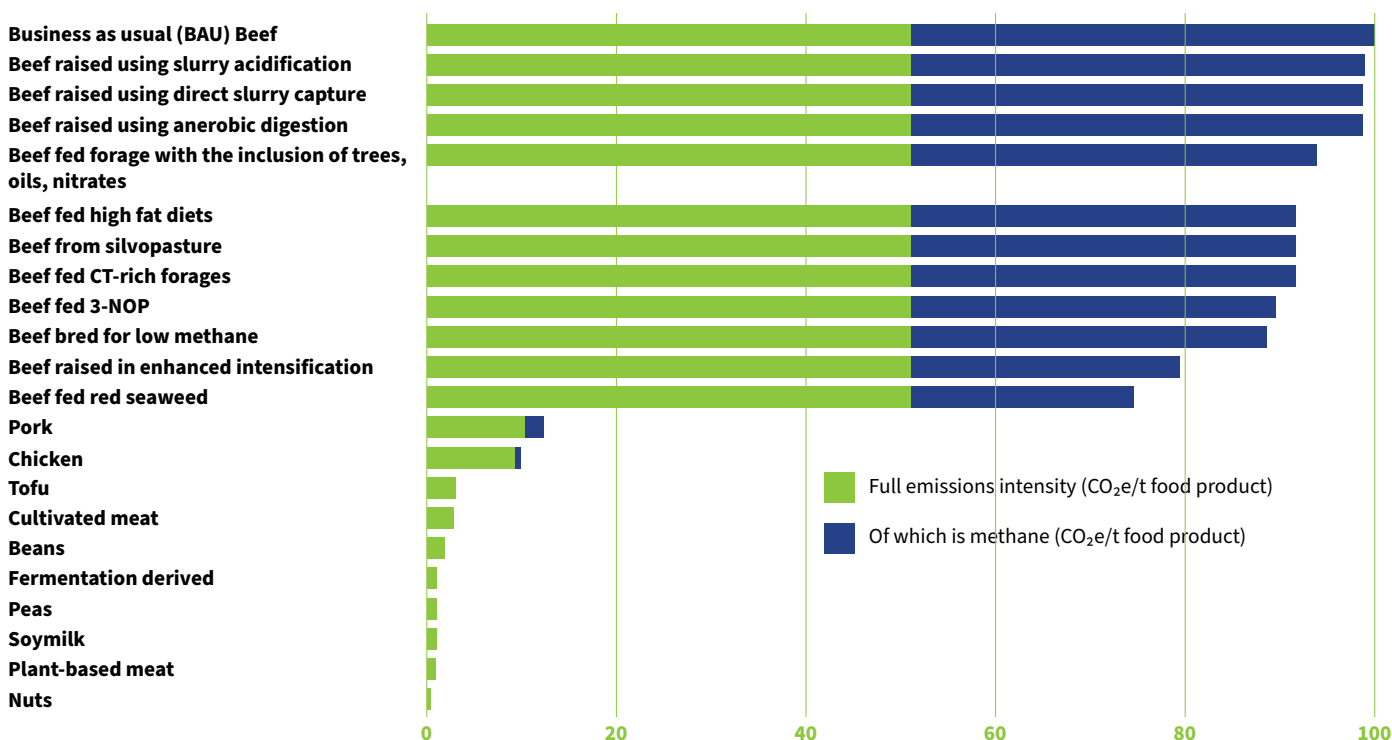
While methane is a major contributor to cattle emissions, and the focus of this report, it is not the only GHG associated with livestock or other protein production systems. For most producers, additional sources of emissions include:

- land use change, particularly the conversion of forests or peatlands to pasture or feed production;
- animal feed production which often requires significant land, fertiliser, and transport;
- pasture management including fertilisation, liming, and irrigation;
- slaughter and processing waste which can emit both methane and nitrous oxide.

These sources contribute significantly to the overall emissions footprint of cattle, other livestock, and protein crop production. Therefore, even where methane emissions are reduced or eliminated, substantial emissions often remain.

Cattle, and particularly beef cattle, still have the highest total emissions of any major protein source, even when methane is excluded. For conventional beef production, methane typically accounts for around half of total GHG emissions. Removing methane alone would decrease the footprint of beef from around 100 tonnes CO₂e per tonne of product to roughly 51 tonnes CO₂e, which is still far greater than other proteins.

Figure 4. GHG emissions intensity and contributions from methane



Source: Compiled by Climate Bonds Initiative from Poore and Nemecek 2018 database

Appendix 4. Methane abatement interventions covered by Climate Bonds Criteria

Climate Bonds Initiative (Climate Bonds) develops Sector Criteria to guide green investments in the agrifood sector, from farm to fork, with a focus on aligning financing with 1.5°C pathways. The table below outlines specific methane abatement measures and how are they referred to in the Sector Criteria for Agriculture Production, Alternative Proteins, and Food Value Chain. Climate Bonds Criteria can be found on the Climate Bonds website

<https://www.climatebonds.net/expertise>.

Methane abatement measure	Sector Criteria	Reference in Climate Bonds Criteria
Diversification into non-ruminant meat and crop production	Agriculture Production	Reduced livestock operation to be at least 50% of LSU with investments in physical assets for potential substitutions in other production systems with lower GHG footprint (i.e., plant-based protein production), while supporting farm income.
Diversification into alternative proteins	Alternative Proteins	Research, development, production and distribution of alternative proteins, and their associated infrastructure, ingredients and inputs.
Diversification into non-agricultural land uses	Agriculture Production	Reforestation and/or restoration, including peatland, mangroves/wetlands, and overgrazed grasslands with depleted soil organic carbon.
Improved forage	Agriculture Production	Measurable reduction of CH ₄ emissions relative to a baseline of at least 1.5% per year (measured following GHG Protocol guidance).
Rotational grazing	Agriculture Production	Landscape diversification. For example, rotational grazing (under climate adaptation measures).
Feed supplementation and inhibitors	Agriculture Production	Measurable reduction of CH ₄ emissions relative to a baseline of at least 1.5% per year (measured following GHG Protocol guidance). R&D on farming practices and technologies to reduce enteric fermentation methane emissions.
Silvopasture	Agriculture Production	Implement or maintain agroforestry (incorporating woody perennials into agriculture production units).
Breeding cattle for low emissions	Agriculture Production	Measurable reduction of CH ₄ emissions relative to a baseline of at least 1.5% per year (measured following GHG Protocol guidance). R&D on farming practices and technologies to reduce enteric fermentation methane emissions.
Manure management	Agriculture Production	Measurable reduction of CH ₄ emissions relative to a baseline of at least 1.5% per year (measured following GHG Protocol guidance).
Food waste reduction	Food Value Chain	Reducing food loss and waste through improved storage and warehousing facilities, and improved cooling and refrigeration.
Food waste reduction	Agriculture Production	Improved harvest, post-harvest and/or storage must aim at achieving a level of food loss no higher than 10% of total food production from post-harvest to distribution.

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