Columbia Business School
Climate Knowledge Initiative

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Reconsidering Proteins

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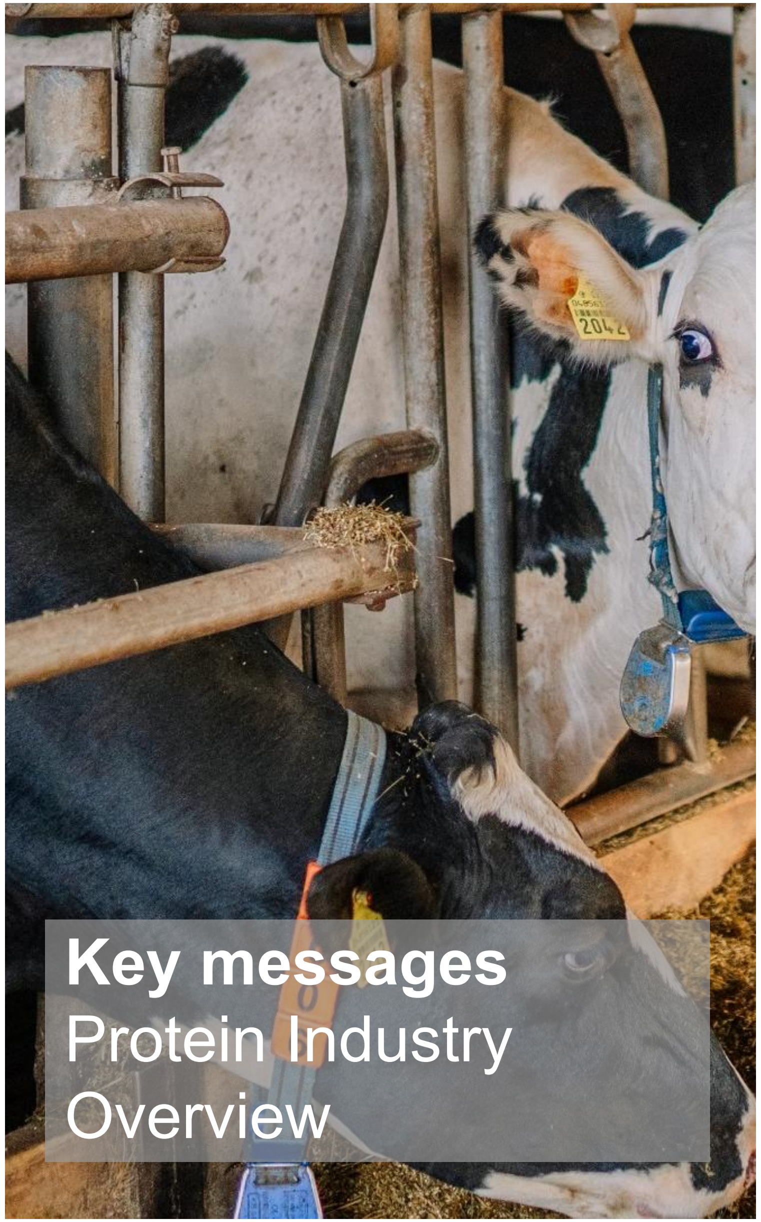
Protein Industry Overview



Key messages
Protein Industry Overview

Global food systems account for approximately 20% of global CO_2e emissions.

- The United Nations estimates that by 2050, **food production will increase 70% to sustain a global population** of 9.1 billion.
- Approximately **60-70% of agricultural emissions can be attributed to livestock** production.
- Production of animal-based proteins comes with other environmental problems, including **significant methane emissions, which accounts for 80% of agricultural land emissions** and drives **half of the global tropical deforestation** emitting CO_2**.**

Animal-based protein consumption is increasing.

- Agricultural emissions **are estimated to reach ~15 GtCO_2e by 2050** (30% higher than 2021 levels), with **60% related to animal protein.**
- Global protein consumption is dominated by vegetal sources. However, **animal protein consumption has accelerated fast**, from 27 grams per capita per day in 2020 to 37 grams in 2022.
- **Increasing income levels are one of the main reasons** for increasing meat consumption, especially in Asia, where **animal protein intake rose by ~300%** over the past five decades.

Methane is inevitable in the animal industry and difficult to offset.

- **Agriculture is the largest source of methane emitter globally (~40%)**, ahead of oil and gas (~35%). Livestock accounts for most of the methane from (~32% of the total).
- **CH_4** is especially concerning in the **short term**, as it is **84 times more powerful than CO_2** on a 20-year timescale, and **global methane emissions increased more rapidly than CO_2** in the past century.
- Cutting methane emissions to slow down global warming is one of the main intentions of this research.

The current deforestation trend is not sustainable in the long term.

- Animal proteins drive **half of the global deforestation**, mainly through **feed (~80%** of global soy production is used for animal feed) and forest clearing for cattle pastures.
- **Some 40% of global habitable land is used to meet animal protein demand.**

Credit: Nadine Palmowski, Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Global food systems are complex and face competing priorities; CKI focuses on the intersection of proteins and climate change

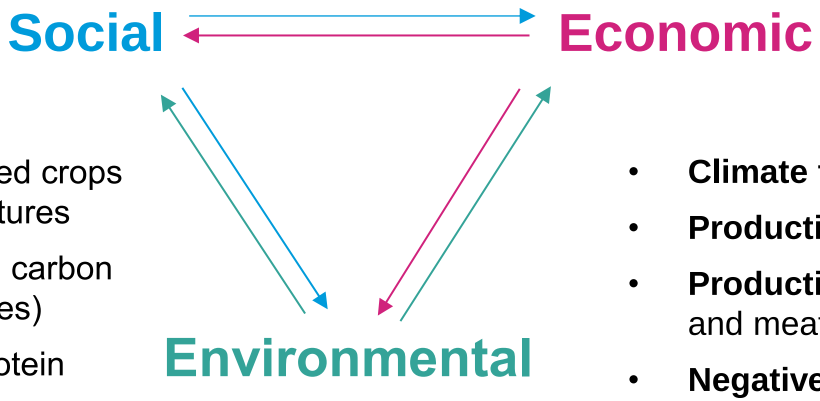
System-level priorities:

- Feed a **growing world population** of 9.1 billion people by 2050
- Meet **nutritional needs** while respecting cultural food norms
- Support **healthy diets** and prevent **diet-related chronic illnesses**

- **Affordability** of high-quality protein
- **Fair labor conditions** across protein production industry

System-level priorities:

- Protect and improve **farmers' livelihoods**
- Ensure continued **viable business models** of food enterprises
- Address **economic costs of transitioning** to sustainable production, including initial investments in technology and infrastructure



- **Shifts in suitable geographies** for feed crops and livestock due to warming temperatures
- **Land-use competition** (e.g., between carbon sinks and net emitting livestock activities)
- Behavioral resistance to alternative protein **consumption decisions**

- **Climate finance** for low-carbon protein solutions
- **Productivity** loss (due to fewer pollinators, soil degradation)
- **Productivity challenges** of sustainable agricultural practices and meat alternatives
- **Negative externalities** of meat alternatives

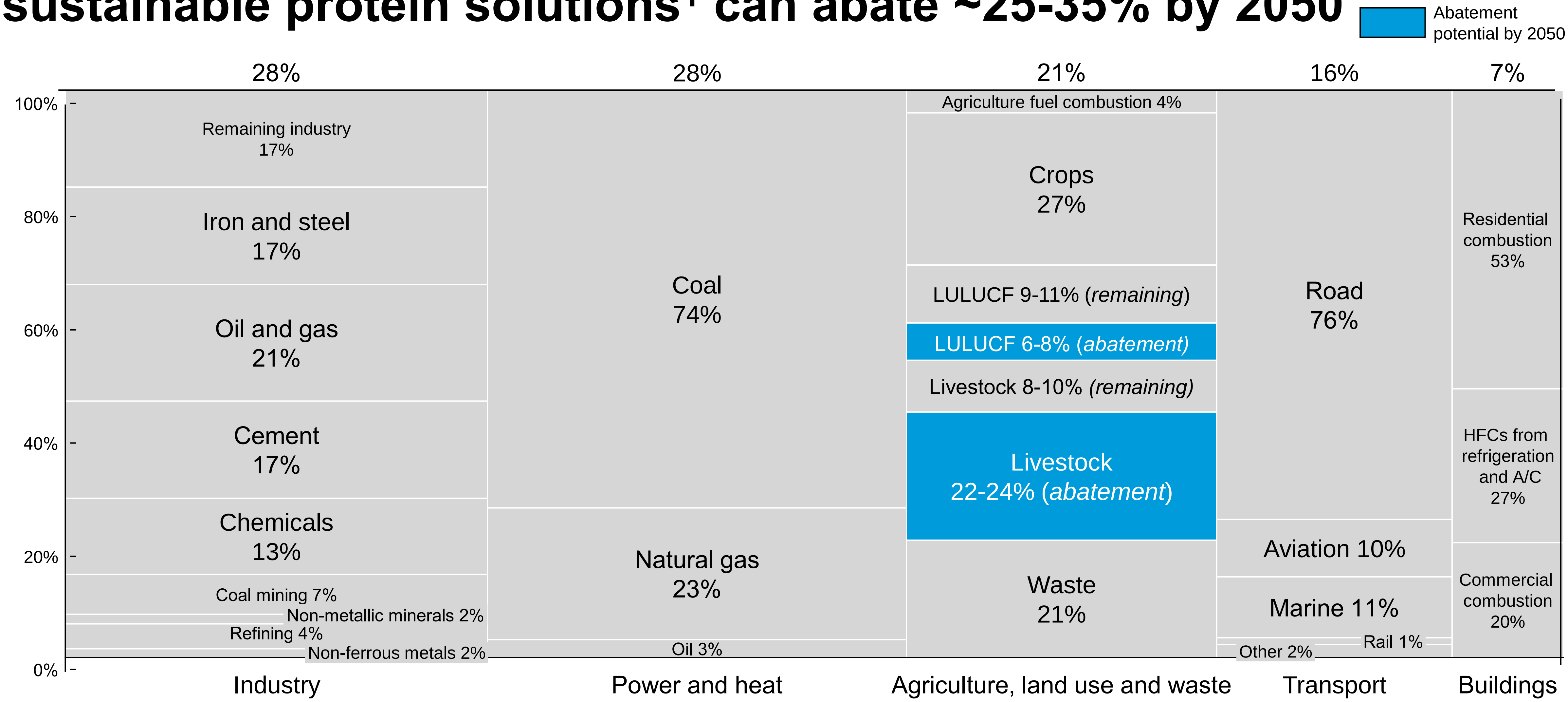
System-level priorities:

- Mitigate **greenhouse gas emissions** from the agriculture and food industry supply chain
- Prevent and reverse **biodiversity loss** from deforestation and unsustainable agriculture
- Reduce intensity of **land and fresh water use**

This deck focuses on sustainable protein production in relation to climate change

Credit: Friedrich Sayn-Wittgenstein, Asya Ikizler, Nadine Palmowski, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Food systems account for ~20% of global emissions, of which sustainable protein solutions[1] can abate ~25-35% by 2050



[1] Shifting to vegetal and plant-based proteins, sustainable pasture-based livestock production, and emissions reduction technologies for industrial livestock production.

Sources: Rhodium Group, ClimateDeck (2023); FAO, Climate change and food security report (2013)

Credit: Friedrich Sayn-Wittgenstein, Asya Ikizler, M.A. Miller, Nadine Palmowski, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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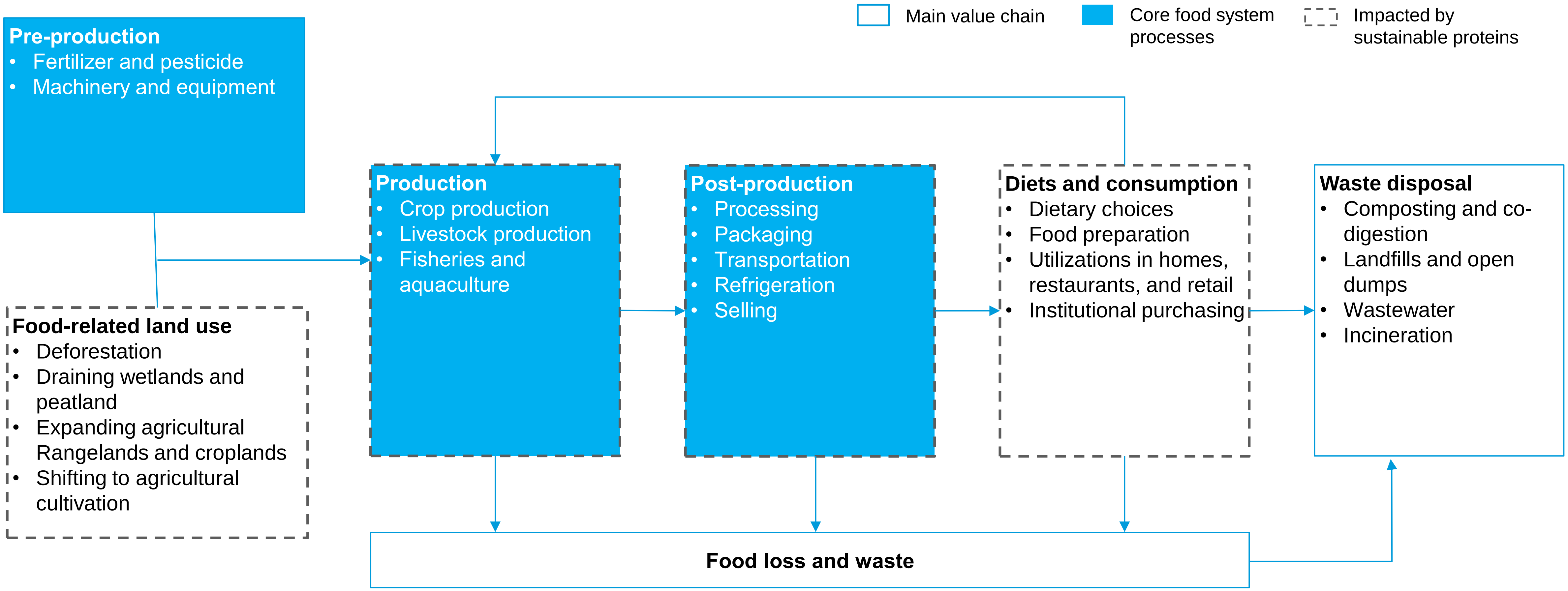
Protein value creation takes place across the food system, focusing on areas from production to consumption

Food system value chain and corresponding end products implicated in sustainable proteins



☐ Main value chain

🟦 Core food system processes

⬚ Impacted by sustainable proteins

Pre-production
- Fertilizer and pesticide
- Machinery and equipment

Food-related land use
- Deforestation
- Draining wetlands and peatland
- Expanding agricultural Rangelands and croplands
- Shifting to agricultural cultivation

Production
- Crop production
- Livestock production
- Fisheries and aquaculture

Post-production
- Processing
- Packaging
- Transportation
- Refrigeration
- Selling

Diets and consumption
- Dietary choices
- Food preparation
- Utilizations in homes, restaurants, and retail
- Institutional purchasing

Waste disposal
- Composting and co-digestion
- Landfills and open dumps
- Wastewater
- Incineration

Food loss and waste

Sources: IOP Science Environmental Research Letters, Greenhouse gas emissions from food systems (2021); McKinsey, Food system GHG emissions (2022).
Credit: Friedrich Sayn-Wittgenstein, Asya Ikizler, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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Scope of sustainable proteins broken down into four categories

	Vegetal proteins	**Livestock proteins**	**Aquatic proteins**	**Alternative proteins**
Description and key indicators	• **Soy, wheat, and pea** are the largest sources. • **Soy dominates supply** due to cost-effective mass production. • **80% of soy supply** serves as livestock feed. • **Brazil leads production (~20% increase** over the past five years), while China leads imports.	• **Poultry and pig meat** dominate supply, followed by **beef and buffalo.** • **High GHG emissions and extensive land and water use** lead to negative environmental impact on biodiversity and soil health. • **Asia dominates global production and supply** (mainly China), followed by the Americas.	• **Fish, shrimp, and algae** are primary sources. • **About 60% of supply is from aquaculture**, which is **efficient** but comes with significant **environmental impacts,** including water use, nutrient runoff, and habitat loss. • **Asia leads in aquaculture supply** (mainly China), followed by Europe and the Americas.	• **Plant-based:** Foods that aim to replicate the sensory feeling of eating animal protein (e.g., soy patties)**.** • **Lab-grown/cultivated:** Meat produced directly from animal cells. • **Fermentation-derived:** Foods produced by the chemical breakdown of biomass by bacteria, yeasts, or other microorganisms (e.g., tempeh).
Products	**Soy, corn, wheat, peas**	**Beef, poultry, pig, sheep, dairy**	**Fish, shrimp, algae, other aquatic protein sources**	**Plant-based protein, lab-grown meat, fermentation-derived proteins**
Key benefits and challenges	**Benefits:** • Cheap production, high scalability • Long history and culture within global food systems **Challenges:** • Lower bioavailability of protein • Some sources overgrown, creating large monocultures with high land use and negative environmental impact	**Benefits:** • High bioavailability of protein • Meat, eggs, and dairy provide bio-available critical micro-nutrients that are not replicated in traditional plant proteins **Challenges:** • Most land-inefficient source of proteins[1] • One of the largest methane source globally • Contributes to biodiversity loss through forest clearing and monocultures for industrial feed	**Benefits:** • High bioavailability of protein • High content of essential omega-3 fatty acids • Can be sustainably farmed with tech advance **Challenges:** • Overfishing, bycatch, and habitat destruction in wild-capture fisheries • Water pollution, disease transmission, high wild fish stock feed, and significant energy input in aquaculture	**Benefits:** • High protein content and digestibility • Depending on the source, can have high micronutrient content and fiber • Increased land and water efficiency • Low methane or other GHG emissions **Challenges:** • Adoption rate and scalability • High energy use, high production cost, and high up-front capital investments (type-dependent)
Global protein supply 2021	**~60%** of global protein supply based on vegetal sources, making it the most prevalent source 	**~35%** of global protein from livestock, although it disproportionately has the most emissions 	**~5%** varying largely across regions according to access 	**<1%,** as current scalability challenges lead to a low rate of implementation and expansion
Food system GHG emissions in 2021	**~30%** 	**~60%** 	**~5%** 	**Could mitigate ~30% of food system emissions by 2050**

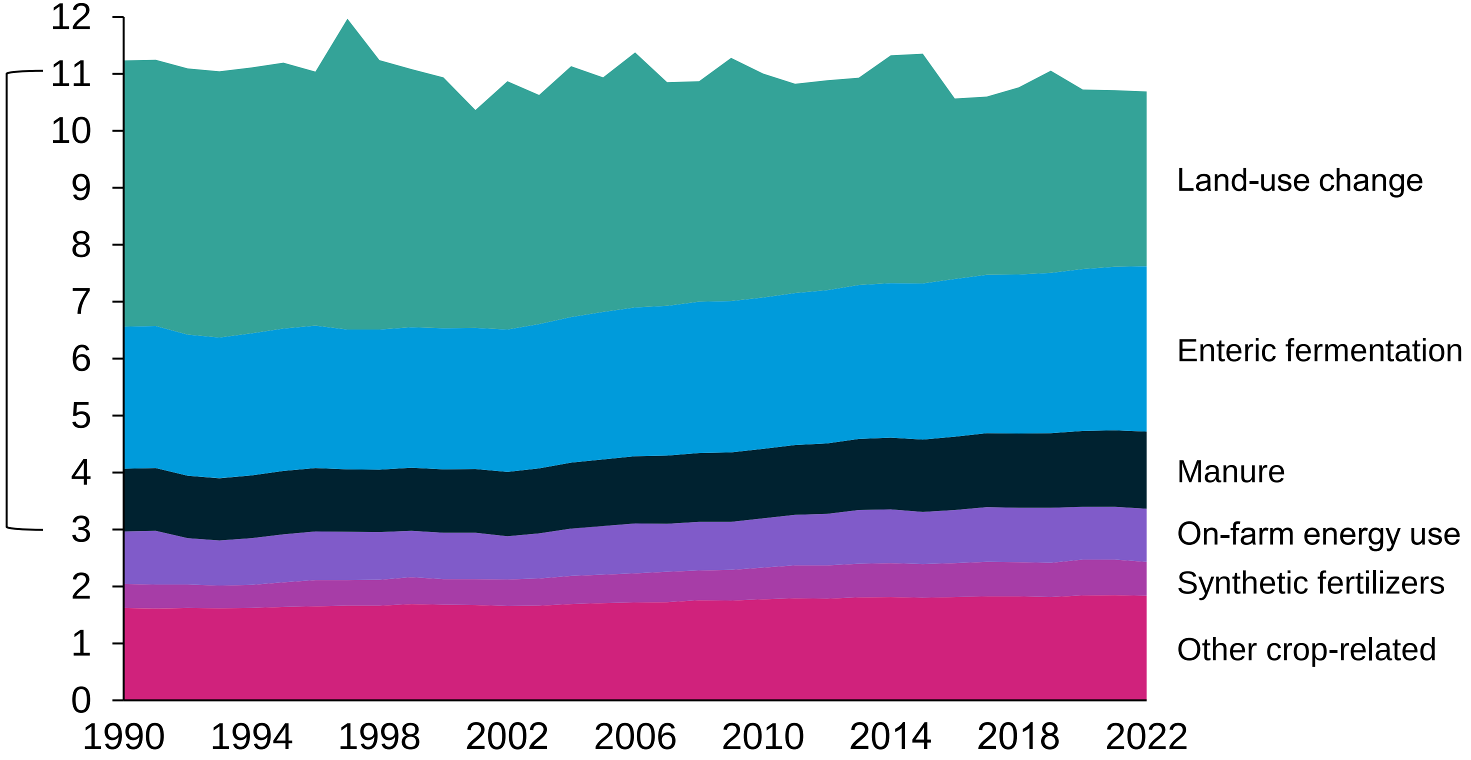
[1] Land efficiency and feed source varies based on management system. See slide 11 for a management system breakdown.

Sources: Nature, Global greenhouse gas emissions (2021); FAO report (2023); New Protein, Global Plant Protein: A Brief Outlook (2022); WWF, Soy (2024); FAO, The State of World Fisheries and Aquaculture (2022).

Credit: Nadine Palmowski, Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Up to ~70% of agricultural emissions come from livestock, driven by manure, enteric fermentation, and land use change

GHG emissions from agriculture from 1990 to 2022, $GtCO_2e$



Up to 70% of agricultural emissions are related to livestock

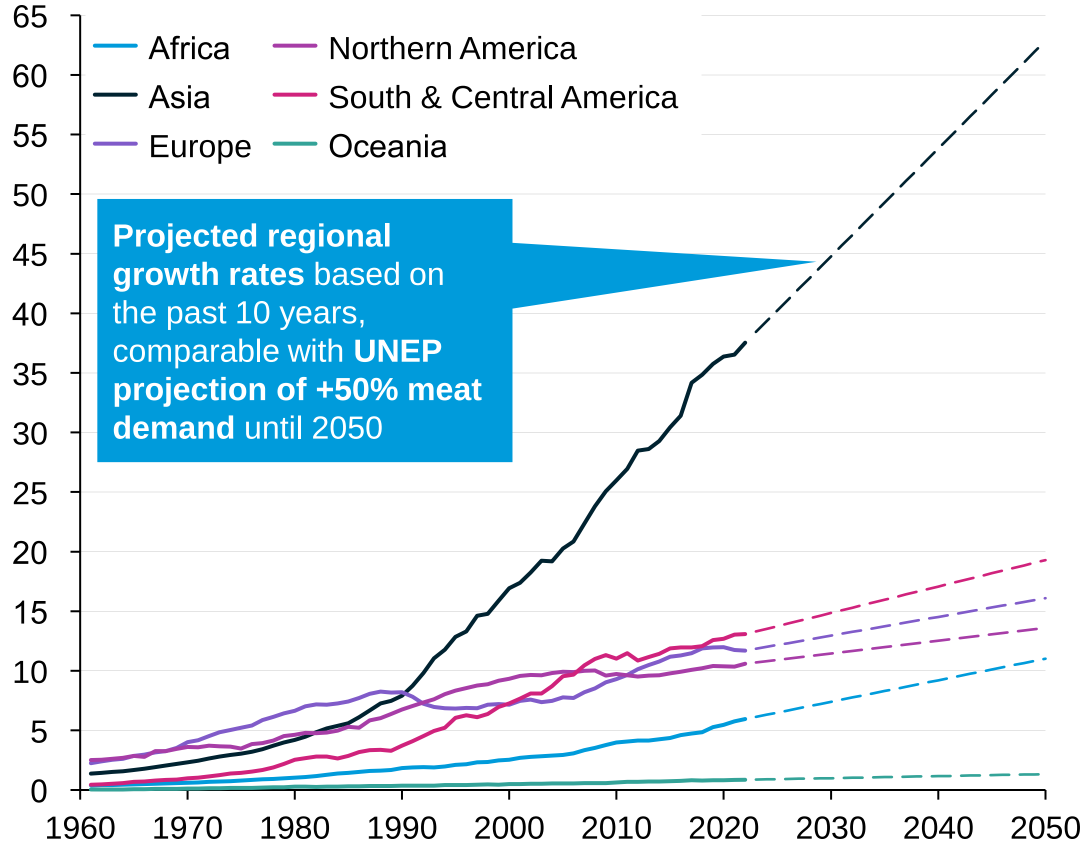
Observations

- Most livestock-related emissions are **direct emissions**, primarily from **enteric fermentation** in ruminants and **manure management practices**, both of which release large amounts of **methane**, a potent greenhouse gas.
- The remaining livestock-related emissions are largely **indirect**, related to land use changes such as **deforestation for feed crop production and grazing land.**
- While land-use change emissions come from various sources, **agriculture-related deforestation is largely driven by the cattle industry.**
- **Overall agricultural emissions are expected to grow by 60% by 2050** to meet the increasing global protein demand.

Sources: FAOSTAT, Food and agriculture data (2024); WRI, Commodities replacing forest areas (2021).
Credit: Friedrich Sayn-Wittgenstein, Isabel Hoyos, Asya Ikizler, Nadine Palmowski, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

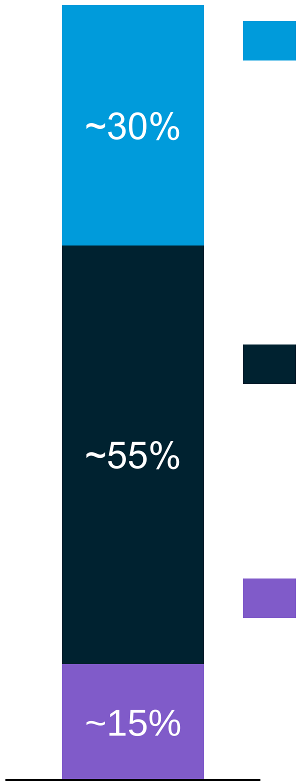
Livestock demand expected to grow, driving carbon dioxide (CO_2), methane (CH_3), and nitrous oxide (N_2O) greenhouse gas emissions

Global livestock* count from 1960-2050 (in billion animals per year)



Projected regional growth rates based on the past 10 years, comparable with **UNEP projection of +50% meat demand** until 2050

Livestock emission types and their sources



Carbon dioxide
- Land-use change (deforestation)
- Feed production
- On-farm energy
- Post-farm

Methane
- Enteric fermentation (ruminant digestion)
- Manure

Nitrous oxide
- Manure
- Feed

Observations

- **Livestock numbers have increased significantly from 1960 to today,** from 8 billion to around 80 billion animals per year.
  - The UN Environmental Programme expects **demand to drive another 50% growth until 2050.**
  - **Growth rates differ by region,** with Asia a strong leader and potential stabilization in Europe.
- Share of gases **vary across locations, livestock species, and production systems.** For example:
  - Main GHG source for chicken is feed production in many regions (e.g., East Asia); for pigs, its manure management.
  - For cattle, enteric CH_4 is dominant; for chicken, CO_2 from land use and feed is higher.

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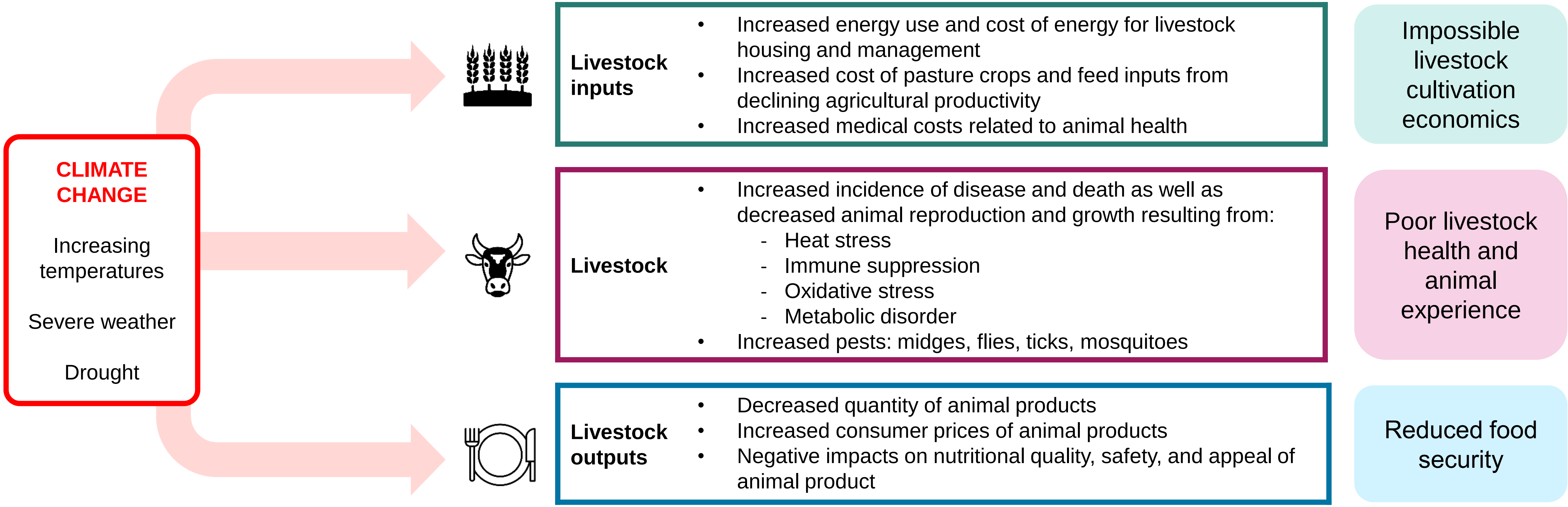
*Livestock: Animals raised and slaughtered for food production, including producing animals (e.g., for dairy) and animals designated for slaughter.

Sources: Our World in Data, Meat and Dairy Production (2024); FAO, Pathways towards lower emissions (2023).

Credit: Nadine Palmowski, Raissa Coan Ribeiro, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Climate change impacts livestock health in a manner that impacts the entire animal protein value chain

The impacts affect farmers, animals, and consumers, economically, nutritionally, and health-wise



CLIMATE CHANGE

Increasing temperatures

Severe weather

Drought

Outcomes

Livestock inputs

- Increased energy use and cost of energy for livestock housing and management
- Increased cost of pasture crops and feed inputs from declining agricultural productivity
- Increased medical costs related to animal health

Impossible livestock cultivation economics

Livestock

- Increased incidence of disease and death as well as decreased animal reproduction and growth resulting from:
  - Heat stress
  - Immune suppression
  - Oxidative stress
  - Metabolic disorder
- Increased pests: midges, flies, ticks, mosquitoes

Poor livestock health and animal experience

Livestock outputs

- Decreased quantity of animal products
- Increased consumer prices of animal products
- Negative impacts on nutritional quality, safety, and appeal of animal product

Reduced food security

Sources: NIH, Impact of climate change on livestock health (2020); NIH, Impacts of CC on livestock (2021); USDA, CC and Agriculture in the U.S. (2013); EPA, Climate impacts on food supply (2024).
Credit: M.A. Miller, Friedrich Sayn-Wittgenstein, Helen Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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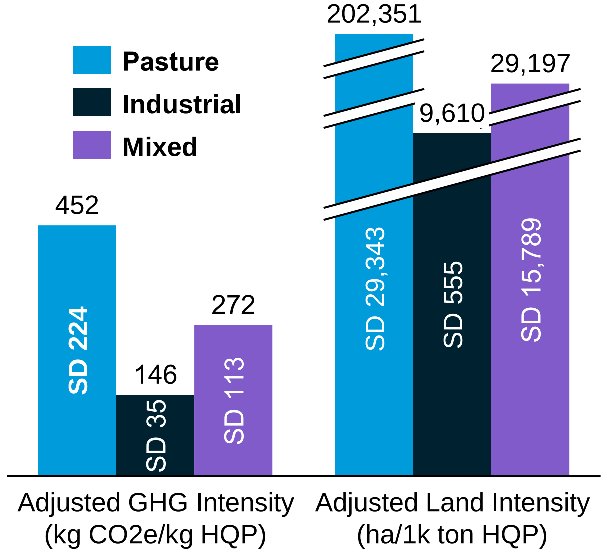
Environmental implications of livestock are diverse and vary significantly based on management system and geography

The landscape of livestock management

Pasture-based	Management system is based on natural ecosystems to which large ruminant have been contributed for millions of years.	⊕ Contributes to the ecosystem's natural equilibrium ⊕ Can be based on natural grasslands or sown pastures, which might result in lower methane emissions and do not contribute to LULUCF ⊕ Provides opportunity to regenerate natural grasslands and improve soil carbon-capture potential ⊖ Can be created on cut or deforested terrains ⊖ Produces the most emissions per kg of beef
Grain- or feedlot-based	Industrial management system is based on the rearing of cattle in large feedlots, where animals are fed with grain and hay.	⊕ Can enable several thousand animals to be raised for food production in a smaller area of land at a lower cost ⊕ Produces least methane per kg of beef ⊖ Presents concerns about animal welfare ⊖ Requires high use of antibiotics and hormones ⊖ Can contribute significantly to water contamination
Mixed management	Combines management practices from pasture- and grain-based systems. Pastures cycle between crops and cattle, and cattle rotate between grazing on pastures and feeding on grains and hay.	⊕ Enhances soil health, improving C and N retention in the soil ⊕ Diversified agrifood system activities can reduce income vulnerability ⊖ Can be labor-, cost-, and infrastructure-intensive

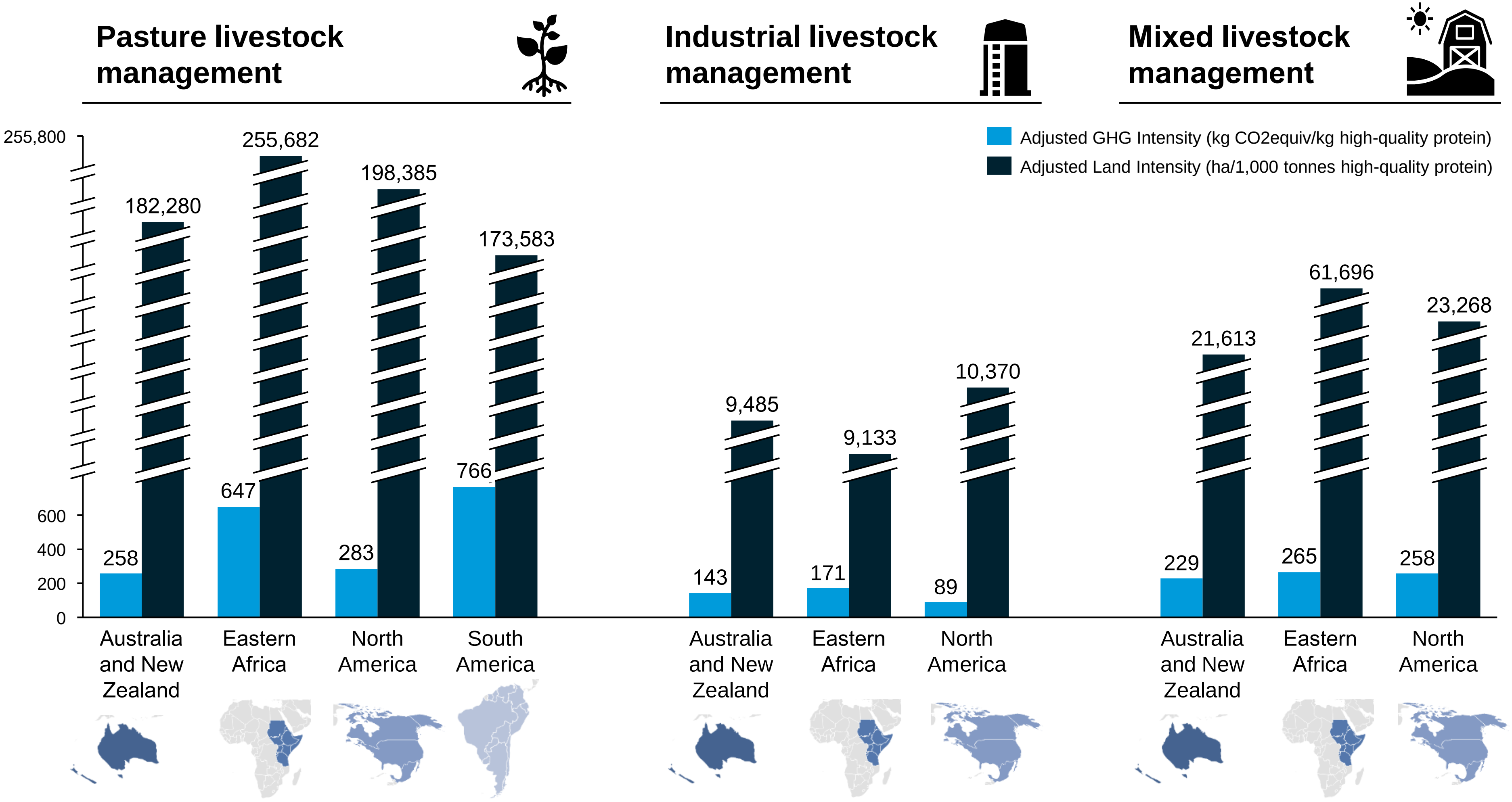


It is important to note:

- Averages are not the most accurate representation of the environmental impact of management systems.
- There is great variability of impact within systems based on factors such as geography, particularly for pasture-based systems.
- Feed procurement is a main source of variation.
- Baseline emissions for pasture-based systems are not zero, as level emissions are part of a grassland's natural ecosystem processes equilibrium.

Sources: Walter E. Baethgen, PhD, (2024); Karl et al., Framework to evaluate livestock-derived protein systems (2024); Giménez, Mixed crop/livestock systems in Pampas (2006).
Credit: Ariela Farchi Behar, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Environmental indicators of livestock management practices vary widely depending on regional conditions



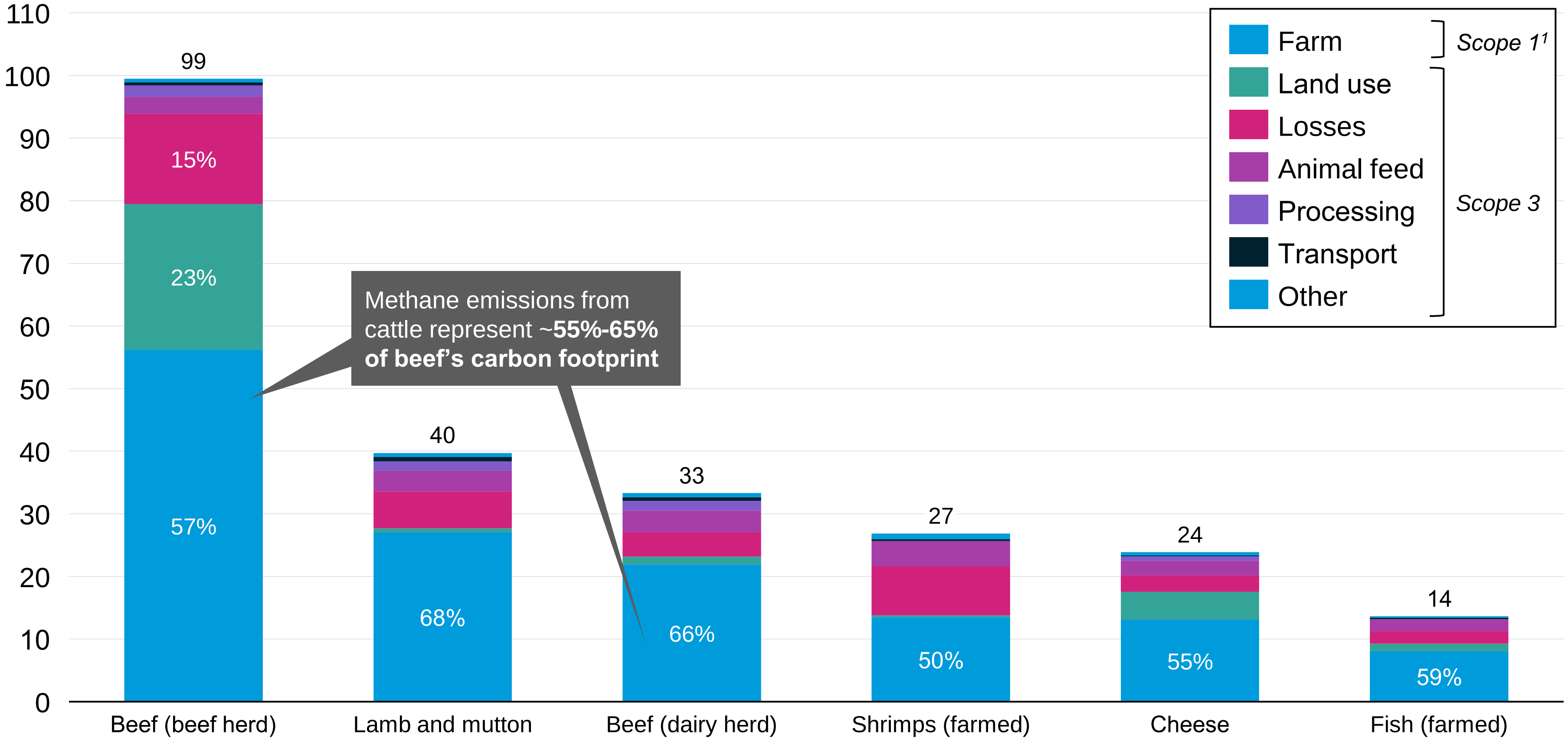
Observations

- **Regionality is key** for sustainable practices in livestock management.
  - **Emissions and land use vary greatly** based on region and management practice.
  - **Regional conditions make practices more relevant** or adept for different livestock management systems.
  - It is essential to **understand what drives these environmental indicators** in each geography.
  - **Pasture-based beef has the highest GHG emissions and land use but also the highest potential for change** from sustainable intensification practices (such as rotational grazing) **in developing geographies.**
  - Such practices could reduce emissions and land use while continuing to provide high-quality protein to food-insecure countries.

Source: Karl et al., Framework to evaluate livestock-derived protein systems (2024).
Credit: Ariela Farchi Behar, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Of all animal protein sources, beef has the highest carbon footprint, mainly due to high methane emissions

Carbon footprint of different protein sources across the supply chain (total in CO_2e/kg)



Methane emissions from cattle represent ~**55%-65% of beef's carbon footprint**

Observations

- **Beef from beef herds** (livestock with the main purpose to grow beef) **has the highest carbon footprint**, followed by lamb and mutton and beef from dairy herds (cattle bred primarily for milk production).
- **Methane emissions are the predominant cause of high Scope 1 emissions** from farms, representing **~60% of beef's footprint.**
  - Methane emissions result from enteric fermentation.
  - Solutions include improved manure management, dietary changes, and adoption of methane-reducing technologies.
- **Reducing beef consumption** would substantially **decrease methane and thereby overall food system emissions.**

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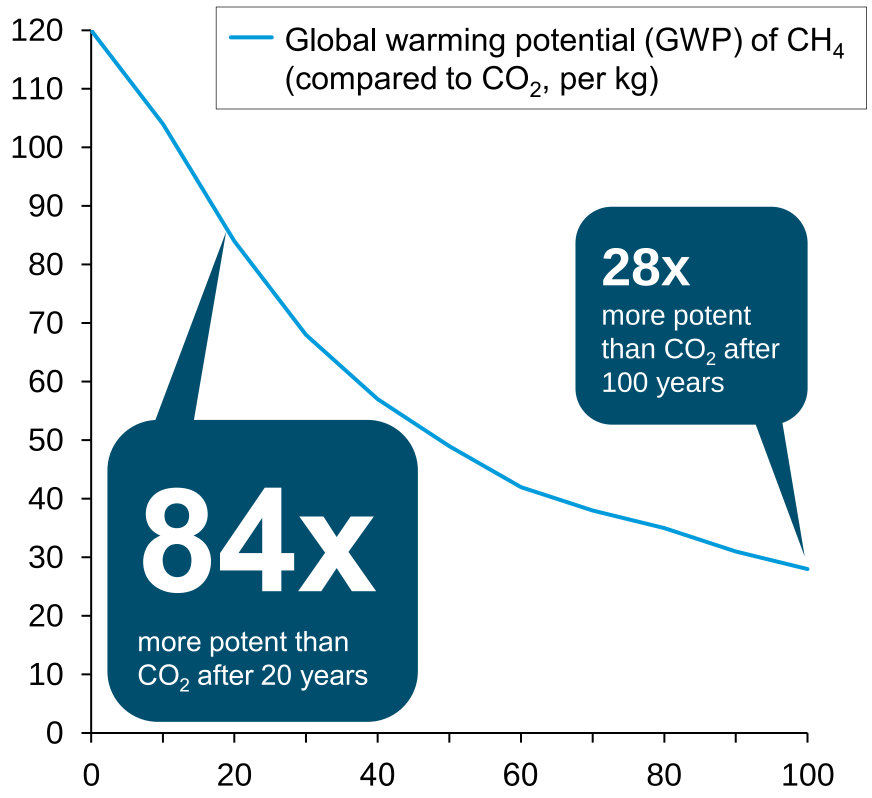
[1] Including negligible Scope 2 emissions for farm operations.

Sources: Rosado & Roser, Environmental Impacts of Food Production (2022); Science, Reducing Food's Impact Through Producers and Consumers (2018).

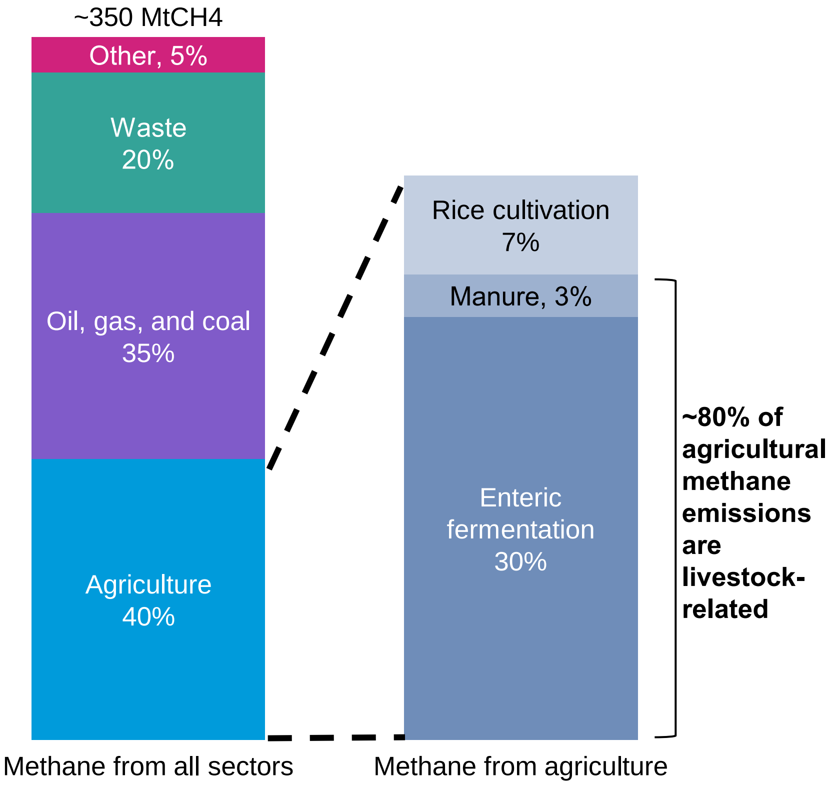
Credit: Asya Ikizler, Nadine Palmowski, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Reducing methane is urgent due to high short-term GHG potency; emissions mainly stem from food systems, specifically livestock

Methane's global warming potential in the atmosphere over 100 years



Global methane emissions breakdown by source, 2022



Observations

- Agriculture is the largest source of global methane emissions, surpassing oil and gas. **Livestock accounts for the majority of agricultural methane,** mainly from enteric fermentation and manure, and contributes about 33% of total methane emissions.
- **Manure-related methane makes up a larger share of livestock emissions in high-income countries** (up to ~18%) due to confined systems, while emissions are mostly enteric in lower-income countries, with manure contributing just 4–8%.
- **Cutting methane** emissions is the **fastest way** to slow down the global average temperature increase due to its potent nature and short lifespan.
- **Methane concentration** in the atmosphere **is rising much faster than CO_2 concentration:** From 1900 to 2020, CO_2 increased by 40%; methane increased by 120%.

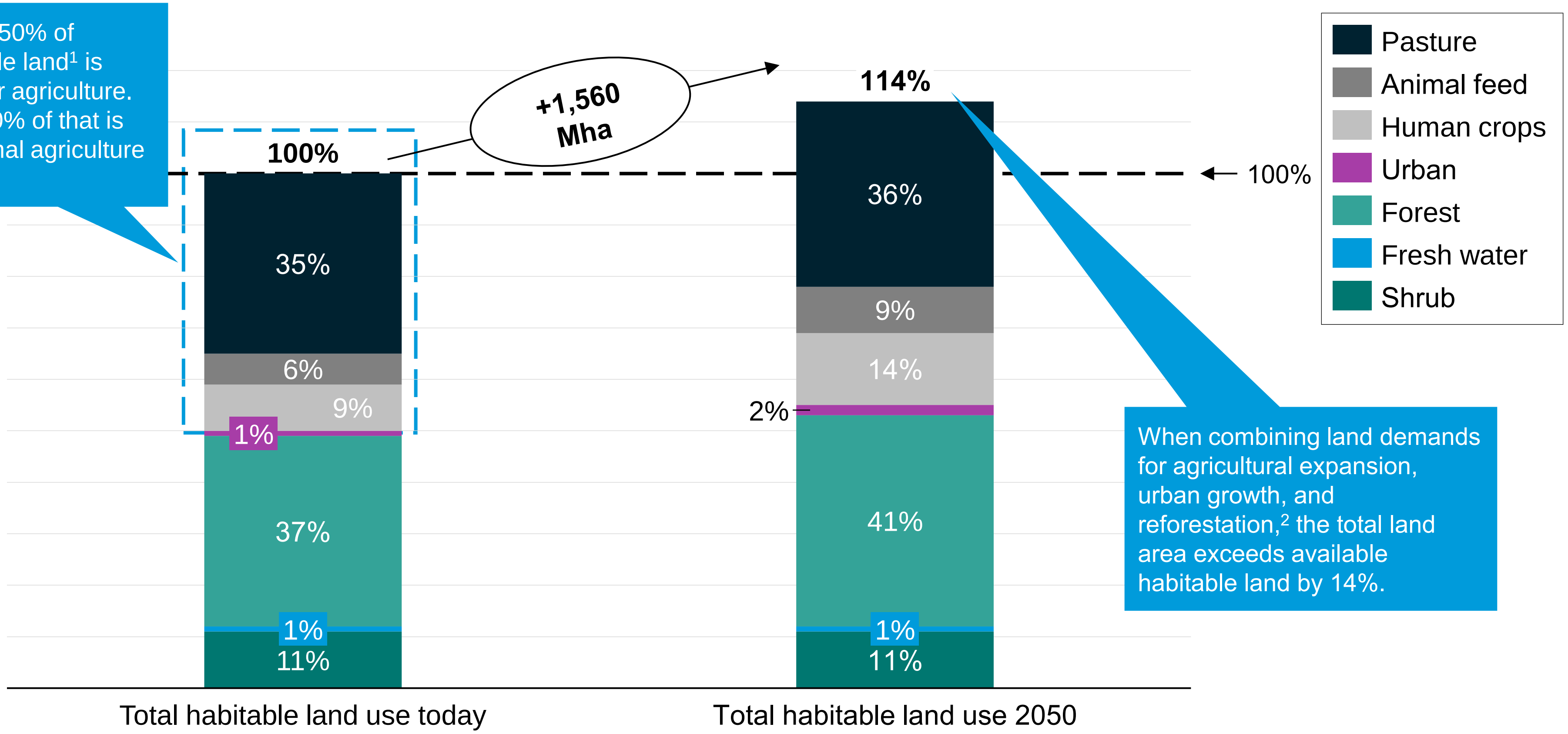
Sources: NASA, Methane report (2024); BCG, Methane: Today's High-Impact Greenhouse Gases (2023); FAOSTAT, Food and agriculture data; ClimateWatch, Historical GHG Emissions; Clean Air Task Force, Accelerating Solutions in agriculture (2024).

Credit: Asya Ikizler, Isabel Hoyos, Nadine Palmowski, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Livestock-derived proteins are driving half of global deforestation, a trend that cannot continue under net-zero climate goals

Livestock-related land use is still growing and will exceed the total available land area in the future, leading to land competition between agriculture and carbon sinks

Today, 50% of habitable land[1] is used for agriculture. Over 80% of that is for animal agriculture only.



When combining land demands for agricultural expansion, urban growth, and reforestation,[2] the total land area exceeds available habitable land by 14%.

Observations

- **With projected agricultural demand growth of +50% by 2050,** land requirements for agriculture and reforestation[1] combined will **exceed available habitable land by 1.56 billion ha** — 2x the U.S. land area.
- This highlights the competition for land, where **reforestation and agricultural expansion cannot occur simultaneously.**
- **Excessive agricultural land use** also comes with several other challenges, such as **biodiversity loss, loss of ecosystem services, and opportunity cost** (land use for more nutritionally diverse food and carbon sequestration).

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[1] Habitable land refers to all land on earth except glaciers and deserts.

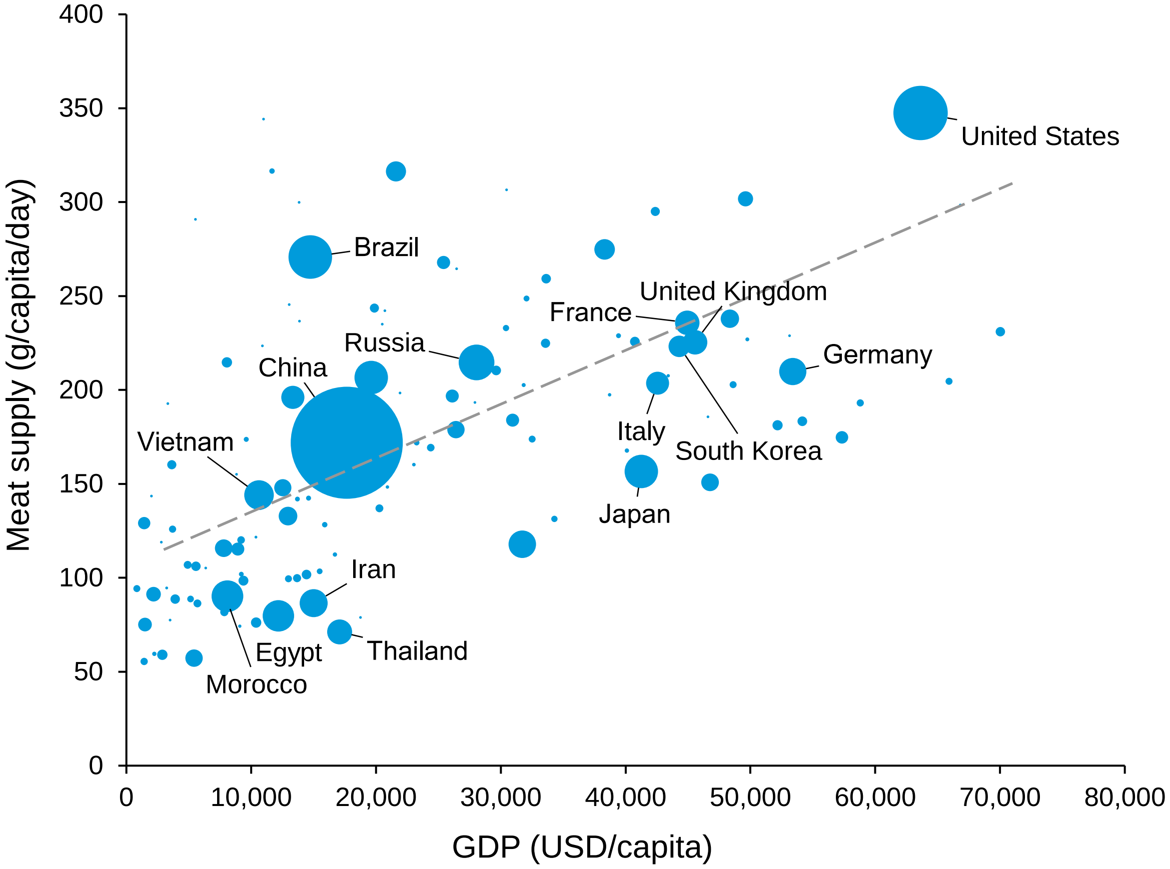
[2] Planting trees for carbon sequestration to reach climate targets.

Sources: WRI, Managing the global land squeeze (2023); Bajželj et al., Importance of food demand management for climate mitigation (2014); McKinsey, The agricultural transition (2023).

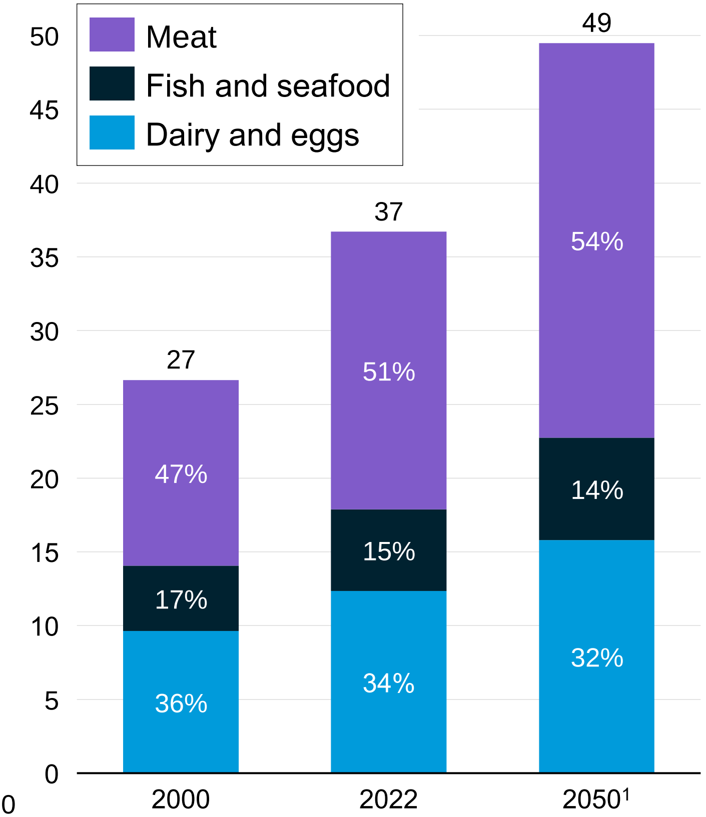
Credit: Asya Ikizler, Friedrich Sayn-Wittgenstein, Nadine Palmowski, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Per-person meat consumption is correlated to income levels and is expected to continue its increase over the next several decades

Meat supply in grams per capita per day in correlation to GDP and population size in 2023



Global protein consumption, 2000 to 2050, in g/capita/day



Observations

- Meat consumption rates are closely related to income levels. **Higher GDP per capita is related to higher meat consumption.**
- **Related data on animal protein consumption —** including not only meat but also fish, seafood, and other animal products (milk, butter, eggs) — **also shows a significant increase:**
  - Animal protein consumption per person increased by 10g on average over the past ~20 years.
  - Meat consumption is slowly increasing the share in overall animal protein consumption.
- Current **growth rates suggest that the trend is going to continue.**

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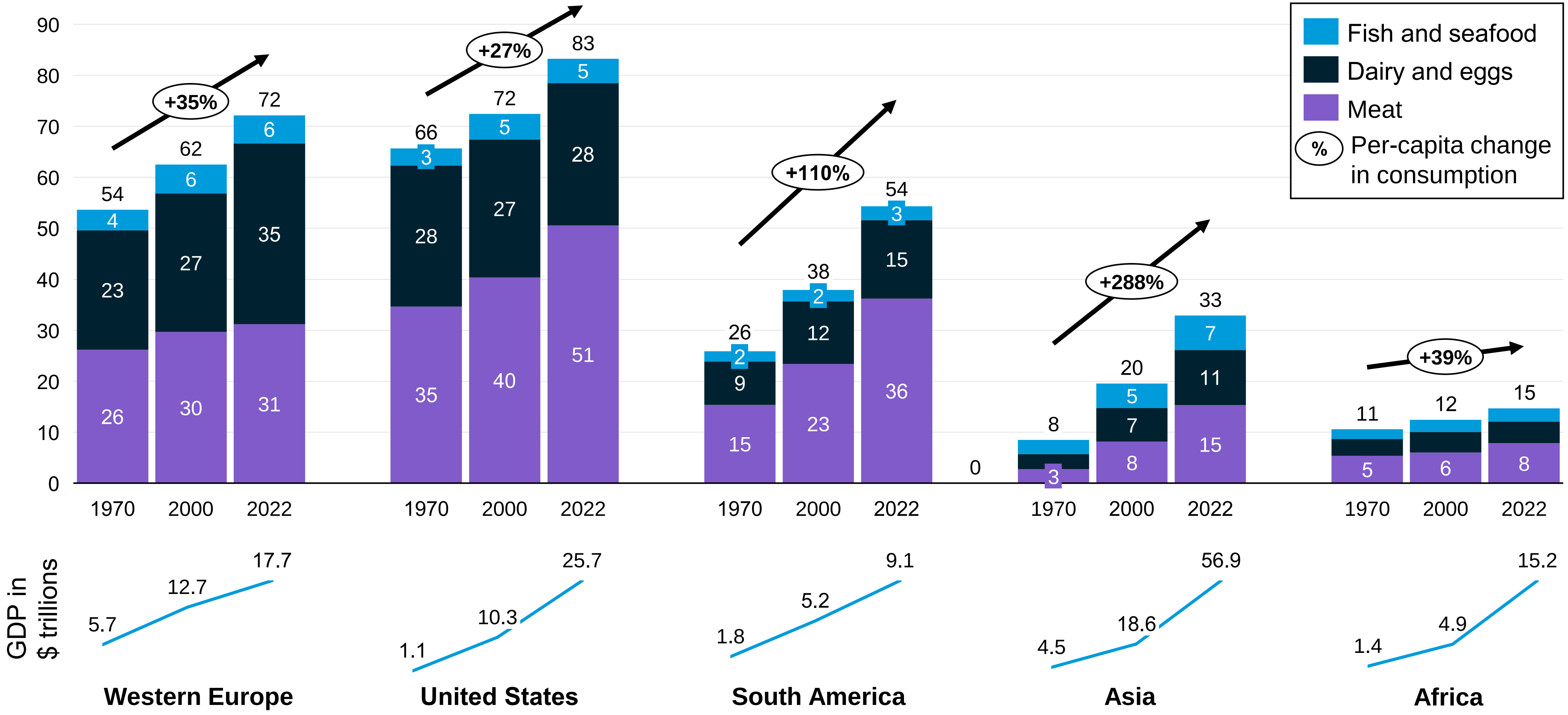
[1] Conservative estimate, based on linear extrapolation based on growth in the past two decades.

Source: Our World in Data, Meat and Dairy Production (2023).

Credit: Nadine Palmowski, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Income-level increase drives growing animal protein consumption, with highest growth rates in South America and Asia

Historic animal protein consumption by region from 1970 to 2022 in g/capita/day



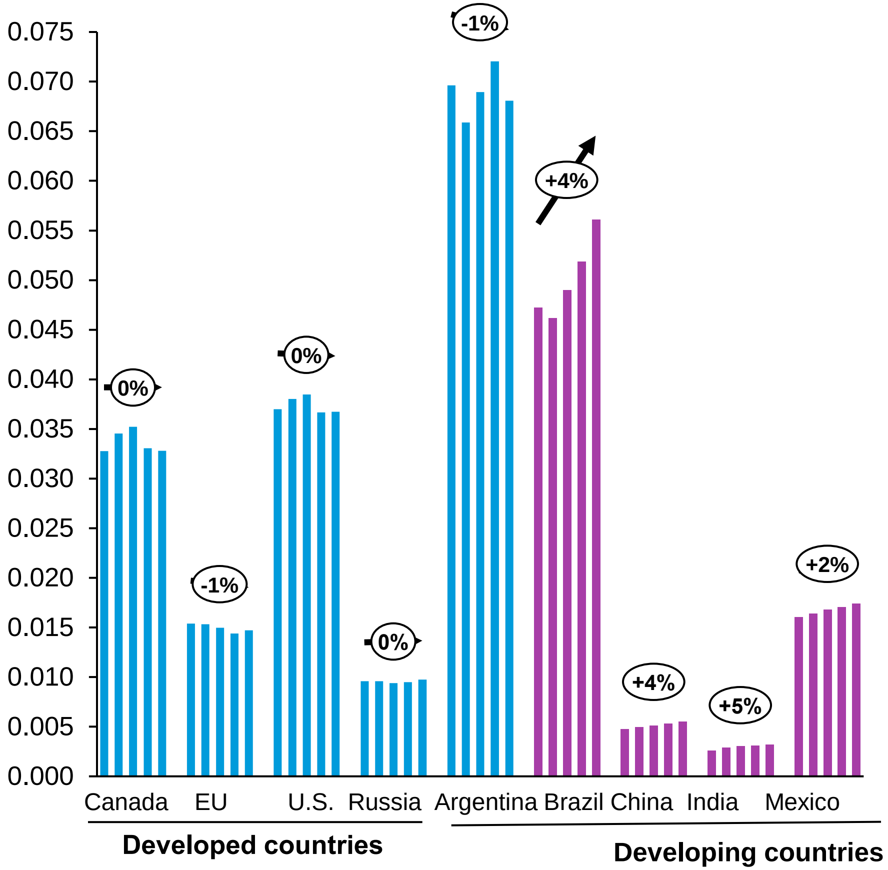
Observations

- **Animal protein consumption per capita increased significantly** over the past decades in all continents.
  - Highest consumption is in the United States and Western Europe.
  - Highest growth rates are in Asia and South America.
- **Meat consumption has the fastest growth rate among all animal proteins** across all continents.
- **The trend is expected to continue**, hence the importance of decarbonizing livestock.

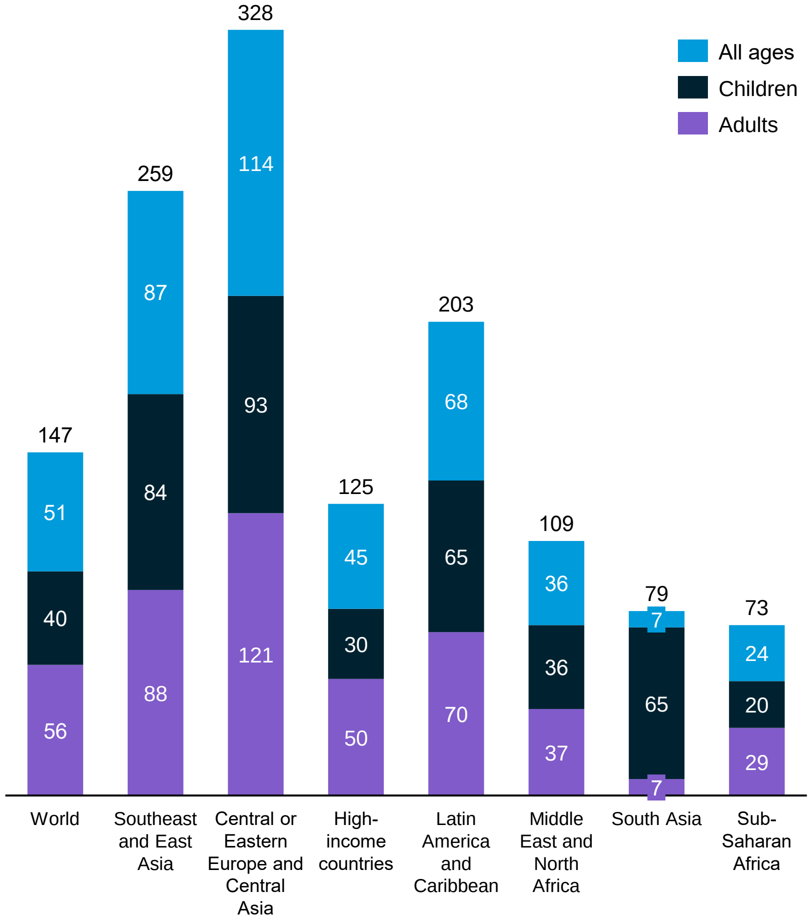
Source: FAOSTAT, Food balances (2024). Credit: Asya Ikizler, Nadine Palmowski, Raissa Coan Ribeiro, Friedrich Sayn-Wittgenstein Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Variations in meat production and consumption across regions highlight the need for tailored sustainable protein strategies

Beef and veal production – 2020-2024 summary, 1,000 kilograms per capita (carcass weight equivalent)



Estimated unprocessed red meat consumption among children and adults, by world region, in 2018 (g/day)



Observations

- The standard recommended dietary allowance (RDA) for proteins is **0.8 kg of protein per kg of body weight.**
  - Animal protein **can fulfill daily dietary minimum needs, especially in developing regions** such as Africa, where 58% of the population is food insecure.
  - Most **American diets exceed recommended meat consumption.** Reduction in red and processed meats is advised by the Dietary Guidelines for Americans.
- **Livestock production growth is driven by increased productivity** — measured as total factor productivity (TFP), or production inputs and outputs — resulting in **lower climate impact, less risk, and improved animal and human health.**
  - The livestock sector is one of the **fastest growing economic sectors in middle- and low-income countries.**
  - There is a **high association between a higher TFP and economic performance,** presenting a major opportunity for small-holders in the agribusiness supply chain.

Sources: USDA, Livestock and Poultry: World Markets and Trade (2024); OECD, Agricultural Outlook (2024); FAO, SoFI (2024); USDA, DGA (2020); USDA, Global Changes in Agricultural Productivity (2024); World Bank, Moving Towards Su stainability (2024).

Credit: Ariela Farchi Behar, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Technological and Industry Advancements

Decarbonizing global protein supply requires a nuanced and multi-faceted approach.

- A **sustainable protein future will see a mix of** animal protein from **sustainable livestock management** practices in developing economies, and a **higher consumption of alternative proteins** in developed economies.
- A protein transition approach with diverse solutions—such as sustainable production practices, methane-inhibitor technologies, and alternative proteins—is essential to achieve that.

Different abatement solutions are being developed for animal-based protein emissions.

- **Sustainable management practices, productivity increases, and selective breeding** present the greatest **mitigation potential for livestock in developing countries.**
- **Livestock methane reduction** strategies and technologies are emerging, but their mitigation potential is still uncertain or depends on **incentives for large-scale implementation** by producers.
- **Reducing the CO_2** emissions of the sector relies on combatting **deforestation.** Switching to less land- and water-intensive animal feed and implementing deforestation-free corporate supply chain policies can cut over 60% of CO_2 emissions related to animal agriculture.
- **Aquaculture** is the world's **fastest growing** food industry. The **species, feed, and production method** determine its emissions. Focusing on **expanding** the right ones and **innovating feed** are critical for a sustainable protein supply.

A diet shift and adoption of alternative proteins are effective ways to reduce emissions.

- Alternative proteins fall under three categories: **plant-based, fermentation, and cultivated.**
- **Plant-based** proteins save **4.4 gigatonnes of CO_2e emissions per $1 trillion invested**. Emissions abatement could increase when accounting for land-use changes and carbon sequestration from rewilding and afforestation.
- **Consumers prioritize taste, price, and health** over sustainability when purchasing food. Companies need to address these key concerns with **product development and improved marketing strategies.**
- Alternative proteins can use **lessons learned from electric vehicles** and the energy transition to **accelerate** the protein transition through alternative proteins, an **innovation that is also struggling with consumer adoption and price parity at first.**
- Strategies to **tap into unexplored markets** like frozen, ready-to-eat foods, displacing ultraprocessed meat and blended products, can help alternative proteins scale.

Credit: Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Decarbonizing proteins requires transforming livestock systems and accelerating growth of plant and alternative sources

H High M Medium L Low

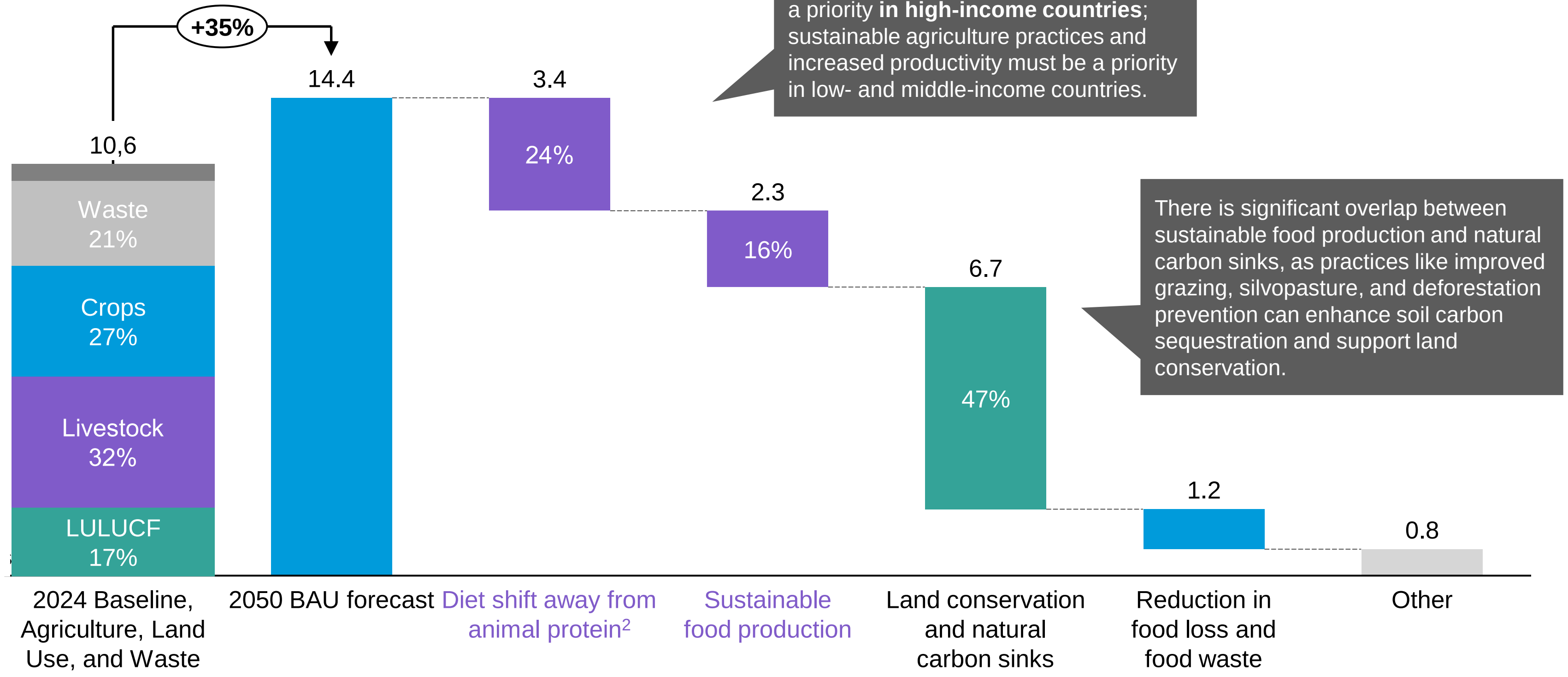
	Sustainable Pasture-Based Livestock Production	Emissions Reduction in Industrial Livestock Production	Shift to Vegetal and Alternative Protein Sources
Description	• Rotational and adaptive **grazing management** • **Silvopasture** system integration • **Selective breeding** for lower methane • **Deforestation-free** supply chains • Improved **animal health and productivity**	• Feed **additives** and **vaccines** • Improved **manure management** • Alternative **animal feed** • **Selective breeding** for lower methane • **Deforestation-free** supply chains • Improved **animal health and productivity**	• Increased adoption of **plant-based, fermented, and lab-grown alternatives** to meat and dairy • Increased consumption **of traditional protein-rich foods** like legumes, pulses, tofu, tempeh, and seitan
Opportunities	• Enhances soil carbon storage • Improved ecosystem health • Potential for value-added markets (e.g. regenerative, organic certification)	• Methane and nitrous oxide reduction • Potential for added value through energy production and nutrient cycling	• Drastic reduction of all emissions, land, and water use relative to animal protein • Aligned with health, sustainability, and ethical consumer trends
Challenges	• Significant land and labor requirement • Vulnerable to climate variability and requires long-term land management • Lower productivity than industrial systems	• High capital and operational costs • Limited maturity and regulatory approval for feed additives and vaccines • Don't solve ethical concerns with industrial animal farming	• Low consumer acceptance • High production costs for alternatives • Regulatory, infrastructure, and supply chain hurdles to scaling manufacturing
Abatement potential	M	M	H
Deployment readiness	H	L	Traditional: H Alternative: L

Sources: Climate and Clean Air Coalition, Global Methane Assessment (2021); Climate and Health Alliance, Methane Report (2023); Clean Air Task Force, Accelerating Solutions in agriculture (2024); WRI, Opportunities for Methane Mitigation in Agriculture (2025); CIAT, Sustainable Livestock Farming Practices for Resilience (2024); FAO, Pathways toward lower emissions (2023).

Credit: Asya Ikizler, Nadine Palmowski, Isabel Hoyos, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Diet shift and sustainable food production can cut ~40% of emissions from agriculture and land use by 2050

Levers to abate agriculture and land-use emissions on a 1.5ºC pathway in 2050, $GtCO_2e$



Protein consumption reduction must be a priority **in high-income countries**; sustainable agriculture practices and increased productivity must be a priority in low- and middle-income countries.

There is significant overlap between sustainable food production and natural carbon sinks, as practices like improved grazing, silvopasture, and deforestation prevention can enhance soil carbon sequestration and support land conservation.

Observations

- By 2050, without interventions (BAU), total emissions are projected to increase from the current **10.7 $GtCO_2e$ to 14.4 $GtCO_2e$,** making it essential to implement multiple strategies to **stay on the 1.5°C climate pathway.**
- However, industrial and process changes alone cannot drive the sector to net zero. The study[1] considers **that 25% of the reduction comes from dietary changes** that reduce demand for animal proteins.
- **Sustainable food production** also has an important role, accounting for a 16%, or 2.3 $GtCO_2e$, emission reduction.
- **Land conservation** and natural carbon sinks are the main drivers of efforts to offset agricultural emissions,[1] representing almost 50% of abatement, highlighting the importance of preventing further deforestation.

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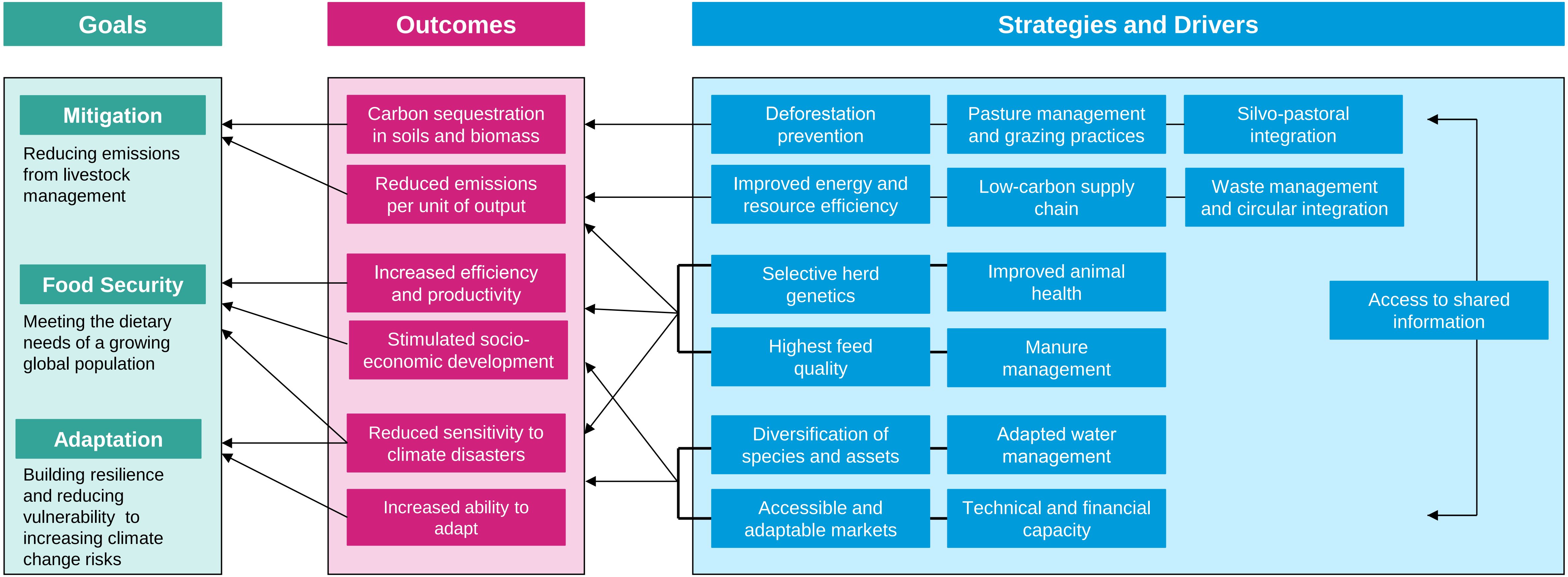
[1] The McKinsey scenario.

[2] Carbon sequestration from spared land being used for nature-based solutions is addressed under “Land conservation and natural carbon sinks.”

Sources: Rhodium Group, ClimateDeck (2023); FAOSTAT, Emissions due to agriculture (2020); McKinsey, The agricultural transition (2023); WRI, Commodities replacing forest areas (2021).

Credit: Asya Ikizler, Raissa Coan Ribeiro , Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Sustainable livestock management mitigates emissions, and supports climate adaptation and food security



Goals

Mitigation

Reducing emissions from livestock management

Food Security

Meeting the dietary needs of a growing global population

Adaptation

Building resilience and reducing vulnerability to increasing climate change risks

Outcomes

Carbon sequestration in soils and biomass

Reduced emissions per unit of output

Increased efficiency and productivity

Stimulated socio-economic development

Reduced sensitivity to climate disasters

Increased ability to adapt

Strategies and Drivers

Deforestation prevention

Pasture management and grazing practices

Silvo-pastoral integration

Improved energy and resource efficiency

Low-carbon supply chain

Waste management and circular integration

Selective herd genetics

Improved animal health

Highest feed quality

Manure management

Diversification of species and assets

Adapted water management

Accessible and adaptable markets

Technical and financial capacity

Access to shared information

Sources: FAO, Climate-smart livestock production, (2019); FAO, Livestock solutions for climate change, (2017)

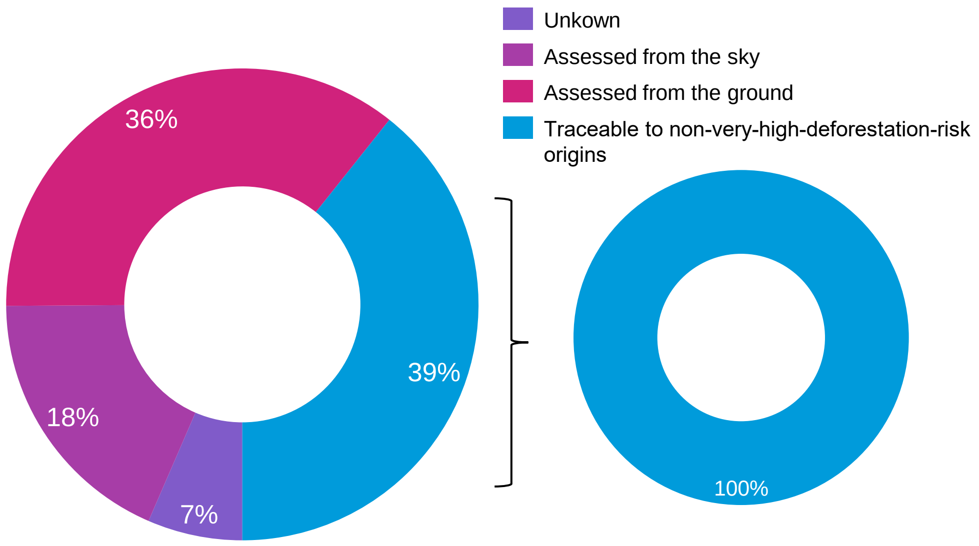
Credit: Ariela Farchi Behar, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Nestlé has made strides in deforestation traceability towards a deforestation-free supply chain across commodities

Founded	1866 by Henri Nestlé
Headquarters	Vevey, Switzerland
Revenue	$91.72 million (2024)

Nestlé primary supply chain
(coffee, cocoa, meat, palm oil, pulp and paper, soy and sugar)

Nestlé meat supply chain



Climate Impact	• **~90% of primary supply chain** assessed as “deforestation free” • Raw materials are confirmed as deforestation-free when either they **can be traced to low-risk origins or have been assessed as deforestation-free** either from the sky or from the ground” • Avoid sourcing raw materials from high-stock carbon forests, converted ecosystems (such as wetlands, savannas, or peatlands), UNESCO world heritage sites, etc.
Risk Assessment Tools	• Supply chain mapping • Desktop-based risk assessment • On-the-ground assessment • Satellite monitoring
Risk Mitigation Tools	• Supplier engagement • Landscaping projects • Smallholder farmer initiatives • Industry collaboration

Levers and Opportunities	• Policy
	  • Regulation on Deforestation-free Products (**EUDR**) in the EU
	  • Task Force on Climate-related Financial Disclosures (**TCFD**) in the UK
	  • Controls aligned with **individual countries’ NDCs**
	• Technology
	  • Maplecroft
	  • Trase
	  • Global Forest Watch (GFW) and GFW Pro
	• Industry collaborations and global programs
	  • Digital Integration of Agricultural Supply Chains Alliance (**DIASCA**)
	  • Consumer Goods Forum (**CGF**) Forest Positive Coalition
	  • Reduced Emissions from Deforestation and Forest Degradation (**REDD**+)

Sources: Nestle, Deforestation-free supply chains, (2024); Yahoo Finance, Nestlé S.A., (2025); WRI, Traceability and transparency in supply chains, (2023)
Credit: Ariela Farchi Behar, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

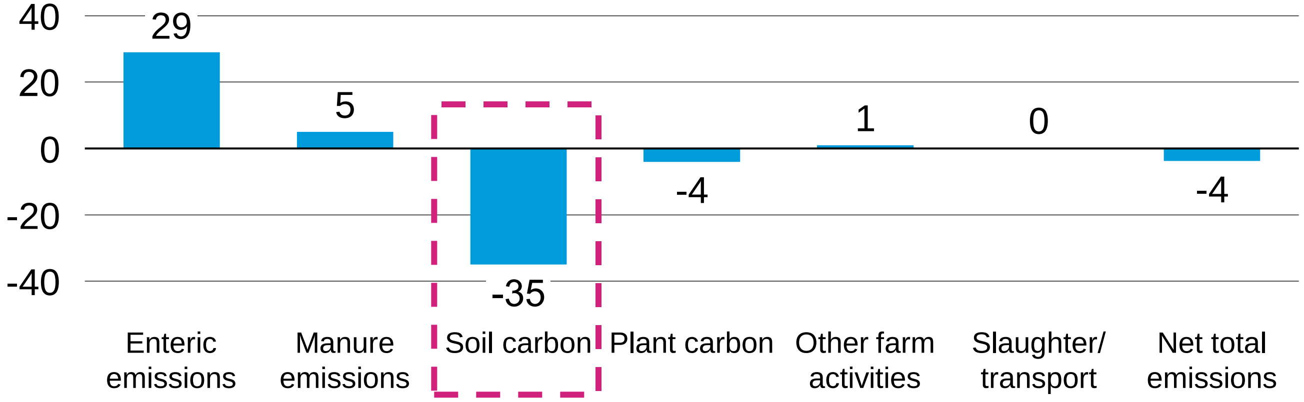
Regenerative grazing shows emissions mitigation potential by sequestering soil carbon, but experts warn against limitations

Key practices of regenerative grazing systems

1. Rotational grazing with rest and regrowth periods
2. Adaptive management adjusted to ecosystem responses
3. Increased plant biodiversity, including native species
4. Minimal synthetic fertilizers and pesticides
5. Integration of trees and perennials
6. Focus on improved soil organic matter, plant cover, root systems, microbial activity, and water-holding capacity

The definition of regenerative practices by system. This list aims to outline the generally accepted principles of regenerative grazing that can be relevant across the board.

Example of emissions breakdown from regenerative beef from White Oak Pastures*, CO_2 e per kg of beef



Observations

- Some evidence has shown that regenerative grazing can reduce GHG emissions per kg of beef by 40% to 80% compared to conventional beef by improving soil health and, consequently, the pasture's ability to sequester soil carbon (~2-3 $MtCO_2e$ per hectare per year).
- While it undeniably improves soil health, experts warn that increases in soil carbon sequestration cannot sufficiently mitigate livestock emissions.
- Limitations of regenerative grazing:
  - The effectiveness can depend on factors like **specific management practices, soil type, and climate.**
  - May **require more land than conventional systems**, conflicting with other land uses like crop production.
  - The **carbon opportunity cost** of using land for grazing instead of **reforestation and conservation** must be accounted for.
  - Soil carbon sequestration is not **guaranteed.** The soil will sequester and hold carbon **until it reaches a state of equilibrium**, not permanently.
  - Requires **active management** and increased investment in **time**, **labor**, **fencing, and monitoring tools.**
  - Regional variability in pasture conditions and soil needs pose a **barrier to scalability.**
- Regenerative agriculture is also called *carbon farming* and *climate-smart agriculture*. Regenerative grazing ranching can include specific systems like adaptive multi-paddock grazing, management-intensive grazing, and rotational grazing.

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* This is an example of emissions data from an individual farm practicing regenerative grazing but does not reflect emissions from all regenerative grazing farms.

Sources: Frontiers, Ecosystem Impacts and Productive Capacity of a Multi-Species Pastured Livestock System (2020); Quantis, Carbon Footprint Evaluation (2019); Forbes, Regenerative Agriculture (2025); Civil Eats, A New Study on Regenerative Grazing Complicates Climate Optimism (2021); Colorado State University, Regenerative Grazing, Carbon, and Climate (2021).

Credit: Isabel Hoyos, Ariela Farchi, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Methane mitigation solutions for industrial livestock are at different stages of development, with uncertain abatement potential

Enteric fermentation methane reduction strategies

Solution	Description and tradeoffs	Enteric CH_4 abatement potential
Livestock efficiency	• Improved feed quality, grazing management optimization, improved animal health • Mature, cost effective, and widely implemented • Limited room for improvement in already highly efficient industrial systems	~ 5-30%
Selective breeding	• Genetic selection for naturally less-methane emitting animals • Intermediate readiness • Slow progress from multi-generational timelines	~ 5-25%
Methane inhibition technologies	• Feed additives: 3-NOP (Bovaer), Red seaweed, and Bromoform-based inhibitors • **3-NOP Bovaer** is commercially available for industrial systems and approved in 60+ countries • High capital costs and regulatory and consumer acceptance hurdles • Vaccines that neutralize methanogens are still in early stage research	~30-90%

Lab trials show up to 90% abatement, but field tests show ~30%

Manure management methane reduction strategies

Solution	Description and tradeoffs	Manure CH_4 abatement potential
Manure collection and storage interventions	• Solid-liquid separation, covered lagoons, improved storage design • Mature and widely used in industrial systems, but costly for farmers and limited to confined, not pastured operations • Lower cost than anaerobic digesters	~ 40-70%
Manure treatment	• Anaerobic digesters (biogas production), chemical additives • Anaerobic digesters are commercially available and deployed in many regions; chemical additives still under development • High upfront infrastructure cost, but energy savings or sales can offset investment	~ 80-90%

Anaerobic digesters can abate the majority of manure-related livestock methane emissions, but total manure emissions are lower than enteric fermentation

Sources: FAO, Pathways toward lower emissions (2023); Chang et al., The Key Role of Production Efficiency Changes in Livestock Methane Emission Mitigation (2021); GeoPard Agriculture, Precision livestock farming (2024); AgFunder News, "CH4 Global raises $29m (2023); Clean Air Task Force, Accelerating Solutions in agriculture (2024); EDF, Livestock Methane Primer for Investors (2024).

Credit: Elizabeth Robertson, M.A. Miller, Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Columbia Business School
Climate Knowledge Initiative

Investment in innovative methane abatement technologies shows some momentum, with Bovaer leading the market

Companies developing livestock methane mitigation technologies

DSM
Bovaer ®

- **Innovation**: Feed ingredient that suppresses the enzyme that forms methane, manufactured by Royal DSM and Elanco Animal Health
- **Opportunities**: With FDA review, Bovaer has proved to be safe for animals, producers, and beef consumers
- **Challenges**: Applicability to grazing dairy cows, supply bottlenecks due to limited production

alga BIOSCIENCES

- **Latest funding**: $4 million seed
- **Innovation**: Algae feed supplement with claims to reduce enteric emissions by up to 97%
- **Opportunities**: High emissions reduction potential
- **Challenges**: Applicability to grazing dairy cows

Rumin8

- **Latest funding**: $12 million Series A
- **Innovation**: Feed supplement with claims to reduce cattle CH_4 emissions by up to 95%
- **Opportunities**: High emissions reduction potential
- **Challenges**: Applicability to grazing dairy cows

ArkeaBio™

- **Latest funding**: $26.5 million Series A
- **Innovation**: Anti-methanogen vaccine that reduces ruminant methane emissions
- **Opportunities**: Deployable at scale
- **Challenges**: Limited commercial viability, cost, R&D

Bovaer is the most widely accepted market-ready solution, with approval for use in 65 countries – including FDA approval in the USA.

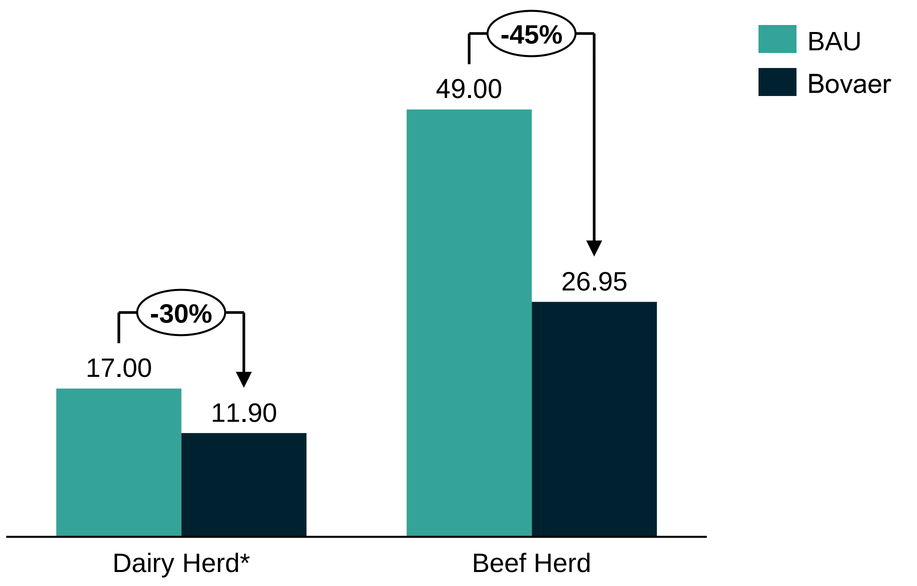
Producers rely on grants, government subsidies, or support to finance the additive.

Sources: Climate Policy Initiative, Landscape of Methane Abatement Finance 2023; Alga Biosciences; ArkeaBio; Rumin8.
Credit: M.A. Miller, Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Bovaer is currently the only enteric methane inhibitor approved by the FDA for use in the United States

Ownership and Manufacturing	DSM-Firmenich Geneva, Switzerland - 2010
Distribution in North America	Elanco Animal Health Greenfield, Indiana
Funding	Primarily privately funded by DSM-Firmenich and royalties.

Estimated Methane Emissions per kg of Food Product (kgCO_2e, 2018)



Impact metrics	• Significant emissions reductions by adding ¼ tsp to a cow's feed per day.
	  • **30% less emissions for dairy cattle.**
	  • **40% less emissions for beef cattle.**
	• 390,000+ MT CO_2e savings up to date.

Limitations	• Primarily used for dairy cattle.
Global Scale	• Developed by a Swiss-Dutch company, this solution has been **authorized for sale in 70+ countries across the world.** • Has received approval by several food safety commissions, including the **FDA (USA), EFSA (Europe), and FSCJ (Japan).** • Bovaer remains the most rigorously tested methane inhibitor, with **100+ trials across 20 countries, and 90 peer-reviewed scientific studies.**
Public perception	• Some dairy consumers, particularly in the UK, **expressed concern in the food safety** of dairy from Bovaer-using farms – despite being previously proven safe. • Some consumers altered their purchasing, prompting dairy farmers to temporarily halt their use of the product. • A consequent assessment by the EFSA further proved that there are **no traces of Bovaer in dairy or any other consumer products, and is safe to drink with no safety issues.**

Market	• Bovaer (3-nitrooxypropanol) has **been trademarked by DSM-Firmenich.**
	  • Other methane inhibitors in the market rely on Tribromomethane or algae-based derivatives.
	• Eleanco, Bovaer's distributor in the US, encourages users to **leverage financial mechanisms to generate additional income.**
	  • Farms using Bovaer may be eligible for carbon credits and government incentives.
	  • Eleanco has allied with third party verifiers for eligibility guidance.

* Data based on kg of beef from dairy herd

Sources: Bovaer, DSM-Firmenich, (2025); Bovaer, Elanco, (2025); Misinformation about cow feed additive, BBC, (2024); Safety and efficacy of Bovaer, EFSA, (2021)

Credit: Ariela Farchi, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

California Bioenergy's South Tulare cluster leads the market in manure to biogas conversion

CALIFORNIA BIOENERGY®

Founded	2006 by N. Ross Buckenham, Neil Black, and John Bidart
Headquarters	Tulare, California
Funding	$506 million

South Tulare cluster

~105,000

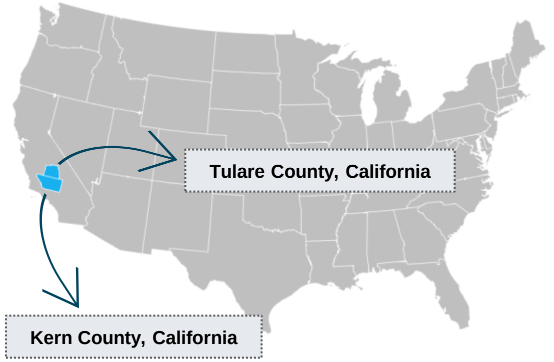
Cattle and dairy cows

19

Farms with anaerobic digesters

1

Central upgrading plant



Biogas production (cubic feet/day)

~5.5 million

Emissions reduction (MTCO2e/year)

~1.0 million

Equivalent to one year of GHG emissions from **~234,000** gasoline-powered cars

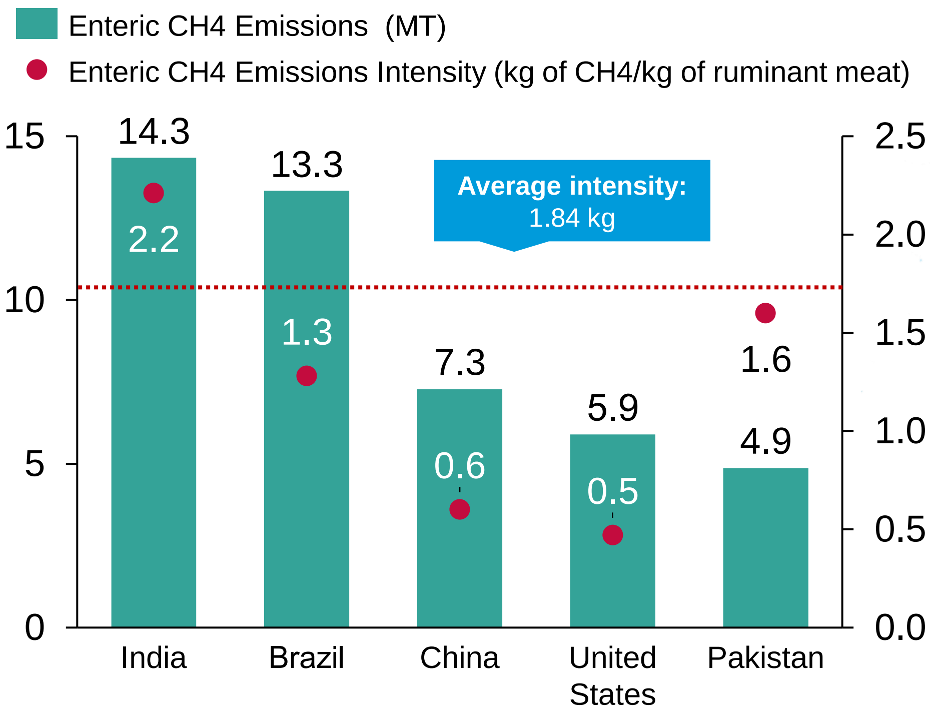
Manure to CNG production process	
Collection	Following its conversion from manure, biogas is collected onsite from each farm's anaerobic digester
Conditioning	Hydrogen sulfide (H2S) and water are removed from the product on-site. Farms also performing other functions like measurement and analysis
Compression	The conditioned product is compressed into gathering and collection trunk lines for transportation from individual farms to a central upgrading plant
Upgrading	Here, the product is further refined, most notably to separate CO2 waste gas from biomethane. The latter is then compressed to become compressed natural gas (CNG)
Injection	CNG that meets pipeline specifications is **injected** into the Southern California Gas Company's natural gas pipeline and is transported to **retail fueling stations** for use in CNG-powered trucks

Note: California Bioenergy logo sourced from company website; Biogas production and emissions reduction statistics based in part on forward-looking construction data from the EPA website as of June 2024 for the Curtimade Dairy Digester, Lerda-Goni Farms Digester, P&M Dairy and VP Farms Digester and the Top O' The Morn Farms Digester.
Sources: California Air Resources Board, California Bioenergy (2024); California Air Resources Board: Staff Summary: California Bioenergy (2024); US EIA, Natural Gas Conversions (2024); US EPA, Livestock Anaerobic Digester Database (2024); Pitchbook, California Bioenergy (2026).
Credit: Ellie Valenica, Isabel Hoyos, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

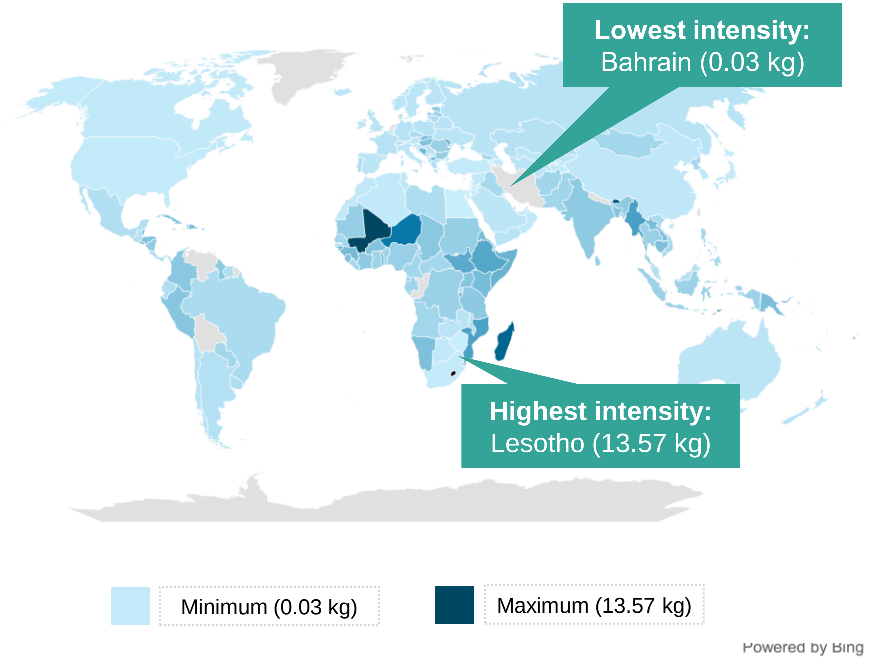
The greatest opportunity for enteric CH4 intensity reduction is the Global South, with values often above the 1.84 kg global average

Despite the volume of enteric CH4 emitted, the top-five emitters have relatively efficient intensities

Emissions intensity of top emitters of enteric CH4 (average, 2019-2023)



Emissions intensity of enteric CH4 (kg of CH4 / kg of ruminant meat) (average, 2019-2023)



Observations

- The average intensity for enteric CH4 emissions is **1.84 kg of CH4 / kg of ruminant meat.**
- The **top emitters** of enteric CH4 are **generally more efficient** than the average global intensity due to modern livestock production systems.
  - **India** is a notable **exception** with an intensity of 2.2 kg.
  - Despite its large cattle population India **does not produce a significant amount of meat from cattle** amid religious considerations, contributing to a higher intensity.
- Higher emissions per unit of output in the Global South can also be attributed to **quality differences in animal feed, breeding and the overall health** of the animal generating output.

Note: For enteric CH4 intensities, CKI has calculated the ruminant livestock output using FAO data on kg of meat from ruminant animals (buffalo, camels, camelids, cattle, goats, sheep). Dairy products have not been included in these calculations to avoid double-counting derivative products (ex. cheese derived from milk).

Sources: CSIS, Methane Reduction in Livestock: Confronting the North-South Gap (2025); FAO, Emissions Totals (2023); FAO, Crops and livestock products (2023); Food Policy, Methane from cattle: facing realities in the global south (2025); University of Missouri, Calculating winter feed costs for beef cows (2022).

Credit: Ellie Valencia, Isabel Hoyos, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Columbia Business School
Climate Knowledge Initiative

Replacing conventional animal feed with lower-emission alternatives is key to industrial livestock decarbonization

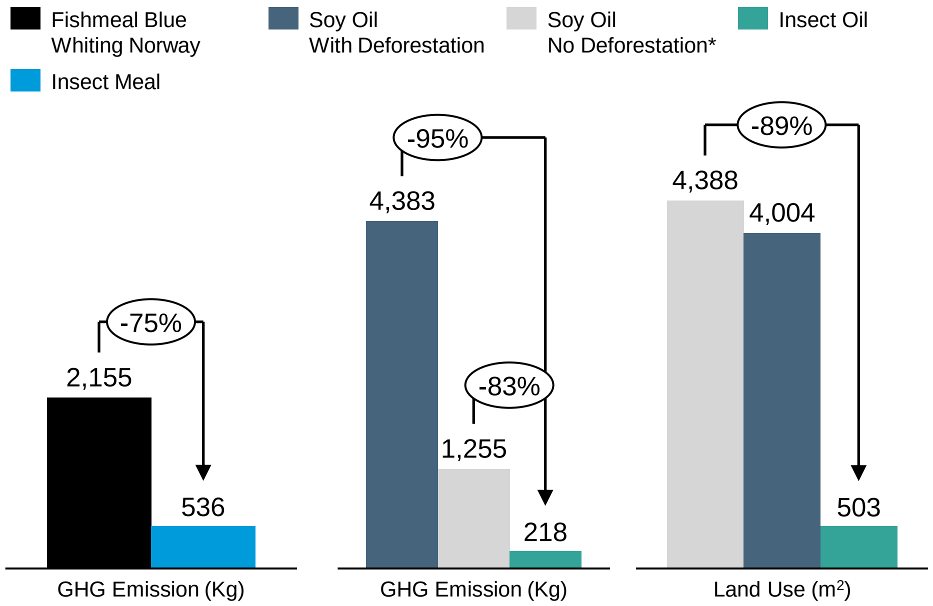
	Conventional feed	Insects	Food leftovers	Alternative crops
Description	• **Soy and corn** are the main global feed ingredients • Soy production **increased >2x** in the past 20 years	**Most promising insects:** • Black soldier fly, yellow mealworm, common house fly	• Former food products (FFP) and bakery by-products (BBP) • Food losses from food supply chain	• Alternative grains (sorghum, millet, oats) • Silage from corn and grass • Seaweed
Land-use and emissions implications	• **Uses more habitable land** (9%) than direct human consumption (6%) • **2.69 $GtCO_2e$ emissions annually**	• **Uses 98% less land** • **61% less emissions-intensive** • Uses less water, pesticides, antibiotics • Potentially more energy-intensive	• **No additional land and water use** • Reduces environmental cost related to grain production • Reduces emissions from food waste	• Alternative grains: More drought resistant • Silage: Energy and nutrients • Seaweed: Added minerals
Benefits and limits	**Benefits** • Already in place **Limits** • Deforestation and land use • Biodiversity loss • Corn not ideal for animal health • High fertilizer use (N2O)	**Benefits** • Meets animals' dietary requirements • High feed conversion efficiency • Consumer acceptance not a barrier **Limits** • Research needed to prove scalability • Communication strategy is important	**Benefits** • Highly digestible and nutritious • Does not limit the growth of the animal **Limits** • Low consumer acceptance • Needs increased participation of food/feed processors • Research needed to have a full lifecycle assessment	**Benefits** • Alternative grains are more drought resistant • Ingredient mixes can add minerals to livestock diets **Limits** • Doesn't represent a scalable set of solutions • Lack of broad adoption
Production leader	China	China	European Union	European Union
Other key players	Brazil and United States	India and Brazil	Japan	India and United States

Sources: Van Huis and Gasco, Insects as feed (2023); Pinotti et al., Recycling food leftovers in feed (2021); Van Huis and Oonincx, Environmental sustainability of insects (2017); Sogari et al., Multi-Perspective Review (2019); ClimateWorks Foundation, Global Innovation Needs Assessment (2021); BBC, Japan is recycling food waste (2024); FMI, Animal Feed Alternative Protein Market Outlook (2024).

Credit: Asya Ikizler, M.A. Miller, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Innovafeed leading the production of animal and aquaculture feed from insects, funded by Cargill, the EU, and the USDA

Founded	2016 by Aude Guo, Bastien Oggeri, and Clément Ray
Headquarters	Paris, France
Funding	$490 million raised; key investors include Cargill, ADM, Temasek, the EU, the U.S. Department of Agriculture, and the Qatar Investment Authority
Revenue	$4.5 million (2023)



Climate impact	• Insect meal reduces GHG emissions by **75%** compared to fishmeal • Insect oil reduces GHG emissions by **83%** compared to traceable soy oil and **95%** to untraceable soy oil • Utilizes **89% less land,** freeing up agricultural space for other uses or carbon sinks
Expansion	• Its Nesle production site in France expanded three times and has the **largest insect production capacity** in the world • Expanded into the United States in 2024 and opened its insect innovation center
Product & innovations	• Cultivates **black soldier flies** and produces a range of products such as **meals and oil to feed chickens, pigs, and aquaculture**, as well as **natural fertilizers** • Launched the world's first **insect protein-fed trout value chain in 2018** and then launched insect oil-fed **chicken and pork** value chains in 2020 and 2021 • Established a **zero-waste framework,** repurposing agricultural by-products from ADM • Reduced its products' emissions by **80%** in three years • Developed an **industrial symbiosis model** that allows it to colocate its production sites with large agricultural processing facilities, reducing plant emissions by 80%
Opportunities	• Aligns with decarbonization goals by replacing high-emission animal-based proteins • Addresses growing demand for biodiversity conservation and deforestation-free products • Partners with global food producers like **Cargill** and **ADM**, as well as all types of stakeholders in the aquaculture value chain, for a farm/water-to-fork approach and business expansion
Benefits	• Achieves significant **reductions in GHG emissions, land use, and marine resource use** for fishmeal and ultimately biodiversity loss
Challenges	• Regulatory hurdles • Consistent feedstock availability at scale • Farmer and consumer acceptance

* Produced from traceable soy supply chains.

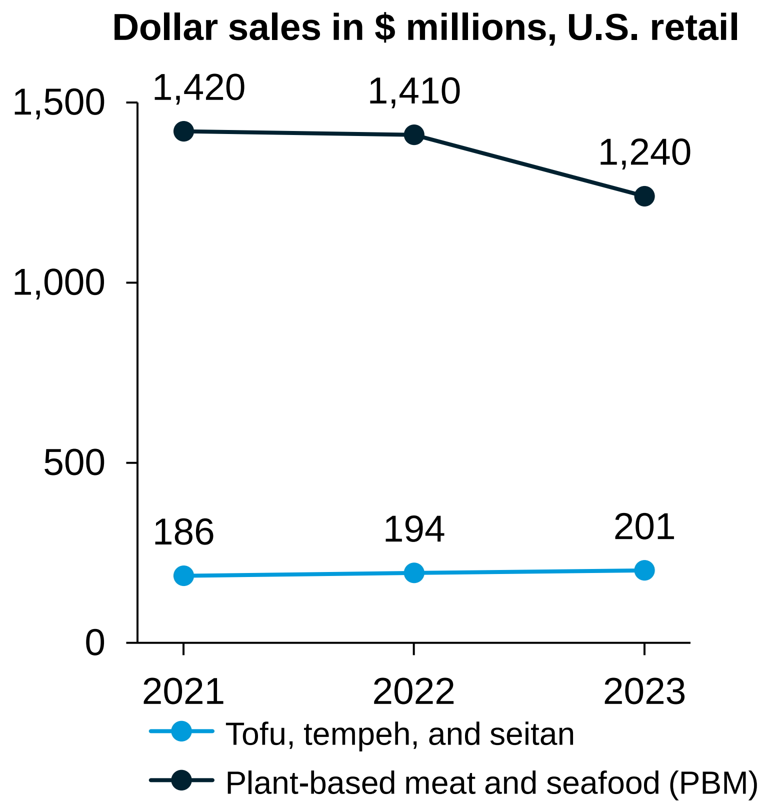
Sources: MDPI, LCA analysis (2020); Innovafeed, Impact report (2024); Crunchbase, Innovafeed (2024); Innovafeed, Our story (2024); Factset (2024).

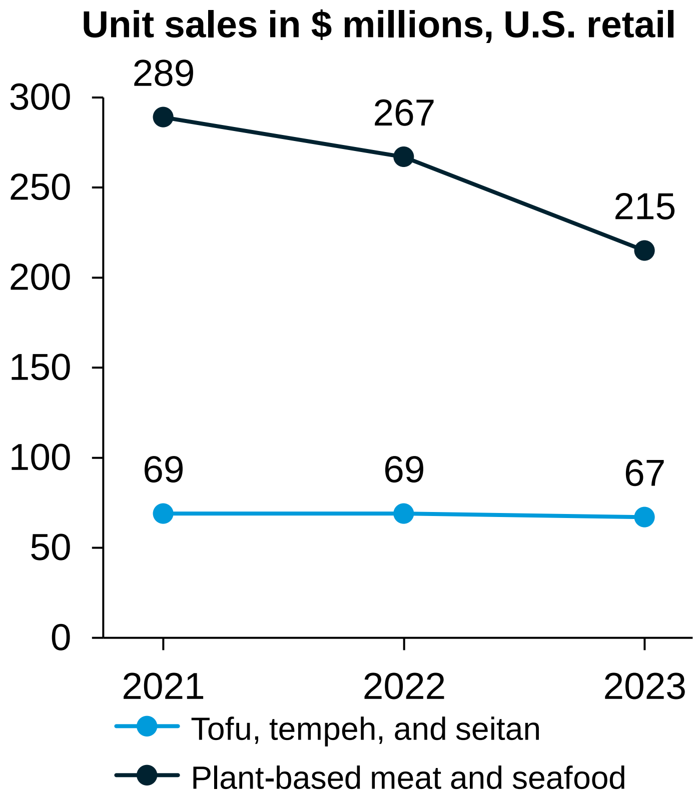
Credit: Asya Ikizler and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Traditional plant-based proteins are 26% of PBM dollar sales in U.S.

Tofu, tempeh, and seitan have a long history and well-established market presence but do not replace meat or PBM

Tofu	Tempeh	Seitan
Made by **coagulating soy milk** and then pressing the resulting curds into solid blocks	Prepared by **fermenting cooked soybeans** with a fungus called Rhizopus, which binds the beans	Wheat gluten is **extracted by washing wheat flour dough** until the starches are removed and only the gluten remains





Observations

- Traditional plant-based proteins have a long presence historically, since they were developed in regions of Southeast Asia:
  - Seitan: 900 BC-600 AD
  - Tofu: 600-1500 AD
- Majority of traditional plant-based protein consumers in the U.S. are of **Asian descent or follow plant-based diets.**
- The decrease in 2023 unit sales is part of a **market-wide return to pre-pandemic consumption levels.**
- Tofu, seitan, and tempeh have a **relatively stable market performance** and did well in 2023 compared to other meat alternatives.
- Traditional alternatives **do not fulfill or mimic the meat-eating experience** as much as modern alternatives. As such, they are **not considered a meat substitute** in countries of origin or Western countries.

Sources: GFI, Retail insights for plant-based industry (2023); He et al., Review of research on plant-based meat alternatives (2020); CSIS, The Future Appetite for Alternative Proteins (2023).

Credit: Ariela Farchi Behar, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Plant-based leads the alternative proteins global market, with cultivated meat trailing in segment growth and commerciality

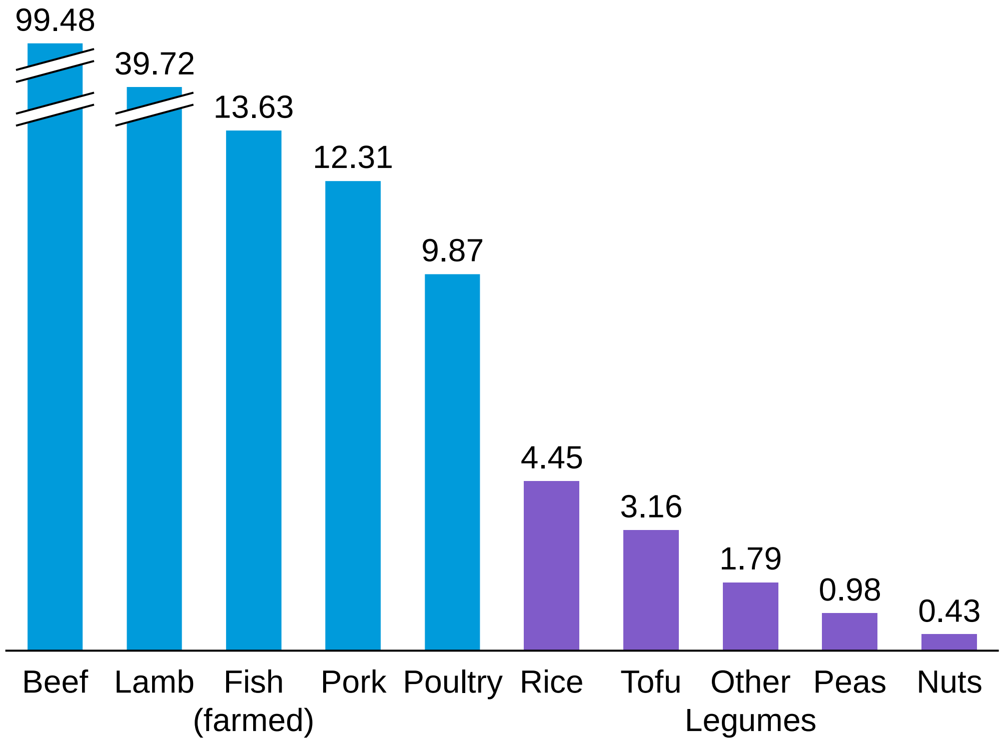
There are three types of alternative proteins, each with different tail- and headwinds

	Description	Tailwinds	Headwinds	Leading players
Plant-based	Made from a combination of protein ingredients: soy, pea, lupin, or wheat, as well as oil and structural ingredients	- Grantmaking for commercialization research to lower costs - Slower projected growth in animal protein production, posing an opportunity to close price gap	- Need to improve product taste and texture - Persistent price premiums – 70% above conventional meat	BEYOND MEAT IMPOSSIBLE Quorn gardein PLANT-BASED PROTEIN
Fermentation	Products made through traditional, biomass, or precision fermentation are used as inputs for food ingredients	- Governments recognizing fermentation-enabled foods as a climate solution - Closest solution for closing the alt. dairy texture and taste gap	- Lack of product understanding - Stressed fundraising landscape - Low manufacturing capacity	Eden Brew DELICIOUSLY ANIMAL-FREE DAIRY phycom Wild MICROBES ENOUGH
Cultivated	Genuine meat produced by cultivating animal cells directly rather than through livestock	- Growing public investment in research - Regulatory approvals in the United States and other key markets	- Regulatory and food safety barriers - Production cost - Ongoing challenges to scaling production	GOOD UPSIDE Foods

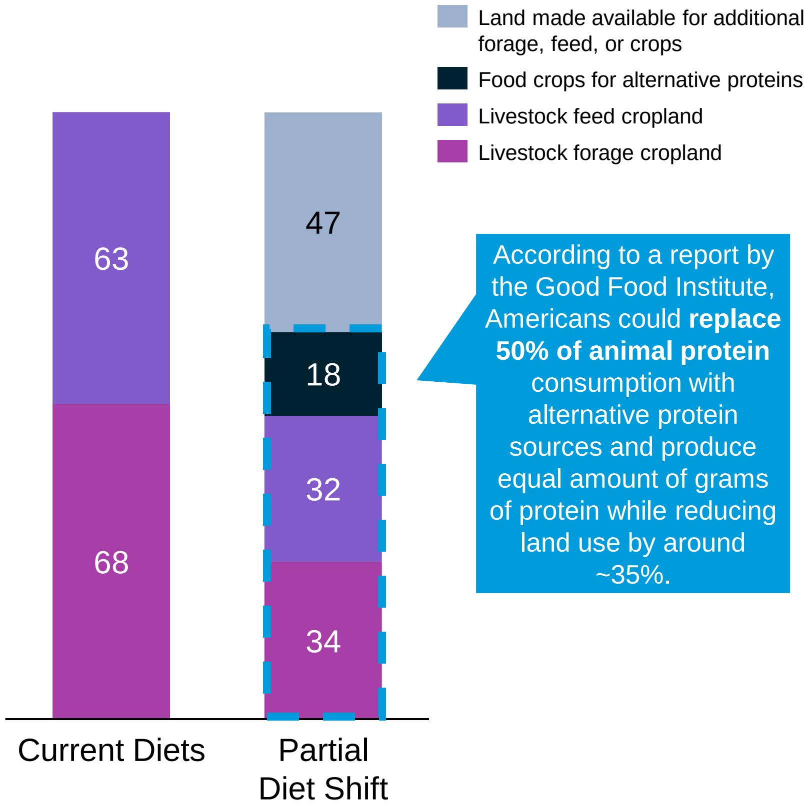
Sources: GFI, State of the industry: Plant-based meat (2023); GFI, 2023 State of the industry: Cultivated meat (2023); GFI, State of the industry: Fermentation (2023).
Credit: M.A. Miller, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Shifting diets from animal to alternative proteins in high-income countries is a highly effective solution to reducing emissions

Average GHG emissions by food product, CO_2e per kg



U.S. land for protein production, million acres



According to a report by the Good Food Institute, Americans could **replace 50% of animal protein** consumption with alternative protein sources and produce equal amount of grams of protein while reducing land use by around ~35%.

Observations

- Even a **partial shift in diets** away from animal proteins can result in significant emissions reductions.
- **Reduction of beef consumption** is the dietary shift with the **highest emissions abatement potential.** Further GHG abatement in high-income countries could come from **methane reduction technologies for industrial livestock.**
- With the right policy support, alternative proteins can represent up **to 22% of global protein market as early as 2035.**

*GHG emissions from beef herd vary based on management system. See slide 11 for a management system breakdown.

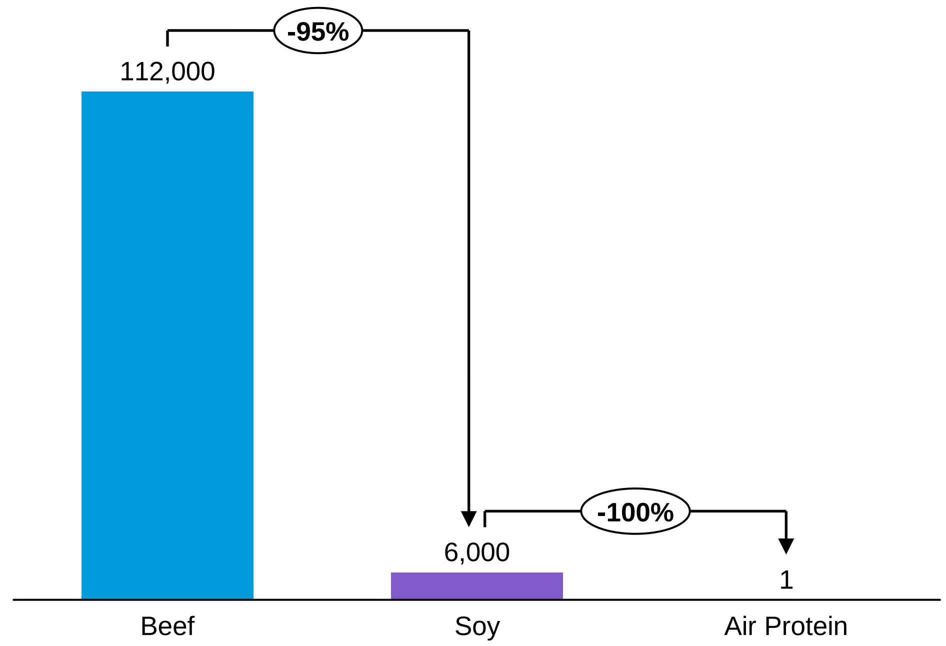
Sources: Kuepper B, Impacts of a Shift to Plant Proteins (2023); BCG, The Untapped Climate Opportunity in Alternative Proteins (2022); Our World in Data, Impacts of Food Production, (2018); GFI, Transforming Land Use: Alternative Proteins (2024)

Credit: Asya Ikizler, Ariela Farchi Behar, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Air Protein creates high-density protein from CO_2 fed cultures, curbing environmental resource use

Founded	2019 by Dr. Lisa Dyson and Dr. John Reed
Headquarters	San Leandro, California
Funding	Series A: $32.1M Additional funding: $75M

Water required to produce 1kg of protein, 1/kg



Innovative process	• The patented technology utilizes water, renewable energy, and – most importantly – air • The elements are combined with a culture which produces protein through a process of Air Fermentation • The protein is harvested, purified, and dried to produce a protein-dense versatile flour

Use-cases	• The flour can be used widely across categories such as:
	  ◦ Meat substitutes - The company produces Air Chicken and Air Seafood (scallops and fish)
	  ◦ Dairy products
	  ◦ Baking
	• Alternative industries: animal & pet food, beauty & personal care, aquafeed, ag bio-stimulants

Opportunities	• Carbon negative, as opposed to carbon and resource intensive traditional proteins
	  ◦ Removes CO_2 from the atmosphere, using air as the main feedstock
	  ◦ Process powered through renewable
	• Affordable dense and bioavailable protein
	  ◦ High-cost competitiveness, projected lower costs than whey, pea, soy, and meat
	  ◦ 80% protein content – with all essential amino acids, and critical vitamins and minerals
	• Performance
	  ◦ Highly versatile across markets while meeting taste and texture requirements

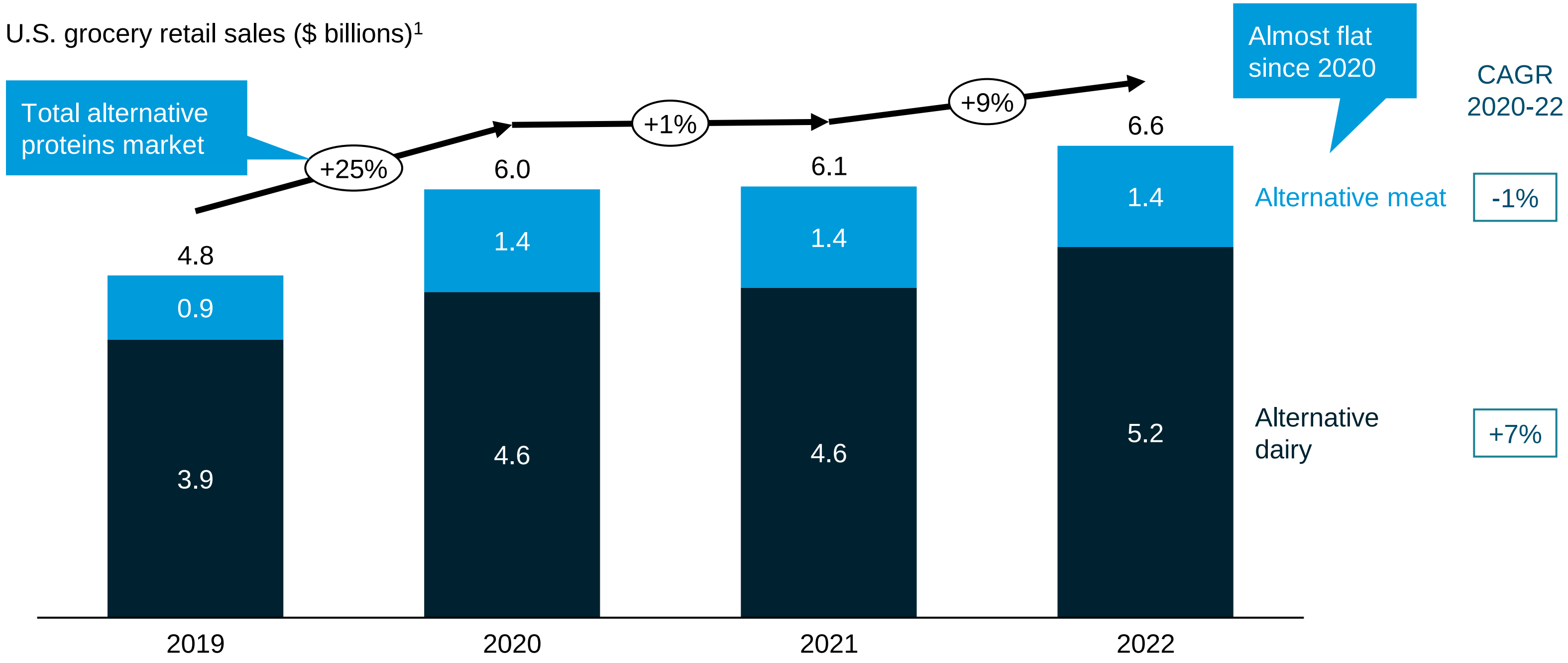
Challenges	• Pending FDA approval

Sources: Air Proteins Proprietary Data, 2025

Credit: Ariela Farchi, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Unlike the alternative dairy industry, the alternative meat industry has been struggling to expand its customer base

Alternative dairy products have gained consumers; alternative meat still struggles



Observations

- **Alternative dairy:** Has appealed to mainstream consumers, with U.S. retail sales growing by 7% annually from 2020 to 2022. Success can be attributed to **product innovation and marketing strategies.**
- **Alternative meat**: Saw an annual decline of 1% from 2020 to 2022.
- Consumers **prioritize taste and health over sustainability** when purchasing food, meaning companies need to address these key concerns.
- Reaching customers remains a challenge. The industry needs to take **different approaches** and invest in **further product innovation and marketing** to bring alternative meat to the customer's table.

---

[1] Includes alternative refrigerated milk, shelf-stable milk, spreads (margarine, cream cheese, sour cream, etc.), yogurt, cheese, frozen/refrigerated meat; does not include alternative eggs and ready-to-eat plant-based meals.

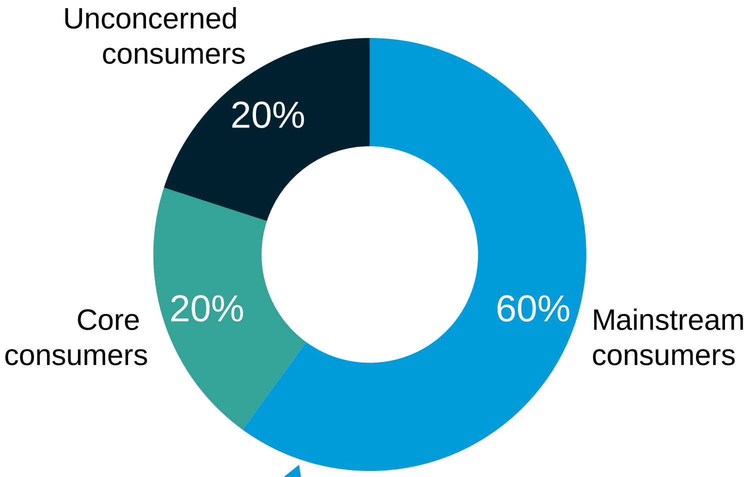
Sources: Profundo, Impacts of a Shift to Plant Proteins (2023); BCG, Taking Alternative Proteins Mainstream (2023).

Credit: Raissa Coan Ribeiro, Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

A consumer-centric approach by brands is critical to achieving market share growth in alternative meat products

Mainstream consumers and easy wins should be the primary targets to accelerate market share growth

Know who they are…



Key segment to focus on to drive growth in the alternative proteins sector:
- Sustainability is not top priority
- Taste and price are main barriers

As in the EV market, alternative proteins will not scale until the new product is on par with the traditional one.

Focus on what consumers want and need:

- **Improve taste and texture:** Innovate to achieve parity of quality and price of animal protein, as these are top priorities for consumers
- **Reach price parity** with animal-based proteins
- Don't underestimate the **health impact** perceptions

It should target the mainstream consumer and what they are looking for.

Marketing strategies to target mainstream consumers:

- **Not labeling *vegetarian* or *vegan*** but rather ***good or complete source of protein*** or ***antibiotic-free***
- **Focus on the taste and sensory experience** like "juicy," "fresh"- food is a sensory choice and experience
- Telling the consumer the protein source, like pea, lentil, or soy, instead of *plant-based* to **increase the feeling of familiarity.**

Pre-made sandwiches
Ready meals

Focus on easy wins and unexplored markets where consumer resistance is lowest:

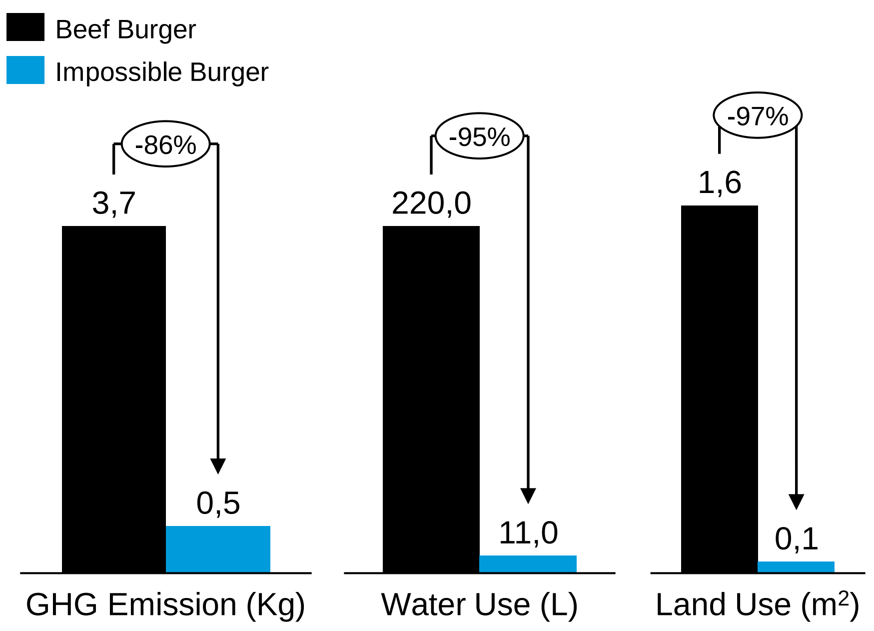
- **Frozen foods** with meat as a side ingredient
- **Ultraprocessed meat**
- **Convenience foods**: It is easier, and **more effective**, to replace it than entrenched traditions.
- **50-50 blends**: e.g., a beef burger with mushrooms
- **Pet food**

Sources: BCG, Taking Alternative Proteins Mainstream (2023); McKinsey, Novel proteins: Consumer appetite for sustainably made ingredients (2024); CKI insights informed by expert and industry engagement (2024).

Credit: Asya Ikizler, Friedrich Sayn-Wittgenstein, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Impossible Foods is a pioneer in developing sustainable plant-based protein innovation to combat climate change

Founded	2011 by Patrick O. Brown
Headquarters	Redwood City, California
Funding	$2.01 billion raised; key investors include Bill Gates and Google Ventures
Revenue	$460 million (2022)



Climate impact	- Reduces GHG emissions by **87%** compared to producing beef - Saves **89% water** (3 gallons vs. 58 gallons per burger) - Utilizes **96% less land,** freeing up agricultural space for other uses or carbon sinks
Transparency	- Conducted ISO-compliant LCAs, validating environmental claims - Developed an **environmental savings tool** for consumers and companies to quantify their impact of switching to plant-based products
Innovations	- Pioneered the use of **soy leghemoglobin (heme)** to replicate meat taste and texture - Established **localized manufacturing hubs,** reducing transportation emissions - Transitioned to **renewable energy sources** for production facilities
Opportunities	- Aligns with decarbonization goals by replacing high-emission animal-based proteins - Addresses growing institutional demand for sustainable food solutions (e.g., schools, hospitals, companies) - Partners with global food chains like **McDonald's** and **KFC,** increasing accessibility to plant-based options - Collaborating on **distribution efficiency technologies** could cut emissions in logistics, while **enhanced plant protein extraction processes** could improve yield and texture
Benefits	- Achieves significant **reductions in GHG emissions, water, and land use** - Transparent environmental performance supports consumer trust and corporate ESG goals - Demonstrates scalability as a viable alternative protein source in the global food system
Challenges	- **High R&D and production costs** impact profitability - Faces **intense competition** in the alternative protein market - Needs to address consumer skepticism about the **"processed" nature** of plant-based products

* Case study based on Impossible Food's impact report and public claims.

Sources: Quantis, Impossible Foods (2019); Impossible Foods, Impact Report (2023).

Credit: Vedant Bhansali, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Finding parallels: The energy and protein transitions both face resistance, high costs, and large-scale infrastructure needs

🟦 Relevant for private investments

	Leverage procurement (public and private)	Product appeal	Value chain buildup	Government support	Increase competitiveness with incumbent products
Transition parallels	**Both energy and protein transitions require continuous large-scale adoption of technology**	**Neither EVs nor alternative proteins will scale until products are appealing**	**Both the energy and protein transitions require a new, large-scale value chain**	**Both EVs and alternative proteins won't scale until products reach price parity and supply is stimulated**	**Both need price parity and wide availability to increase their comparative market share**
Description	• Public-private partnerships: **Partnering with government** (supply for schools, hospitals, prisons) poses as a scalable alternative vs. B2C market • Leveraging **large private procurements** with food retailers	• **Overcome negative perceptions** related to texture, smell, and overall sensory experience • **Nutrition:** Consumers desire familiar, yet potentially healthier, options	• Investing in **all stages** of alternative protein's lifecycle, from **raw material sourcing to R&D, manufacturing, distribution, marketing, and even culinary adoption support** • **Industrial-scale** manufacturing processes like fermentation tanks	• Support with **infrastructure** and **raw material needs** has helped EVs to scale, similar to alternative proteins • **Tax and credit breaks** to lower costs for both suppliers and consumers • **R&D support** for startups and companies	• **Expand presence** in restaurant chains (good way for customers to try new things) and grocery stores to normalize consumption • Address **price competitiveness** to reach conventional meat price parity through scale-up in production
Advantages	• **Provides a stable, large-scale demand** without requiring immediate mass-market consumer adoption • **Increases visibility** of alternative proteins across various food service settings	• **Increases acceptability** among consumers, hence adoption • **Reduces the feeling of making a "sacrifice"** and focuses on food's taste	• To address and **prevent bottlenecks** • Creates a more **reliable supply chain**, encouraging **investment from larger corporations**	• Supports startup R&D, as well as **public, open research and sharing of best practices** • **Reduces cost and encourages private investment** • **Public charging stations** for EVs have been instrumental; supporting **wide availability of alternative proteins** in grocery stores can have a similar effect	• Increased visibility in restaurants and stores **positions alternative proteins as a mainstream rather than niche option** • **Reaching price parity** with conventional meat attracts price-sensitive consumers
Key examples	• School meals, public institutions' canteens • **USPS** started procuring EVs and establishing charging stations nationwide, with plans to have **66,000 EVs by 2028**	• **Tesla** for EVs • **Oatly**, which has successfully marketed its oat milk as both healthy and enjoyable	• Tesla's investment in battery production and gigafactories • EVs were able to scale after heavy investments in **critical minerals and charging stations**	• **The U.S. IRA and EU Green Deal** have increased EV adoption by stimulating supply and driving demand • **China** became a leader in EVs thanks to the **$29 billion** the government spent on credits and tax breaks from 2009 to 2022	• Supermarkets like Tesco in the UK are **expanding plant-based sections in stores** • **Starbucks**' has adopted alternative milk options globally

Sources: BCG, What the alternative protein industry can learn from EV companies (2024); MIT Technology Review, How did China come to dominate the world of electric cars? (2023); Good Food Institute, Advancing solutions for alternative proteins (2024); USPS, USPS Intends to Deploy 66,000 Electric Vehicles by 2028 (2022).

Credit: Asya Ikizler, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Lessons from the electric vehicle market penetration for the alternative protein industry and widespread product adoption

EV adoption milestones

Pre-takeoff → **Takeoff** → **Post-takeoff (scaling)**

Pre-takeoff

- **EV: Different models** like Nissan, Hybrid, Tesla 2012, **government subsidies** for EVs
- **AP:** Beyond Meat, Impossible Foods launched their burgers in 2016 and gained large attraction in 2019

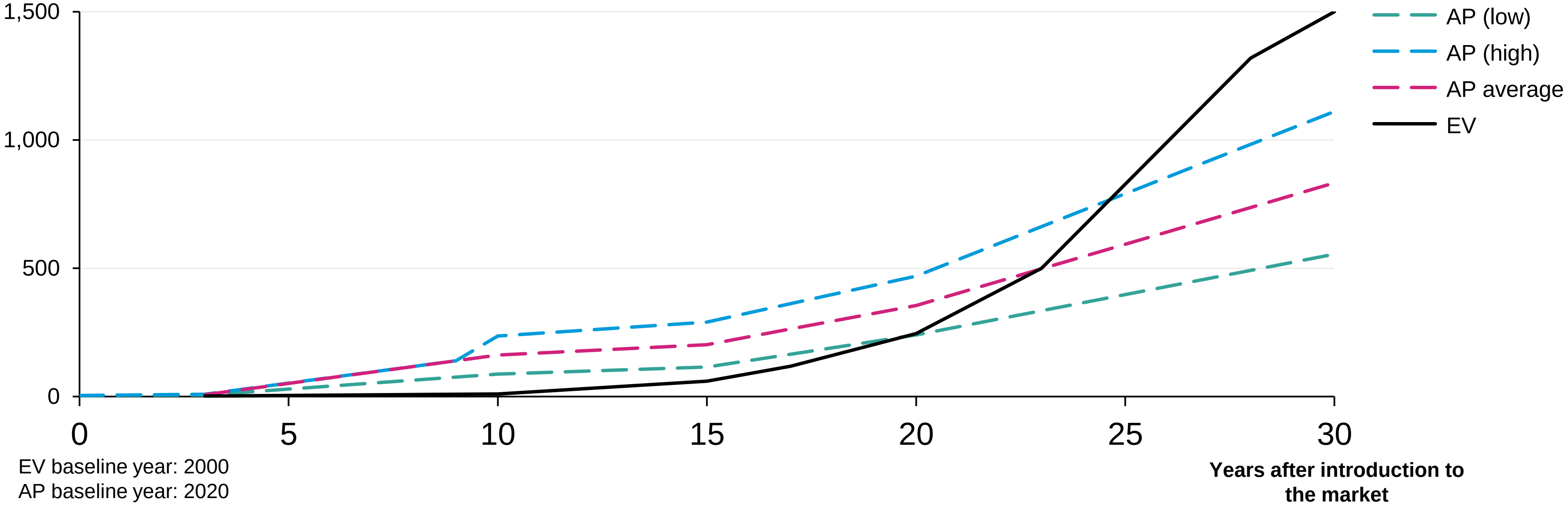
Takeoff

- **EV: Tesla Gen 3** affordable breakthrough (2017)
- **Tax credits** to stimulate supply and **drive down cost**

Post-takeoff (scaling)

- **EV:** IRA and consumer tax credits to **stimulate demand**
- **Investment in supply chain** to avoid bottlenecks in scaling

Global market size of EVs vs. alternative proteins, $ billions



Observations

- It took **government support and private investment** for EVs to compete with conventional cars.
- Significant product development and closer price parity are essential for mass market adoption.
- When comparing the global market size relative to the years after introduction to the market, EVs and alternative protein forecasts follow a similar trajectory.
- To enable the takeoff and scaling of alternative proteins, it will be essential to **stimulate demand, achieve price parity, and invest in the supply chain** to prevent bottlenecks.

Sources: UNEP, What's Cooking? (2023); Yahoo Finance, EV market size (2023); Fortune Business Insights, EV market size (2022).
Credit: Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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Blended meat products like Spare Burgers reduce GHG emissions while preserving flavor and minimizing disruption to consumer habits

Founded	2018 by Adam and Jeremy Kaye
Headquarters	Dobbs Ferry, New York
Market Size	Beef burgers are a ~ $100B market; ~ 20% are consumed through food service

Company's focus

- **Healthier alternatives** through plant-forward blends
- **Emission reduction** without major behavioral change
- **Products crafted by professional chefs**, prioritizing flavor
- **Upcycled surplus** farm produce to reduce food waste

THE SPARE FOOD CO.

The Spare Food Co. value creation: Spare Starter

Farm-level Innovation

Expanded specifications for edible surplus

Processing Innovation

Minimizing vegetable trimming/cutting

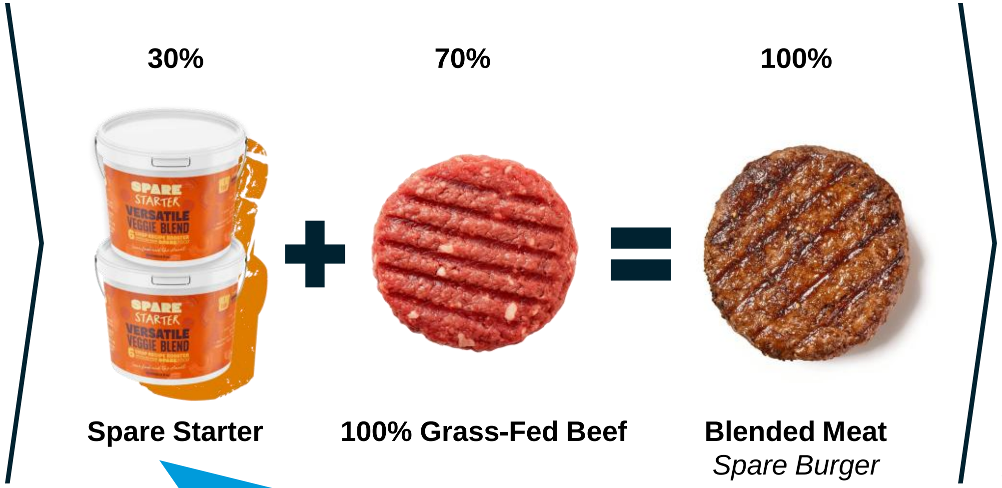
Manufacturing

Optimize flavor and minimize residues

Extending Shelf Life

Prolonging surplus shelf life by 18-24 months

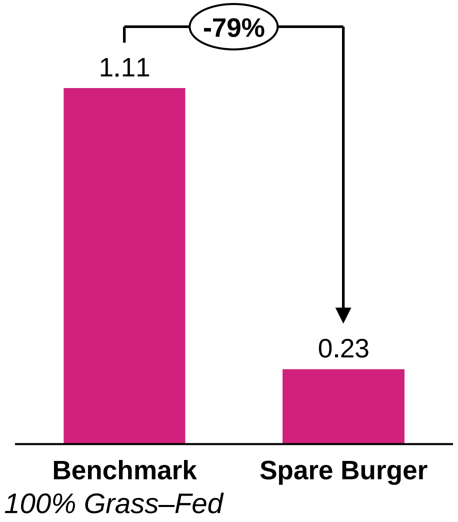
Product innovation: 30/70 blended meat



A cooked mix of 6 surplus farm vegetables that would otherwise go unsold.

Ex. Serving 500 burgers daily with 30% Spare Starter saves over 1,200 lbs of beef each month

Emission reductions *kg CO_2e/lb*



Sources: The Washington Post, Plant-Based Meat (2025); The Spare Food Co., Official Website (2025); Planet FWD, About Spare Food (2024); Good Food Institute, Blended Meat (2024); Good Food Institute, U.S. Market Insights (2024); FactSet, Spare Food Co. (2024)
Credit: Andrea Castro, Ariela Farchi, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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AT THE VERY CENTER OF BUSINESS

Protein Transition Finance & Policy

Key messages
Finance & Policy

Accelerating the global protein transition for net zero by 2050

- Reaching **net zero by 2050** requires a rapid decarbonization of global food systems, with approximately 60% of emissions coming from animal-based proteins. Carbon sequestration in soil and forests will **not** be sufficient to offset current animal-based protein production emissions. There needs to be a global protein transition.
- Policymakers can and should step in to assist with **the protein transition**, providing incentives for adoption of technologies, shifting of diets, scaling of alternative proteins, and a holistic framework accounting for **livelihoods, climate change, food security, and health.**

Aligning livestock policies with climate goals through innovation and investment

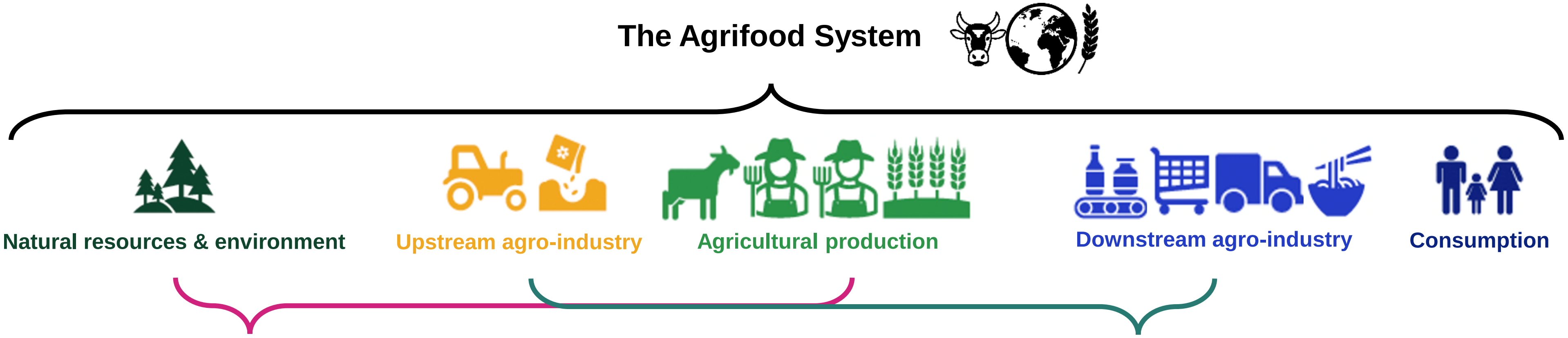
- **Public policy actors can disincentivize land use for animal husbandry** through several mechanisms, including the introduction of **PES mechanisms** that compensate livestock farmers for **transitioning to ecosystem restoration** as a function of reduced emissions from livestock and carbon sequestration.
- **Climate risks** are often not considered while developing livestock policies, for the sector’s mitigation nor adaptation needs. They need to be **better aligned with national climate plans** and require **cross-sectoral and stakeholder collaboration** for effective emission reduction and adaptation.
- Global public spending is not only necessary for R&D but also for **commercialization** efforts, especially for early-stage innovations that aren’t commercialized through private investments yet. Governments need to support policy and finance for alternative proteins to achieve their economic and climate benefits.

Necessary action supporting the uptake of technological and demand solutions

- **Technologies** to reduce emissions from protein production are on their way and should be widely adopted. However, **they are not enough** to decarbonize the food and protein systems.
- A **global reduction of animal-based protein demand** is imperative to reach food security and a net-zero pathway. Through national and global financial and policy frameworks, demand for alternatives can be supported.

Credit: M.A. Miller, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Conventional animal proteins and alternative proteins overlap within the broader agrifood system



Conventional animal protein

Finance	• Limiting land-use change is a problem/solution set affected mostly by policy change • Current finance flows to methane-abatement solutions meets 45% of projected need
Policy	• 158 countries have signed the Global Methane Pledge, with varied policy implementation • Case study: Brazil

Alternative protein

Finance	• Alternative protein finance grew significantly from 2014 to 2021 but has since slowed with negative incremental investment annually • Corporate investment in alternative protein is concentrated in R&D and manufacturing
Policy	• Inconsistent policies, subsidies, and lobbying remain important barriers for the protein transition • Case study: Denmark, Singapore

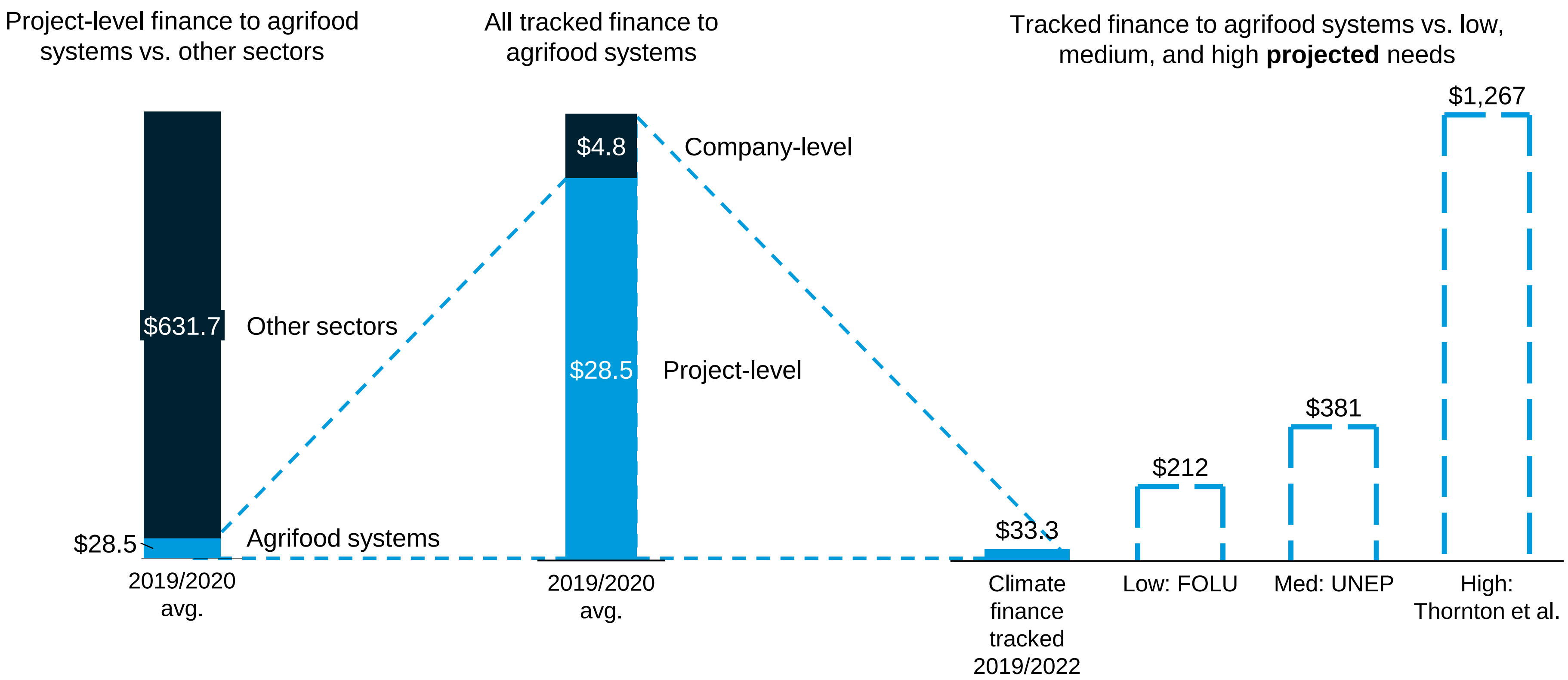
*Animal protein

Source: Climate Policy Initiative, Landscape of Climate Finance for Agrifood Systems (2023).

Credit: M.A. Miller, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Food systems are significantly underinvested as a sector, with only 3% of total global climate finance flows despite 34% of emissions

2019/2020 average funding vs. total investment gap under different scenarios, $ billions


Project-level finance to agrifood systems vs. other sectors

All tracked finance to agrifood systems

Tracked finance to agrifood systems vs. low, medium, and high **projected** needs

**Project-level finance represents standalone investments most likely to be debt; company-level investments represent VC investments in companies, more likely to be equity. The difference between them is not significant, but they are not aggregated given the challenges and fragmentation collecting financial flows data for this sector.*

Observations

- To achieve conservative needs for climate transition, **climate finance for agrifood systems needs to increase by 7x.**
- In the 2019-2020 period, **only 20% of dollars invested in agrifood tech** were directed towards companies focused on climate change solutions.
- Partly repurposing public subsidies to agriculture and fisheries — most of which support harmful practices — could open up to $670 billion to boost climate interventions.
- Upstream and downstream agro-industries received a low proportion of project-level finance flowing to agriculture, leaving potential capacity weaknesses at either end of the supply chain.

Source: Climate Policy Initiative, Landscape of Climate Finance for Agrifood Systems (2023).
Credit: M.A. Miller, Elizabeth Robertson, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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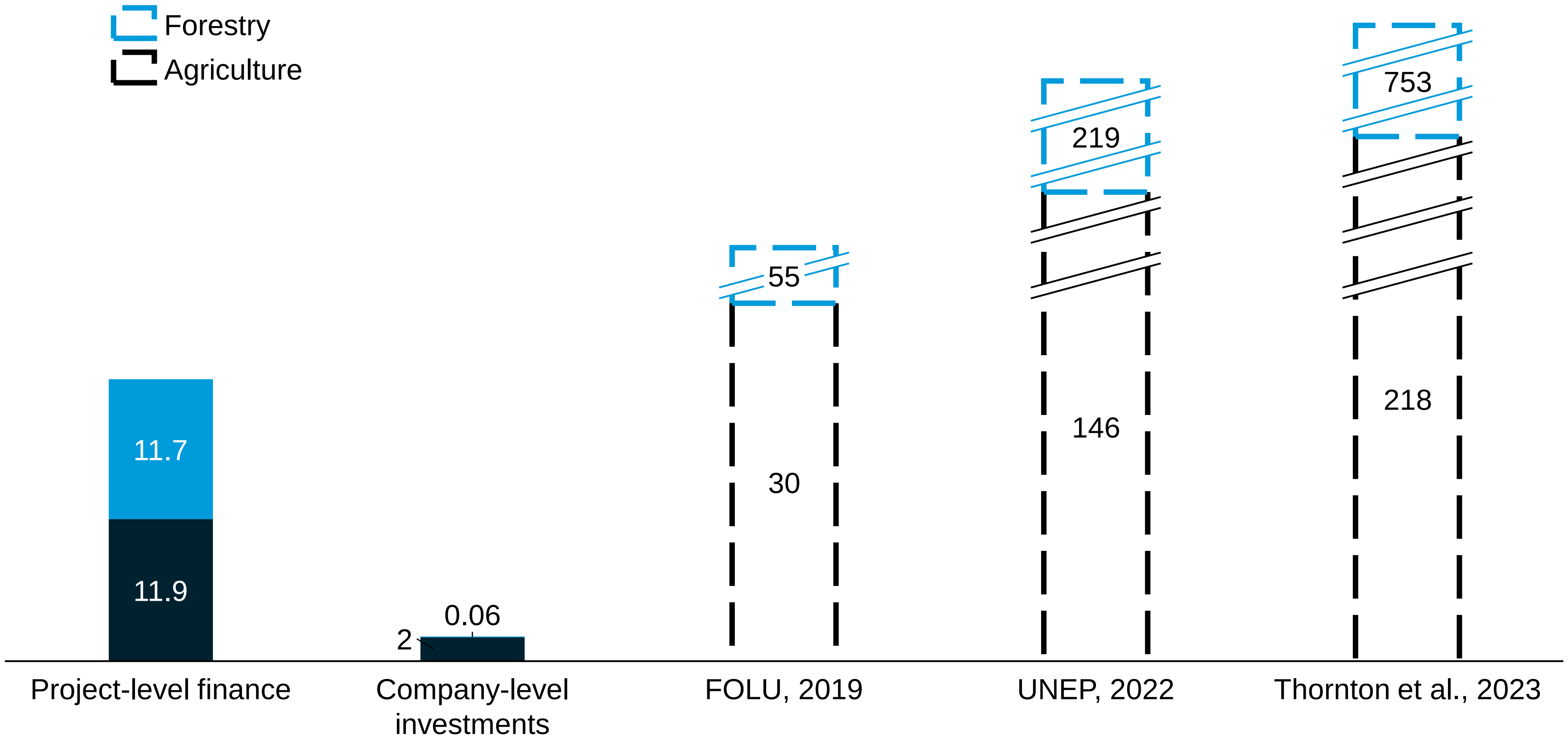
Forestry and agriculture receives ~80% of financing flows to agrifood systems but does not measure up to needs

Current funding fulfills only 30% of need in best-case scenario (FOLU, published 2019)

Funding concentrated at project level vs. high, medium, and low scenarios, $ billions



Observations

- 42% of project-level finance to agrifood systems was to agriculture and 41% to forestry.
- **70% of project-level agriculture investments target production,** e.g., climate-smart measures at farm level, lower carbon fertilizers, and cover crops.
- **94% of VC in agriculture (company level) targeted *upstream* agro-industries:** farming systems and biotech for crop inputs.
- Project-level finance for forestry funding dominated (75%) by investment in forest management, including afforestation and forest conservation.
- In 2022, **more than half of forestry-related tracked finance went to domestic investments in China**, a significant funder of PES programs for farmers.

Source: Climate Policy Institute, Landscape of Climate Finance for Agrifood Systems (2023).
Credit: M.A. Miller, Elizabeth Robertson, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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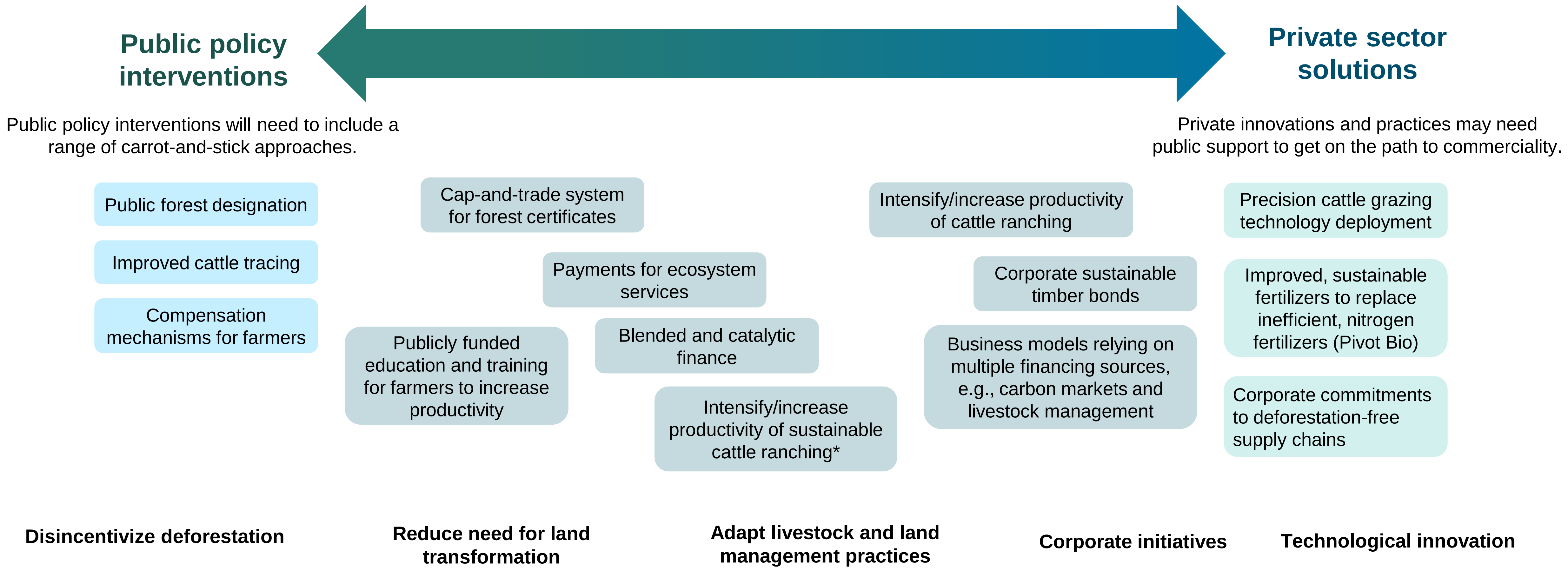
Reducing agriculture emissions and combatting deforestation requires a multipronged, public-private approach

Targeted strategies to reduce emissions and protect forests through collaborative efforts



Public policy interventions

Private sector solutions

Public policy interventions will need to include a range of carrot-and-stick approaches.

Private innovations and practices may need public support to get on the path to commerciality.

Disincentivize deforestation

- Public forest designation
- Improved cattle tracing
- Compensation mechanisms for farmers

Reduce need for land transformation

- Cap-and-trade system for forest certificates
- Payments for ecosystem services
- Publicly funded education and training for farmers to increase productivity
- Blended and catalytic finance

Adapt livestock and land management practices

- Intensify/increase productivity of sustainable cattle ranching*
- Intensify/increase productivity of cattle ranching

Corporate initiatives

- Corporate sustainable timber bonds
- Business models relying on multiple financing sources, e.g., carbon markets and livestock management

Technological innovation

- Precision cattle grazing technology deployment
- Improved, sustainable fertilizers to replace inefficient, nitrogen fertilizers (Pivot Bio)
- Corporate commitments to deforestation-free supply chains

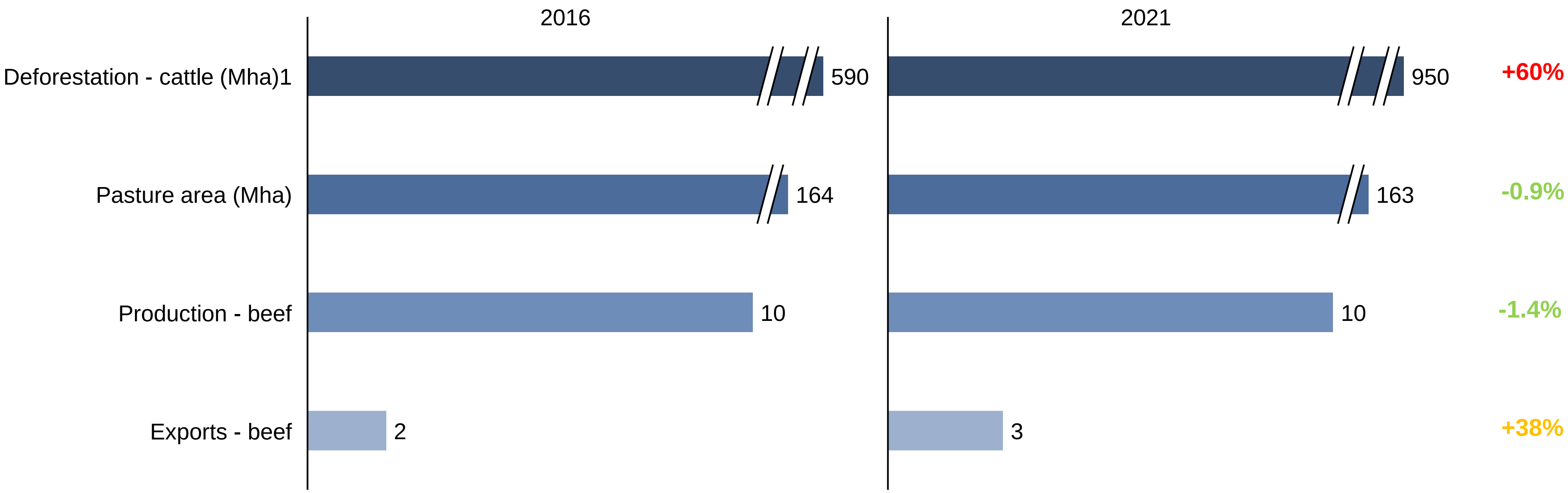
* Livestock production can de a driver of deforestation based on management type and practices being employed. Increased sustainable productivity should aim to curb deforestation.

Sources: FAO, The State of the World's Forests (2022); Land Use Policy (vol. 91), Solving Brazil's land use puzzle (2020); Breakthrough Energy, The State of the Transition (2024).

Credit: M.A. Miller, Elizabeth Robertson, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Land speculation and illegal activities worsen the deforestation problem in Brazil — beyond beef production

Brazilian cattle industry and land use 2016-2021



Observations

- Land speculation is the **conversion of natural ecosystems, based on expected revenues** from future agricultural land use.
- A 60% increase in **deforestation, mainly driven by land speculation** and unfulfilled agricultural potential, misleadingly indicates a drop in cattle productivity. The amount of actual pastureland is decreasing.
- Continued **illegal deforestation is driven by:**
  - Ambiguous land ownership
  - Lack of documentation and monitoring of agricultural areas
  - Fires spreading from forest clearing and land clearing/management
- **Exports** to China (32%) and Hong Kong (14%) **drive continued production.**

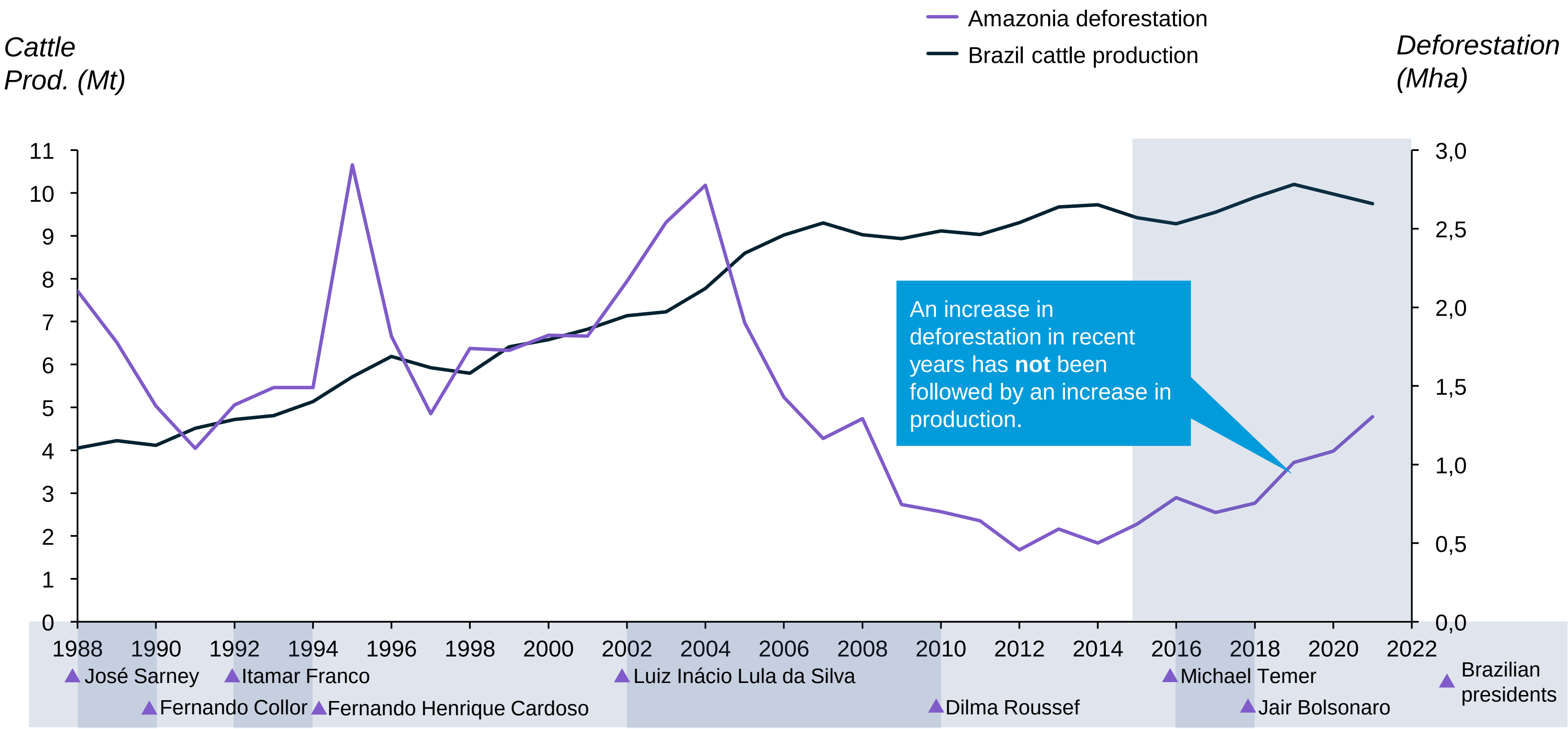
---

[1] According to the Trase methodology, cattle deforestation and conversion, which is calculated based on the area of pasture on areas of land deforested in the five preceding years; e.g., cattle deforestation and conversion in 2020 refers to the area of pasture in 2020 that was converted between 2016 and 2020 and linked to beef production.

Sources: Trase, Brazilian beef supply chain (2023); WRI, Commodities replacing forest areas (2021). Credit: Raissa Coan Ribeiro, Ariela Farchi , M.A. Miller, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Pasture area and cattle production see little change as deforestation and land-use change continue to increase

Brazilian cattle industry and land-use change 1988-2020



An increase in deforestation in recent years has **not** been followed by an increase in production.

Observations

- Since 1988, different parties in power have had **conflicting approaches to deforestation policies**, marked by Bolsonaro's budget cuts from illegal deforestation protection groups and indigenous land tenure.
- Bolsonaro's **recent policies have allowed space for increased land-use change** from land speculation.
- **Brazil exports ~75% of its beef production**, which makes supply chains **vulnerable to international deforestation policies,** affecting the economic prospects of unregulated land speculation and deforestation.

[1] According to the Trase methodology, cattle deforestation and conversion, which is calculated based on the area of pasture on areas of land deforested in the five preceding years; e.g., cattle deforestation and conversion in 2020 refers to the area of pasture in 2020 that was converted between 2016 and 2020 and linked to beef production.

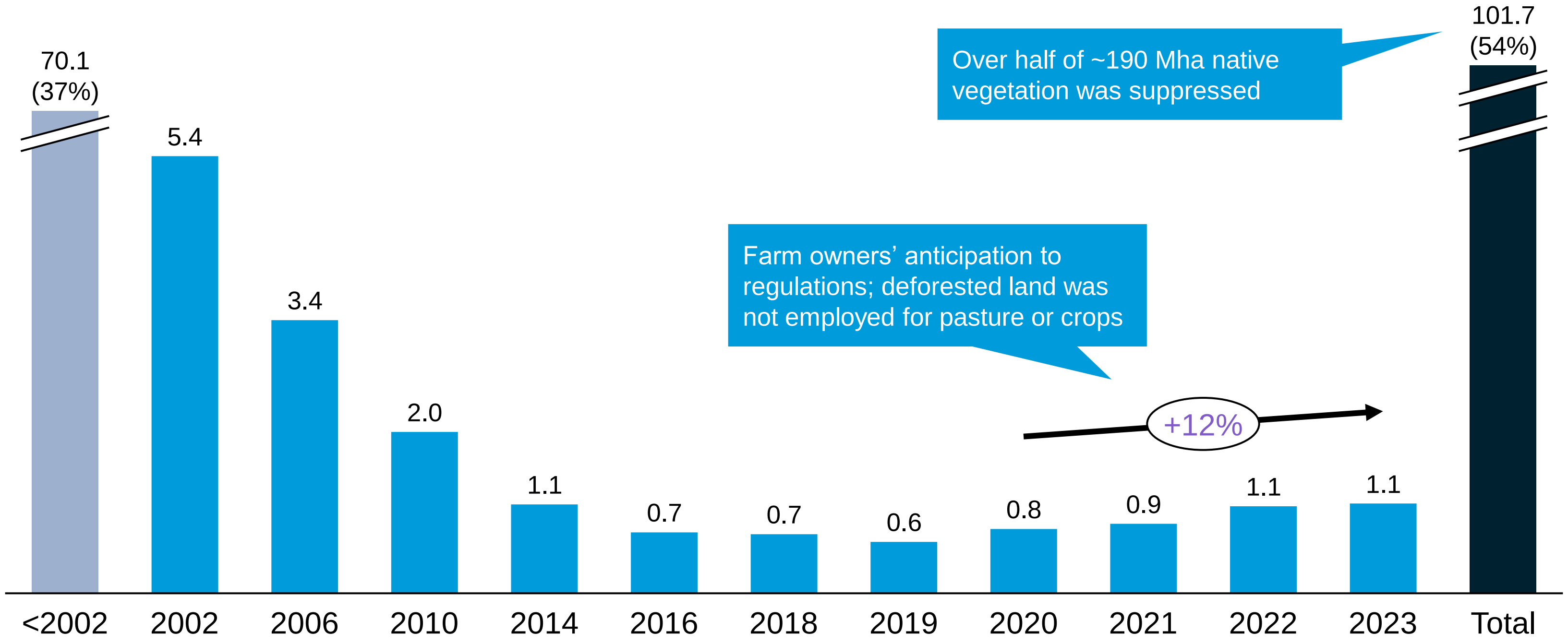
Sources: Trase, Brazilian beef supply chain (2023); WRI, Commodities replacing forest areas (2021).

Credit: Raissa Coan Ribeiro, Ariela Farchi, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Unlike in the Amazon, Cerrado’s deforestation is legal and occurs on private property

The second-largest biome in Latin America (~25% of Brazil) faces rapid legal deforestation

Annual increase of deforestation in the Cerrado, Brazil, 2002-2023, Mha



Over half of ~190 Mha native vegetation was suppressed

Farm owners’ anticipation to regulations; deforested land was not employed for pasture or crops

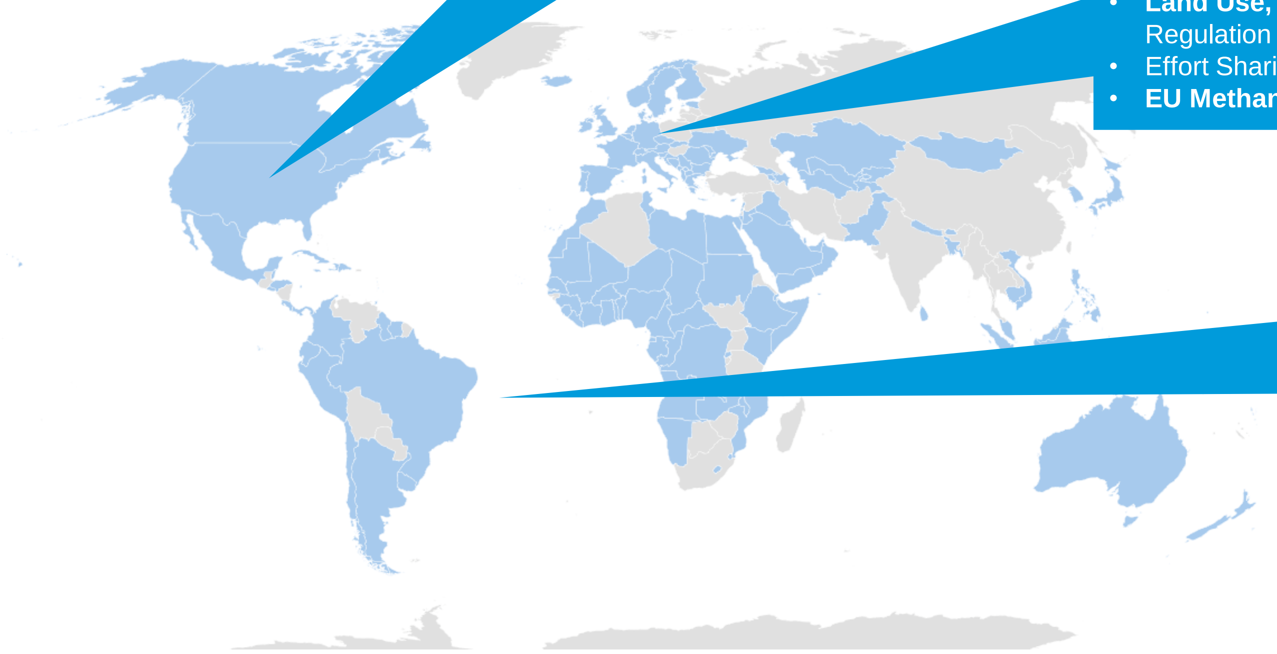
Observations

- Over the past four decades, Cerrado has **lost half of its native vegetation**, driven by **government programs promoting agricultural expansion** under the narrative, “Breadbasket of the world.”
- Unlike in the Amazon, **deforestation in the Cerrado is legal** and occurs on private property (up to 65%; 35% native vegetation must be kept).
- Since 2023, when President Lula started his new mandate, Cerrado farm owners have begun to **deforest legal areas, fearing new and more restrictive policies** that could potentially hinder their business.
- The Cerrado has largely remained **invisible to society**, receiving little media attention and **lacking continuous satellite monitoring**, which has led to outdated data on deforestation.

Sources: INPE, Land observation (2024); Brazil’s National Forests Monitoring Satellite Program, PRODES (2024); INPE. PRODES Technical Note (2022).
Credit: Raissa Coan Ribeiro, Ariela Farchi, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

A wave of new policies and agreements worldwide are addressing methane emissions and food security

158 countries are participating in the Global Methane Pledge



🟦 Signed the Global Methane Pledge

In 2023, the United States established a methane regulatory policy to **reduce emissions by 80% between 2024 and 2038**, focusing on high-emitting industries.

The EU’s Methane Action Plan aims to **reduce total methane emissions by 30% by 2030**, with agriculture accounting for 54% of those emissions.

Key policies:

- European Climate Law
- **Land Use, Land-Use Change, and Forestry (LULUCF**) Regulation
- Effort Sharing Regulation
- **EU Methane Strategy**

Brazil’s Zero Methane Programme aims to **reduce methane emissions by promoting biomethane and biogas production.** The program seeks to integrate methane credits and the dissemination of methane mitigation technologies through scientific and technological innovation, with the support of **national and international financing.**

Observations

- Globally, food systems emissions and food security is coming under the spotlight. Multiple policies and initiatives have emerged, including:
  - Enteric fermentation: $200 million USD
  - **160 countries** pledged to **include food in climate action** at COP28
  - **Carbon tax for agriculture** (Denmark)
  - **EU From Farm to Fork**
  - **EDF Dairy Methane Action Alliance**
  - **Global Methane Hub,** launched to reduce methane emissions with **$328 million USD**
- However, a **lack of policy implementation** exists despite growing government strategies.
- Governments seem to avoid explicitly mentioning the need to reduce livestock and meat production.

Sources: Global Methane Pledge, Methane plan and policies (2024); COP28, Food and agriculture (2024); Ministry of Denmark, Livestock carbon tax (2024); IEA, EU Methane Action Plan (2023). Credit: Asya Ikizler, Ariela Farchi, Raissa Coan Ribeiro, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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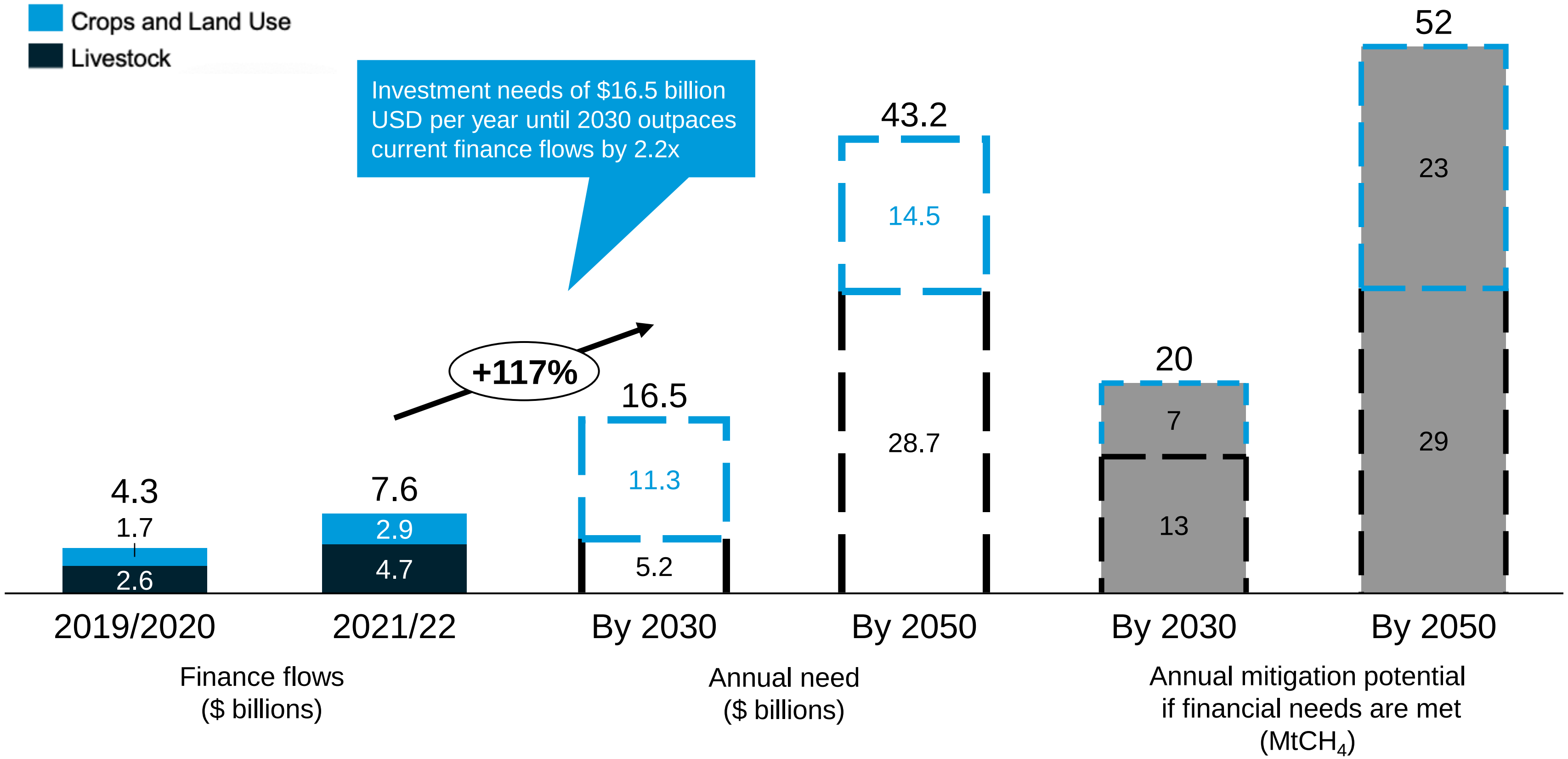
Delays in realizing methane abatement solutions result in part from financing flows not meeting financing needs

Methane abatement finance flows vs. needs and annual mitigation potential, $ billions, $MtCH_4$



Observations

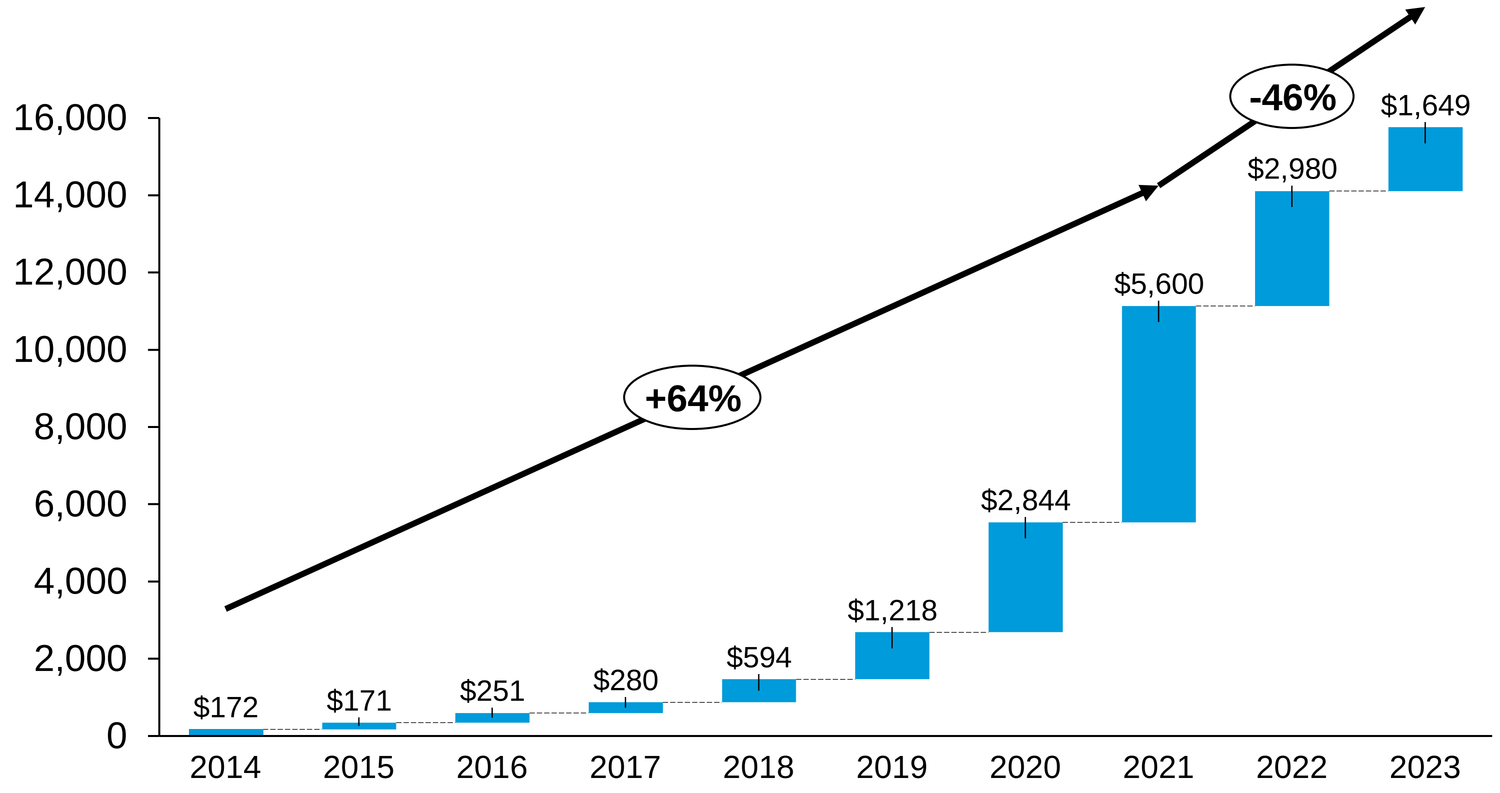
- Hard-to-abate methane emission sources such as enteric fermentation, food waste, and rice paddies have fragmented value chains that hinder solution scalability.
- In 2021-2022, methane abatement finance to livestock-related activities attracted
  $2.9 billion annually, a significant increase from $1.6 billion in 2019-2020.
  - Enteric fermentation: $200 million USD
  - Animal health and productivity: $410 million USD
  - **Manure-to-energy and manure management: $2.5 billion USD**
- Even with the increase in investment in enteric fermentation between 2019-2020 and 2021-2022, there has been a consistent lack of investment in such initiatives across the dairy and beef sector to date.
- The public sector, namely development finance institutions, accounts for 95% of funding to animal health and productivity.

Sources: Climate Policy Initiative, Landscape of Methane Abatement Finance (2023).
Credit: M.A. Miller, Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Alternative proteins are commercially viable, but promising investment up to 2021 has stalled in recent years

Cumulative investment in alternative proteins in the past decade surpassed $15B USD

Annual and cumulative investment in alternative proteins, $ millions USD



Observations

- The sector experienced a contraction in investment after 2021, aligning with global funding trends across the ecosystem, **which fell 42% year over year in 2023.**
  - CAGR for the past 10 years has been 29%, drawn down from 64% in 2014.
  - A higher interest rate environment slowed investment and fundraising significantly.
- Many technologies for producing alternative proteins are now commercially viable, particularly plant-based innovations.
- **$40 billion in annual investment will be needed to stimulate and sustain adoption. Funders are now meeting only 7% ($3 billion) of this need.**
- Investment in cultivated meat and seafood is the most commercially nascent among the three innovation groups, and deal count is concentrated at the incubator and early/seed VC stages.

Source: Good Food Institute, 2023 State of the Industry Report: Cultivated meat and seafood (2023).
Credit: M.A. Miller, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Conventional CPG companies’ participation in plant-based meat and alternative proteins is concentrated in investment and R&D

Conventional companies with involvement in alternative proteins

🟣 Cultivated meat 🔵 Fermentation 🟢 Plant-based

	CPG companies							Meat companies					
	PEPSICO	Nestlé	KraftHeinz	ABInBev	General Mills	DANONE	Coca-Cola	MAPLE LEAF	Tyson	JBS	Cargill	Smithfield	Hormel Foods
Investment	🟢	🟣🔵🟢	🔵	🔵	🟢	🟣🔵🟢	🟣	🟣🔵	🟣🔵🟢		🟣🟢		
Acquisition		🟢	🟢			🟢		🟢		🟣🟢			
Partnership	🟢	🟣	🟢	🔵	🔵			🔵		🟣	🟣🔵🟢		🔵
R&D and manufacturing	🟢	🟣🔵🟢	🟢	🔵🟢	🔵🟢	🟢	🟢	🟢	🟢	🟣🟢	🟢	🟢	🟢

Observations

- In 2023, JBS broke ground on a $62 million cultivated meat research center in Brazil.
- In 2022, Tyson Foods participated in a $36.5 million Series A funding round for cultivated meat company Omeat. Tyson previously invested in cultivated meat companies UPSIDE Foods in 2018 and Believer Meats in 2021.
- Relative involvement in acquisitions indicates the absence of any consolidation trends and lack of sector agreement on possible segment or technology “winners” and “losers.”
- Sample companies’ concentration in investment and R&D/manufacturing can leverage incumbents’ scale but potentially misses out on maximizing innovations in consumer experience (taste, mouthfeel) without greater partnerships and acquisitions.

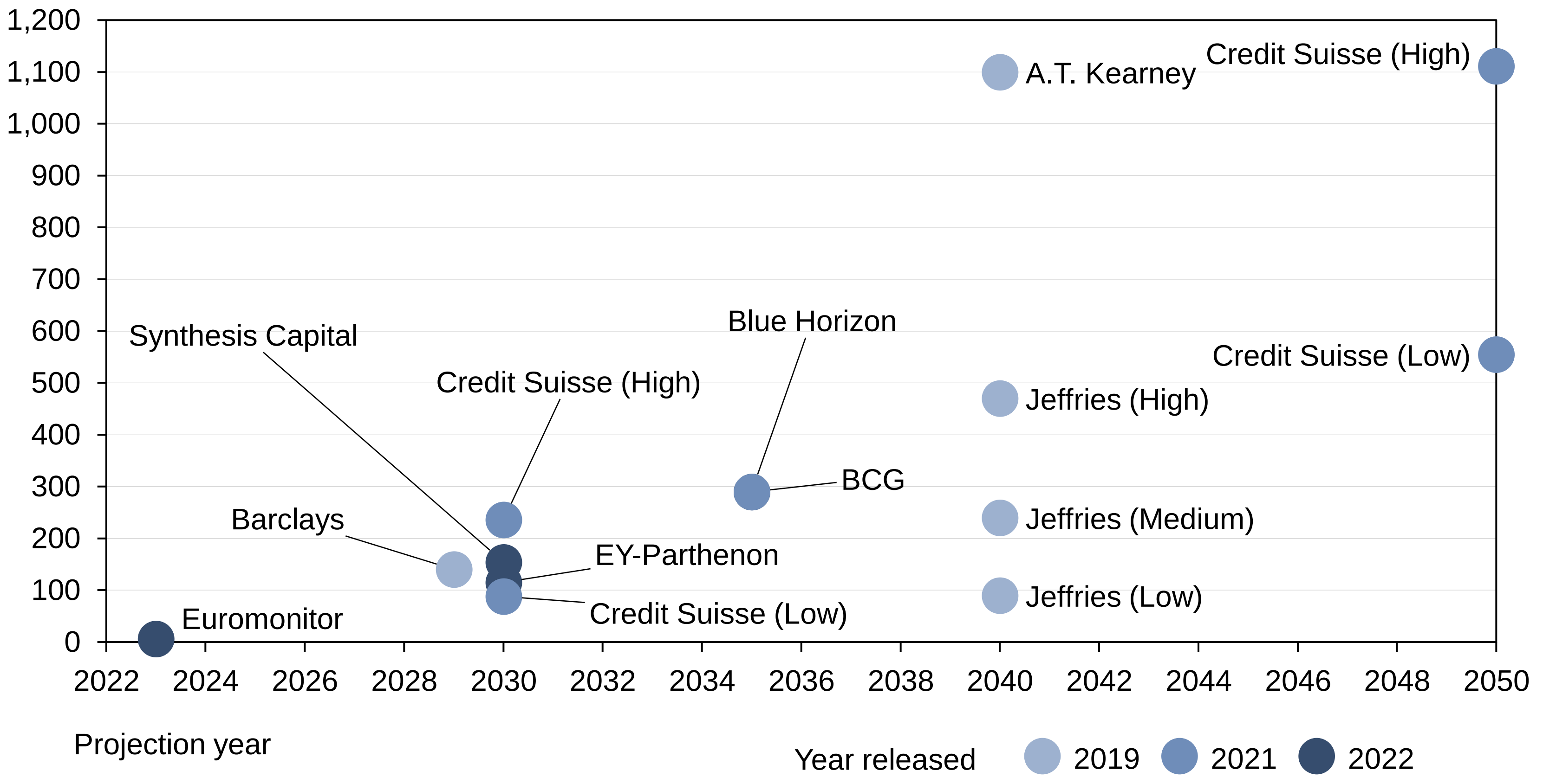
Source: Good Food Institute, 2023 State of the Industry Report: Plant-Based (2023).

Credit: M.A. Miller, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Alternative protein market projections vary significantly, but even the lowest projections show exponential growth

Meeting 2035 projections will require 25% CAGR from Euromonitor's 2023 baseline

Global alternative meat market, $ billions USD



Observations

- **Demand for alternative proteins forecasts vary significantly,** not only between different sources but also between the upper and lower bound projection of the same source.
- Even reaching the lower bound market growth will **require significant investment and advancement in technology.**

Sources: UNEP, What's Cooking? (2023); Good Food Institute, 2023 State of the Industry Report: Plant-based (2023).
Credit: M.A. Miller, Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Significant funding gaps in the alternative protein value chain

Only a few sections have sufficient funding for successful at-scale deployment

	Research & development	**Procurement of ingredients**	**Production**	**Distribution**	**Branding & marketing**	**Food service & retail**
Is there sufficient funding?	✓		✓			
How is value created?	Innovative product development and existing product enhancement	Sourcing of sustainably produced feedstock; understanding the functionality of protein structures	Processing of the feedstock to allow for further product development at scale	Leveraging existing food logistics channels to circulate alternative proteins	Increasing the public's **awareness, trust in, and demand for** the product	Serving products to customers; catering to different tastes through product versatility
Priorities	• Optimize **taste** • Find and process **novel sources of proteins** • Conduct **consumer preference studies** • Expand **scientific collaboration** • **Accelerate development** of successful alternative proteins • **Reduce cost**	• **Optimize ingredients** and their processing • **Improve market mechanisms** for supply chain efficiency • **Establish relationships** between distributors and manufacturers • Upcycle and **commercialize traditional food process by-products**	• Contract development to **achieve necessary manufacturing capacity** • **Evolve past pilot-scale projects** to serve greater populations • **Scale up capacity** • Utilize **novel texturizing equipment** • Optimize and **retrofit existing manufacturing equipment** • ,	• Find **distribution partners** • Find **early-adopter** consumers to **demonstrate market interest** to sustain distribution • **Expand** into additional channels, including **e-commerce and direct to consumer**	• Conduct consumer preference studies to **understand what appeals to consumers** and drives demand • **Highlight the sensory food experience** over environmental benefits • Focus on the **taste of the product**	• **Reskill the relevant workforce** for best practices on cooking different sources of protein that appeal to general consumers

Observations

- There are currently **significant funding gaps** in the value chain, with only R&D and production receiving sufficient funding.
- Investment in critical **infrastructure for industrial-scale production and consumer adoption** is still lacking.
- Investing in a **strong value chain** is necessary to successfully scale production and optimize costs of alternative proteins.
- Most funding for alternative proteins comes from VC. **Funding from industry, capital markets, and governments** is not yet as prevalent.
- **Knowledge sharing and open access to information** is key in such an interdisciplinary industry, in all development stages.
- **More research is needed,** to not only develop better taste and texture but also understand what the general consumer wants — both of which are critical to generate demand at scale.

Sources: Good Food Institute, Advancing Solutions for Alternative Proteins (2024); BCG, What Alternative Proteins Can Learn from EV Companies (2024).
Credit: Asya Ikizler, Ariela Farchi, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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Inconsistent policies, subsidies, and lobbying remain important barriers for the protein transition

	Inconsistent government policies	**Subsidies**	**Lobbying**
Global	• Agriculture, climate, and health ministries around the world are not working together on food transition bills, creating **inconsistent and incoherent** policies surrounding food and protein systems.	• From 2008 to 2017**, the Brazilian government invested $22.2 billion in the beef industry,** resulting in increased deforestation to make more room for cattle ranching.	• The number of lobbyists representing meat and dairy industries **tripled** from 2022 to 2023 at the UN's Conference of the Parties (COP).
U.S.	• Providing further ethanol subsidies under the IRA has been criticized for being counterproductive for emissions reduction. • Half of the IRA's agriculture budget ($20 billion) is for "climate-smart agriculture." In 2024, it added to this list new **"provisional**" methods that have **not yet proved to reduce emissions.**	• Since 1995, the United States has provided **$116 billion** to corn and **$44.9 billion** to soybean production in subsidies for animal feed. • U.S. subsidies to the meat and dairy industry total **$38 billion** a year. • Between 1997 and 2005, through direct subsidies provided by various U.S. Department of Agriculture programs, **Tyson Foods managed to save an estimated $288 million per year.**	• Six U.S. lobbying groups have spent over **$200 million** in political lobbying since 2000, including against climate regulations like the Clean Air Act and the Cap-and-Trade program. • **Tyson** alone spent $25 million since 2000, which is **33% more than Exxon** when comparing as revenue shares. • In the United States, the meat industry spent **190 times more on political lobbying** than on alternative proteins.
EU	• EU From Farm to Fork vs. CAP investments • Over 80% of the European Union's Common Agricultural Policy supports emissions-intensive animal products.	• An analysis of lobbying, subsidies, and regulations revealed that livestock farmers in the EU received **1,200 times more government funding** than plant-based and cultivated meat organizations.	• Meat and dairy lobbies have held over 600 top-level meetings with the European Commission in the past decade.

Sources: MIT Technology Review, Why ethanol aviation fuel tax subsidies aren't a clear climate win (2024); Changing Markets Foundation, How Big Meat and Dairy Avoid Climate Action (2024); The Daily Economy, The True Cost of a Hamburger (2022); Béné and Lundy, Political Economy of Protein Transition (2023); The Guardian, 'Gigantic' power of meat industry blocking green alternatives (2023); Nature Food, EU policy (2024).

Credit: Asya Ikizler, Ariela Farchi, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Denmark published world’s first national action plan for plant-based foods, which supports robust funding

Denmark is investing €195 million in the Fund for Plant-Based Foods until 2030 to promote its plant-based industry as a whole

Creating a strong plant-based value chain…

A good food base	• Transforming agricultural land to grow protein-rich crops, organic crops, and land-based seaweed cultivation • Green biorefining
Production and processing	• Develop ingredients • Refine and scale the ingredients • Support producers in the fruit, vegetables, nuts, and mushrooms sectors
Healthy, plant-based foods for all	• Green skill building through vocational training and higher education • Mainstreaming through public procurement
Export and internationalization	• Green skill building through vocational training and higher education • Mainstreaming through public procurement
R&D and innovation	• For plant-based foods and technologies • For more sustainable agricultural and food production

…with a robust funding plan

Plant-Based Foods Grant (at least half of the fund):

- To develop the plant-based food sector across the value chain, e.g., food companies, sales promotion, research institutions, innovation, and knowledge dissemination

Other uses of the fund:

- Farmers planting protein-rich crops for human consumption
- Strategy for Green Jobs in Agriculture
- Overall promotion of the sector in Denmark

Strategy for Green Proteins (2024)

- This plan is to increase production of green proteins for animals and humans, to not only boost plant-based food production but also replace animal feed such as soy.

Sources: FVM, Strategy for green proteins (2024); FVM, Danish Action Plan for Plant—Based Food (2023); GFI, National action plan for plant-based foods (2023); Food and Agriculture Council, Food and farming (2023); Forbes, Denmark’s $195M Plant-Based Fund (2023).

Credit: Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Denmark wants to be the first mover and a leader in the sustainable proteins market by publishing the world’s first national action plan

Denmark’s sustainable proteins leadership strategy imitates wind energy trajectory

How did Denmark pass this policy?

Beyond the environment, the case for simply smart business

- The action plan is a strategic move based on the business case to make Denmark a front-runner in the plant-based food market and capture the growing market.
- Denmark adopted a similar strategy to become a leader in wind energy; it's on track to do the same with plant-based food.
- This precedent enabled the policy to gain bipartisan support.

Pragmatic and cooperative approach to avoid backlash

- The action plan aims to make Denmark a front-runner in plant-based proteins. The role of its Strategy for Green Jobs in Agriculture is to grow jobs and develop plans with farmers' associations to avoid political backlash. Previously, countries trying to pass agricultural policies, like the Netherlands, faced mass protests.

Holistic framework and planning

- **Supply chain development:** Investment in agriculture, food innovation, and processing infrastructure to expand sustainable protein production and avoid bottlenecks.
- **Demand stimulation:** Public awareness campaigns, chef training, and school curricula to promote plant-based diets and drive consumer adoption.
- **Research and innovation:** Significant funding for R&D to improve plant-based product quality, alongside policies and incentives that support market growth.

Observations

- The comprehensive plan includes **funding, new jobs, and creation of a value chain** to add value to the Danish economy, allowing agricultural carbon tax **without alienating farmers and creating mass political backlash.**
- Denmark’s plant-based action plan focuses on the **attractiveness of plant-based food production** rather than a crack-down on the meat industry.
- The plan was developed closely with Denmark’s **largest farmers’ association to avoid backlash.**
- 22% of total Danish exports are agricultural products, notably pork, dairy, and fish, yet it also introduced the world’s first **agricultural carbon tax.**

Sources: FVM, Strategy for green proteins (2024); FVM, Danish Action Plan for Plant—Based Food (2023); GFI, National action plan for plant-based foods (2023); Food and Agriculture Council, Food and Farming (2023); Forbes, Denmark’s $195M Plant-Based Fund (2023).

Credit: Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Singapore is the global commercial and policy leader for cultivated meat and the first nation to approve its sale

Its leadership in cultivated meat innovation stems from national food security priorities, providing tailwinds for the market

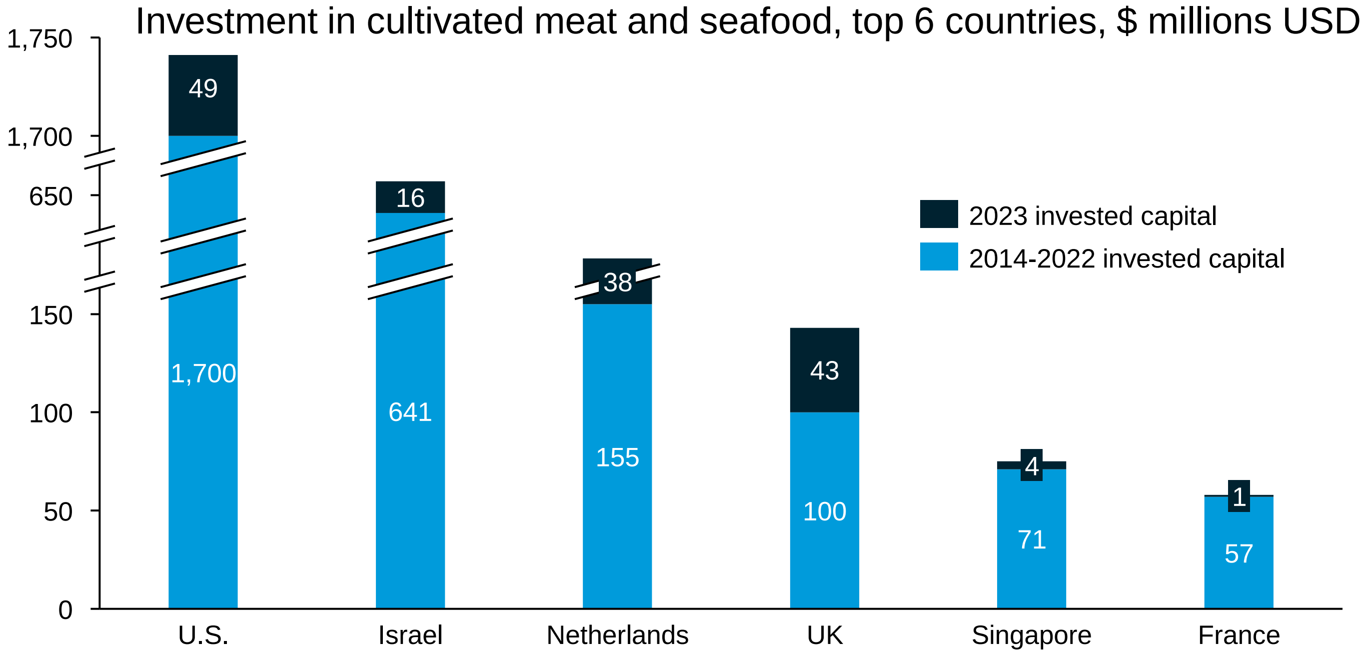
Singapore context

- 6 million population, island country
- Relies on imports for **90% of its food**
- Malaysia banned exports of chicken to Singapore during COVID
- **First country to approve cultivated meat** for human consumption and to sell cultivated meat in retail locations[1]

30 by 30 food security strategy

- 30% of food produced nationally by 2030
- Devised in May 2019
- Addresses food insecurity and climate risk through three strategic pillars:
  - (1) Diversifying sources of food imports
  - **(2) Increasing local production**
  - (3) Growing food overseas
- The Singapore Food Story R&D Programme has allocated **more than $309 million in funds:**
  - A 2022 call for grant proposals under Theme 2 targeted productization, prototyping, and sustainability of production.
  - Promised subsequent funding to projects that demonstrated commercial potential.
- The targets, policies, and incentives facilitated by 30 by 30 have set the stage for cultivated proteins

Investment in cultivated meat and seafood, top 6 countries, $ millions USD



Enthusiasm for cultivated meat in Singapore is at odds with policies around the world: The sale of cultivated meat has been banned in Italy and in at least two U.S. states (Alabama and Florida).

While Singapore does not represent the highest level of investment in cultivated meat, it does represent one of the **largest investment markets proportional to its population.**

Sources: Singapore Food Agency, 30 by 30 (2024); Singapore Agency for Science; Technology, and Research, Seed Grant (2022); Wired, Lab-Grown Meat Is on Shelves Now; GFI, National action plan for plant-based foods (2024); Good Food Institute, State of the Industry Report: Cultivated meat (2023).

Credit: M.A. Miller, Ariela Farchi, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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Attribution: Sayn-Wittgenstein et al., "Reconsidering Proteins" Columbia Business School Climate Knowledge Initiative (2025).

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Appendix

Nutritional profile of animal and alternative proteins depends on source and processing

	Animal-based proteins (ABP)	**Alternative proteins (plant-based and fermentation)**
Nutrients	Protein, zinc and iron, vitamins D, B6, and B12, but includes cholesterol	Protein, fiber, others (depends on specific ingredients used to produce the product)
Pros and cons	⊕ Can be a critical component of healthy diets especially in low- and middle-income countries ⊖ **Excessive consumption** is associated with **cardiovascular** diseases and **type II diabetes** ⊖ **Zoonotic diseases,** antimicrobial resistance, and **35% of foodborne diseases** like salmonella are associated with animal agriculture ⊖ A lot of ABP products are ultraprocessed	⊕ Can have ABP-comparable levels of protein, fat, and sodium but more fiber and no cholesterol ⊕ Increased intake of plant-based foods is associated with improved health outcomes ⊖ Some alternative meat products contain excessive amounts of sodium
Opportunity for improvement	• Improved feed and antibiotic stewardship • Moderate consumption – average individual in North America and Europe consume more ABP than recommended in dietary guidelines	• Fortification and product development • Further research and regulation to maximize the health and nutritional benefits of these products while minimizing excessive sodium • Replacing unhealthy types of meats with alternative proteins • **Fermentation** is known to **improve the nutritional value** of foods; expanding on precision fermentation techniques can be a solution

Observations

- The **health outcomes** and nutritional value of both animal-based and alternative proteins are **determined by the specific product formulation,** rather than just the protein source.
- **Negative public perception** of alternative proteins due to **health concerns** can be mitigated by addressing such issues during **product development,** enhancing consumer trust and acceptance.
- While some alternative proteins are viewed negatively for being processed, **dietary quality is a better determinant than processing level for nutrition-associated health outcomes.** In some cases, alternative proteins have higher dietary quality than animal proteins.
- Makers of alternative proteins can **capitalize on nutritional benefits** by targeting the replacement of less healthy meat options, **positioning the products as a healthier choice for consumers.**

Sources: UNEP, What's Cooking? (2023); Fang, et.al., Association of ultra-processed food consumption and mortality (2024).
Credit: Asya Ikizler, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

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Climate Knowledge Initiative

Switching to better feed for aquaculture and expanding unfed species can cut the sector’s CO_2 emissions by 50%

Blue foods are a vital protein source; selecting the right species can support a low-emission protein supply

Global blue-food consumption expected to increase 80% by 2050

Trends

- Aquaculture is the **fastest growing** food industry in the world, but its expansion should be done carefully.
- Production results in **less emissions than land-based animals**, with room for improvement.
- Most blue foods are **dense in protein** and other nutrients, **like B12, vitamin A, and omega-3.**
- Globally, 3 billion people depend on seafood for **20% of their diet.**

Emission and marine ecosystem concerns

Risks in the sector

- Aquaculture relies on **wild fish for feed** and is **not** a replacement for wild-caught fish. Using wild fish feed disrupts the ocean food chain and natural ecosystem.
- **Overfishing** is a high risk and has significant impacts on biodiversity.
- Switching to soy as feed drives mass deforestation and therefore is **not** a sustainable alternative.
- Blue foods are **highly sensitive to climate change;** their future availability depends on the health of ecosystems and environmental stressors.

Species and production methods matter

- All blue foods are **not the same** when it comes to emissions and environmental impacts:
  - Production methods and species matter.
  - Salmon requires more resource-intensive feed than others and is one of the species with the fastest growing demand rate.
  - **90%** of salmon’s environmental impact is from **feed.**

Solution opportunities in the sector: Alternative aquafeed, bivalves, and more attractive fish products

Existing solutions

- For aquaculture, **improving aquaculture feed** to blue-food weight gain represents the biggest opportunity to improve environmental performance.
- **Expand** unfed aquaculture like **bivalves (mussels, oysters, clams, and scallops).**
- **Sardines, anchovies, and mackerel** are some of the most **emission-efficient fish** and packed with healthy nutrients.

Innovation opportunities

- Innovations and businesses that **increase the availability and attractiveness** of these more sustainable species are important opportunities to increase the sustainable protein supply.
- **Innovations** for alternative salmon feed can be explored..
- **Microalgae,** an unfed aquaculture type, is also an alternative protein source that can be explored.

Sources: The Blue Food Assessment, Science (2021); EIT Food, Fish feed: Why we need sustainable ; GFI, National action plan for plant-based foods (2023); WWF Aquafeed (2022).

Credit: Asya Ikizler, Friedrich Sayn-Wittgenstein, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Sayn-Wittgenstein *et al.*, "Reconsidering Proteins" (6 October 2025).

Glossary

AFOLU	Agriculture, forestry, and other land uses
AA	Annual average percentage change
BAU	Business as usual
CapEx	Capital expenditure(s)
CCUS	Carbon capture, utilization, and storage
CH4	Methane
CO_2	Carbon dioxide
CPG	Consumer packaged goods (company)
EBITDA	Earnings before interest, taxes, depreciation, and amortization
FID	Final investment decision
GHG	Greenhouse gases
HQP	High-quality protein
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land-use change, and forestry
N2O	Nitrous oxide
O&M	Operations and maintenance
PBM	Plant-based meat
PES	Payments for ecosystem services
R&D	Research and development
RED	Renewable Energy Directive
SMR	Steam methane reforming
UN	United Nations
VC	Venture capital
FAO	Food and Agriculture Organization
WWF	World Wide Fund for Nature
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
SDG	Sustainable development goals
WRI	World Resources Institute