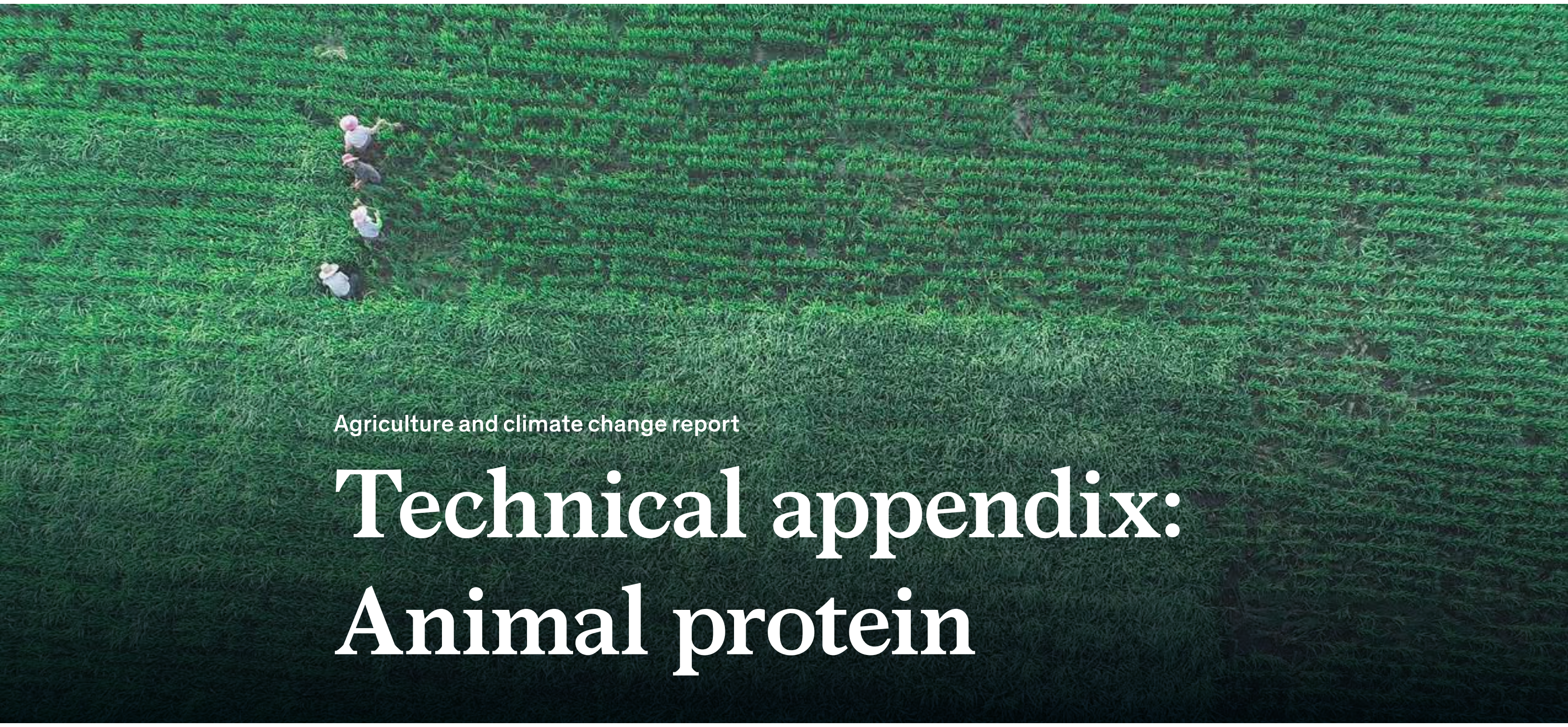
McKinsey & Company



Agriculture and climate change report

Technical appendix: Animal protein

Calculating the baseline of agriculture emissions

The agriculture emissions baseline is calculated based on the Food and Agriculture Organization's Agriculture Emissions Database (Agriculture Total, FAOSTAT, FAO, accessed July 2019, fao.org/faostat), with the following minor adjustments:

— Adapted emissions to reflect AR5 GWP values (*Climate change 2014: Synthesis report*, Intergovernmental Panel on Climate Change, 2015, ar5-syr.ipcc.ch, p. 87)

— Cross-checked with crop and livestock demand estimates contained within FAO's database ("Food and agriculture projections to 2050," Global Perspectives Studies, FAO, 2018, fao.org; see also *The future of food and agriculture: Alternative pathways to 2050*, FAO, 2018, fao.org) and the McKinsey Food Demand Model. This resulted in minor adjustment to emissions expected to be driven by crop agriculture production area (up 9 percent by 2030 and up 13 percent by 2050)

— Given that FAO's estimates for emissions from "energy use in agriculture" were discontinued from 2013 forward, we used 2007–12 compound annual growth rates (CAGRs) by region (Brazil, Europe, China, India, and the rest of Asia) and energy source (electricity, fuel oil, natural gas) to project emissions forward to 2015. Forecasts to 2050 were based on discrete CAGRs (2012–30 and 2030–50) for agricultural acreage projections (*The future of food and agriculture: Alternative pathways to 2050,* FAO, 2018, fao.org)

Key assumptions, by MACC measure

All assumptions made for each part of the marginal abatement cost curve (MACC) are based on published literature.

● 100-year GWP[2]   ■ 20-year GWP[2]

Improved fuel efficiency of fishing vessels

34 | 34 **Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): GHG emissions from energy used for fishing vessel fuel

75 **Incremental lever implementation,** % [B]

Source: McKinsey analysis

65 **Greenhouse gas reduction factor,**[1] % CO_2e [C]

Source: James F. Muir, *Fuel and energy use in the fisheries sector: Approaches, inventories and strategic implications*, FAO Fisheries and Aquaculture Circular, 2015, fao.org; Lee Kindberg, "Improving vessel and supply chain fuel efficiency," Maersk Line, 2012, epa.gov; Gary Wollenhaupt, "Study says ships are less fuel efficient; operational evidence differs," *Professional Mariner*, July 30, 2015, professionalmariner.com

17 | 17 **Emissions reduction potential,** MMT CO_2e [A × B × C][3]

12 | 12 **Lever implementation cost savings,** $/t$CO_2e$

Source: James F. Muir, *Fuel and energy use in the fisheries sector: Approaches, inventories and strategic implications*, FAO Fisheries and Aquaculture Circular, 2015, fao.org

Improved animal health monitoring and illness prevention

4,680 | 11,923 **Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): non-CO_2 emissions from enteric fermentation, manure management, and manure left on pasture for all commercial livestock

25 **Incremental lever implementation,** % [B]

Source (current implementation): McKinsey baseline model (via FAOSTAT data): non-CO_2 emissions from enteric fermentation, manure management, and manure left on pasture for all commercial livestock

Source (incremental implementation): Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl; Lanigan et al., "An analysis of abatement potential of greenhouse gas emissions in Irish agriculture 2021–2030," Teagasc Greenhouse Gas Working Group, March 2019, teagasc.ie

14 **Greenhouse gas reduction factor,**[1] % CO_2e [C]

Source: Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl; Alexander N. Hristov et al., "Mitigation of greenhouse gas emissions in livestock production," FAO, 2013, fao.org; Michael MacLeod et al., "Assessing the greenhouse gas mitigation effect of removing bovine trypanosomiasis in Eastern Africa," *Sustainability*, May 2018, Volume 10, Number 5, pp. 1633–47; McKinsey analysis regarding prevalence and economic impact of top 10 US cattle diseases

162 | 411 **Emissions reduction potential,** MMT CO_2e [A × B × C][3]

5 | 5 **Lever implementation cost savings,** $/t$CO_2e$

Source: To see weighted-average cost across MACC, excluding measures at cost of >$200/t$CO_2$eq, see *Study to model the impact of controlling endemic cattle diseases and conditions on national cattle productivity, agricultural performance and greenhouse gas emissions*, ADAS, February 2015, randd.defra.goc.uk; Lanigan et al., "An analysis of abatement potential of greenhouse gas emissions in Irish agriculture 2021–2030," Teagasc Greenhouse Gas Working Group, March 2019, teagasc.ie; Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl

100-year GWP[2] | 20-year GWP[2]

Feed-grain processing for improved digestibility

2,836 | 8,507 **Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): emissions from enteric fermentation for large ruminant animals (only cattle and buffaloes)

15 **Incremental lever implementation,** % [B]

Source (current implementation): KL Samuelson et al., *Nutritional recommendations of feedlot consulting nutritionists: The 2015 New Mexico State and Texas Tech survey*, *Journal of Animal Science*, June 2016, Volume 94, Number 6, pp. 2648–63, ncbi.nlm.nih.gov

Source (incremental implementation): Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl

17 **Greenhouse gas reduction factor,**[1] % CO_2e [C]

Source: "Cattle grain processing symposium," Oklahoma State University, November 2006, beefextension.okstate.edu; Alexander N. Hristov et al., "Mitigation of greenhouse gas emissions in livestock production," FAO, 2013, fao.org; Khalil Safaei et al., "Effects of grain processing with focus on grinding and steam-flaking on dairy cow performance," March 8, 2017, intechopen.com; "Cattle grain processing symposium," Oklahoma State University, November 2006, beefextension.okstate.edu

73 | 219 **Emissions reduction potential,** MMT CO_2e [A × B × C][3]

8 | 3 **Lever implementation cost savings,** \$/tCO_2e

Source: Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl; C. N. Macken et al., "The cost of corn processing for finishing cattle," *The Professional Animal Scientist*, February 2006, Volume 22, Number 1, pp. 23–32, sciencedirect.com

GHG-focused breeding and genetic selection

3,317 | 9,952 **Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): methane emissions from enteric fermentation by ruminant animals; emissions from manure on pasture and management for all

45 **Incremental lever implementation,** % [B]

Source (current implementation): McKinsey baseline model (via FAOSTAT data): methane emissions from enteric fermentation by ruminant animals

Source (incremental implementation): "Animal genetics market by products & services (live animals [poultry, porcine, bovine, canine] genetic material [semen {bovine, porcine}], embryo [bovine, equine]) genetic testing (DNA testing, DNA typing, genetic disease testing]) - forecast to 2023," Markets and Markets, December 2018, marketsandmarkets.com

11 **Greenhouse gas reduction factor,**[1] % CO_2e [C]

Source: Matthew Bell et al., "Effect of breeding for milk yield, diet and management on enteric methane emissions from dairy cows," *Animal Production Science*, January 2010, Volume 50, Number 8, pp. 817–26; Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl; "Animal genetics market by products & services (live animals [poultry, porcine, bovine, canine] genetic material [semen {bovine, porcine}], embryo [bovine, equine]) genetic testing (DNA testing, DNA typing, genetic disease testing]) - forecast to 2021," Markets and Markets, December 2018, marketsandmarkets.com; Viking Genetics, "Breeding for climate-friendly cows is possible – VikingGenetics focuses on reducing methane emissions at herd level," February 2018, vikinggenetics.com

169 | 506 **Emissions reduction potential,** MMT CO_2e [A × B × C][3]

- | - **Lever implementation cost,** \$/tCO_2e

Source: Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl

100-year GWP[2] | 20-year GWP[2]

Livestock nutrient use efficiency

100-year GWP	20-year GWP	
782	779	**Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): nitrous oxide emissions from manure left on pasture and manure left on soil by dairy and non-dairy cattle

6 Greenhouse gas reduction factor,[1] % CO_2e [C]

Source: Benjamin J. DeAngelo et al., "Methane and nitrous oxide mitigation in agriculture," *International Association for Energy Economics*, 2006, Volume 27, pp. 89–108, jstor.org

100 Incremental lever implementation, % [B]

Source: McKinsey analysis

100-year GWP	20-year GWP	
47	47	**Emissions reduction potential,** MMT CO_2e [A × B × C][3]
-	-	**Lever implementation cost,** $/t$CO_2e$

Source: Benjamin J. DeAngelo et al., "Methane and nitrous oxide mitigation in agriculture," *International Association for Energy Economics*, 2006, Volume 27, pp. 89–108, jstor.org

N-inhibitors on pasture

100-year GWP	20-year GWP	
826	823	**Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): nitrous oxide emissions from manure left on pasture by ruminant animals

30 Greenhouse gas reduction factor,[1] % CO_2e [C]

Source: Alexander N. Hristov et al., "Mitigation of greenhouse gas emissions in livestock production," FAO, 2013, fao.org; Jiafa Luo et al., "Nitrous oxide and greenhouse gas emissions from grazed pastures as affected by use of nitrification inhibitor and restricted grazing regime," *Science of the Total Environment*, Volume 465, November 1, 2013, pp. 107–14, sciencedirect.com; Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl

50 Incremental lever implementation, % [B]

Source (current implementation): Samuelson et al., *Nutritional recommendations of feedlot consulting nutritionists: The 2015 New Mexico State and Texas Tech survey*, *Journal of Animal Science*, June 2016, Volume 94, Number 6, pp. 2648–63, ncbi.nlm.nih.gov

Source (incremental implementation): Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl

100-year GWP	20-year GWP	
124	123	**Emissions reduction potential,** MMT CO_2e [A × B × C][3]
15	15	**Lever implementation cost,** $/t$CO_2e$

Source: Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl; McKinsey Fertilizer Demand Model, 2019 (via Controlled-Release and Stabilized Fertilizers lever), adjusted to per head estimates via FAOSTAT "livestock intensity" data

Animal feed additives

100-year GWP	20-year GWP	
3,281	9,842	**Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): methane emissions from enteric fermentation by cattle, buffalo, goats, and sheep

15 Greenhouse gas reduction factor,[1] % CO_2e [C]

Source: Stefan Frank et al., "Structural change as a key component for agricultural non-CO_2 mitigation efforts," *Nature Communications*, March 13, 2018, Volume 9, nature.com

20 Incremental lever implementation, % [B]

Source (current and incremental implementation): Timothy P. Robinson, *Global livestock production systems*, 2011; restricting adoption to (potentially) intensive production; Wina H.J. Crijns-Graus et al., "Marginal greenhouse gas abatement curves for agriculture," *Ecofys*, August 2013

100-year GWP	20-year GWP	
100	299	**Emissions reduction potential,** MMT CO_2e [A × B × C][3]
263	88	**Lever implementation cost,** $/t$CO_2e$

Source: Stefan Frank et al., "Structural change as a key component for agricultural non-CO_2 mitigation efforts," *Nature Communications*, March 13, 2018, Volume 9, nature.com

100-year GWP[2] | 20-year GWP[2]

Anaerobic manure digestion

182 | **547** **Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): non-CO_2 emissions from manure management in dairy and hog production

60 **Incremental lever implementation,** % [B]

Wina H. J. Crijns-Graus et al., "Marginal greenhouse gas abatement curves for agriculture," *Ecofys*, August 2013, researchgate.net

79 **Greenhouse gas reduction factor,**[1] % CO_2e [C]

Source: Stefan Frank et al., "Structural change as a key component for agricultural non-CO_2 mitigation efforts," *Nature Communications*, March 13, 2018, Volume 9, nature.com; Benjamin J. DeAngelo et al., "Methane and nitrous oxide mitigation in agriculture," *International Association for Energy Economics*, 2006, Volume 27, pp. 89–108, jstor.org; Benjamin van Doorslaer et al., *An economic assessment of GHG mitigation policy options for EU agriculture*, EU Science Hub, 2015, ec.europa.eu

86 | **260** **Emissions reduction potential,** MMT CO_2e [A × B × C][3]

277 | **92** **Lever implementation cost,** \$/tCO_2e

Source: *Greenhouse gas mitigation options and costs for agricultural land and animal production within the United States*, ICF International, February 2013, usda.gov; Benjamin J. DeAngelo et al., "Methane and nitrous oxide mitigation in agriculture," *International Association for Energy Economics*, 2006, Volume 27, pp. 89–108, jstor.org; variable cost index built via World Bank/FAOSTAT data

Technologies that increase livestock production efficiencies

2,646 | **6,748** **Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): non-CO_2 emissions from enteric fermentation, manure management, and manure left on pasture for meat-producing livestock (non-dairy cattle, market swine, buffalo, and broilers)

25 **Incremental lever implementation,** % [B]

Source (current implementation): Thomas P. Van Boeckel et al., "Global trends in antimicrobial use in food animals," *PNAS*, May 5, 2015, Volume 112, Number 18, pp. 5649–54, pnas.org; Timothy Landers et al., "A review of antibiotic use in food animals: Perspective, policy, and potential," *Public Health Reports*, January 2012, Volume 127, Number 1, pp. 4–22, researchgate.net; Ziping Wu, "Antibiotic use and antibiotic resistance in food-producing animals in China," *OECD Food, Agriculture and Fisheries Papers*, Number 134, oecd-ilibrary.org

Source (incremental implementation): "Animal growth promoters & performance enhancers," Markets and Markets, 2016, marketsandmarkets.com; Timothy P. Robinson, *Global livestock production systems*, 2011; "Accounting for intensive livestock production," FAO, 2011, fao.org; restricting adoption to (potentially) intensive production

7 **Greenhouse gas reduction factor,**[1] % CO_2e [C]

Source: *Special report: Animal pharm antibiotic replacement in modern animal production*, Agribusiness Intelligence, May 2018, agribusinessintelligence.informa.com; Stefan Frank et al., "Structural change as a key component for agricultural non-CO_2 mitigation efforts," *Nature Communications*, March 13, 2018, Volume 9, nature.com; KR Stackhouse et al., "Growth-promoting technologies decrease the carbon footprint, ammonia emissions, and costs of California beef production systems," *Journal of Animal Science*, December 2012, Volume 90, Number 12, pp. 4656–65, ncbi.nlm.nih.gov

70 | **180** **Emissions reduction potential,** MMT CO_2e [A × B × C][3]

119 | **119** **Lever implementation cost,** \$/tCO_2e

Source: Stefan Frank et al., "Structural change as a key component for agricultural non-CO_2 mitigation efforts," *Nature Communications*, March 13, 2018, Volume 9, nature.com

100-year GWP[2] 20-year GWP[2]

Animal feed mix optimization

100-year GWP	20-year GWP	
3,087	9,261	**Baseline applicable emissions,** MMT CO_2e, 2050 [A]

Source: McKinsey baseline model (via FAOSTAT data): methane emissions from enteric fermentation by cattle, buffalo, and sheep only

40 **Incremental lever implementation,** % [B]

Source (current and incremental implementation): Jan Hartger Mathijs Harmsen, "Non-CO_2 greenhouse gas mitigation in the 21st century," Utrecht University, 2019, dspace.library.uu.nl

Source (incremental implementation): Timothy P. Robinson, *Global livestock production systems*, 2011; restricting adoption to (potentially) intensive production; Stefan Frank et al., "Structural change as a key component for agricultural non-CO_2 mitigation efforts," *Nature Communications*, March 13, 2018, Volume 9, nature.com

10 **Greenhouse gas reduction factor,**[1] % CO_2e [C]

Source: Michael MacLeod et al., "Cost-effectiveness of greenhouse gas mitigation measures for agriculture," OECD, August 1, 2015, oecd-ilibrary.org

100-year GWP	20-year GWP	
123	370	**Emissions reduction potential,** MMT CO_2e [A × B × C][3]
131	131	**Lever implementation cost,** $/t$CO_2e$

Source: Michael MacLeod et al., "Cost-effectiveness of greenhouse gas mitigation measures for agriculture," OECD, August 1, 2015, oecd-ilibrary.org

[1] Difference due to greenhouse-gas reduction factor, % rounding.
[2] Global warming potential.
[3] A × B × C doesn't always equal the exact final emissions abatement number due to GHG reduction/applicability percentage rounding.