USC Viterbi School of Engineering

ENE 527 - Final Project

Food Production and Climate Change

Presented by
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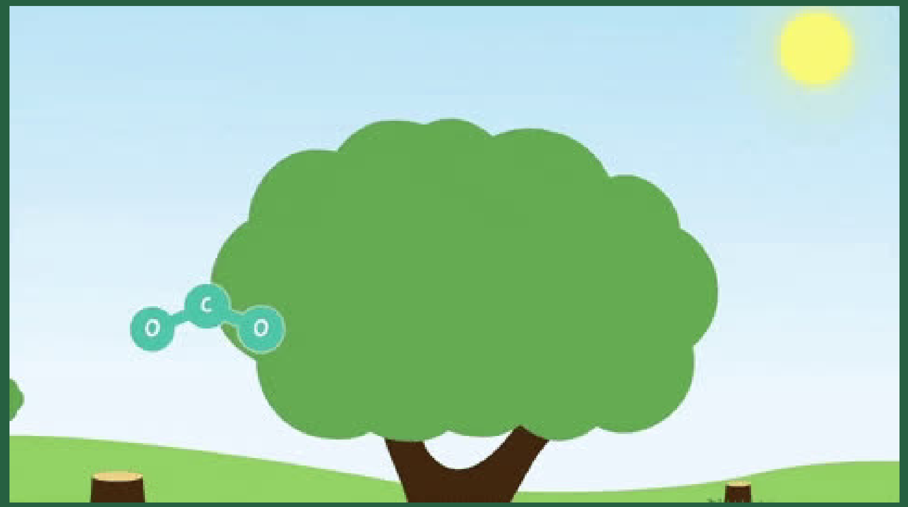
November 18, 2021

Contents

Part 1:

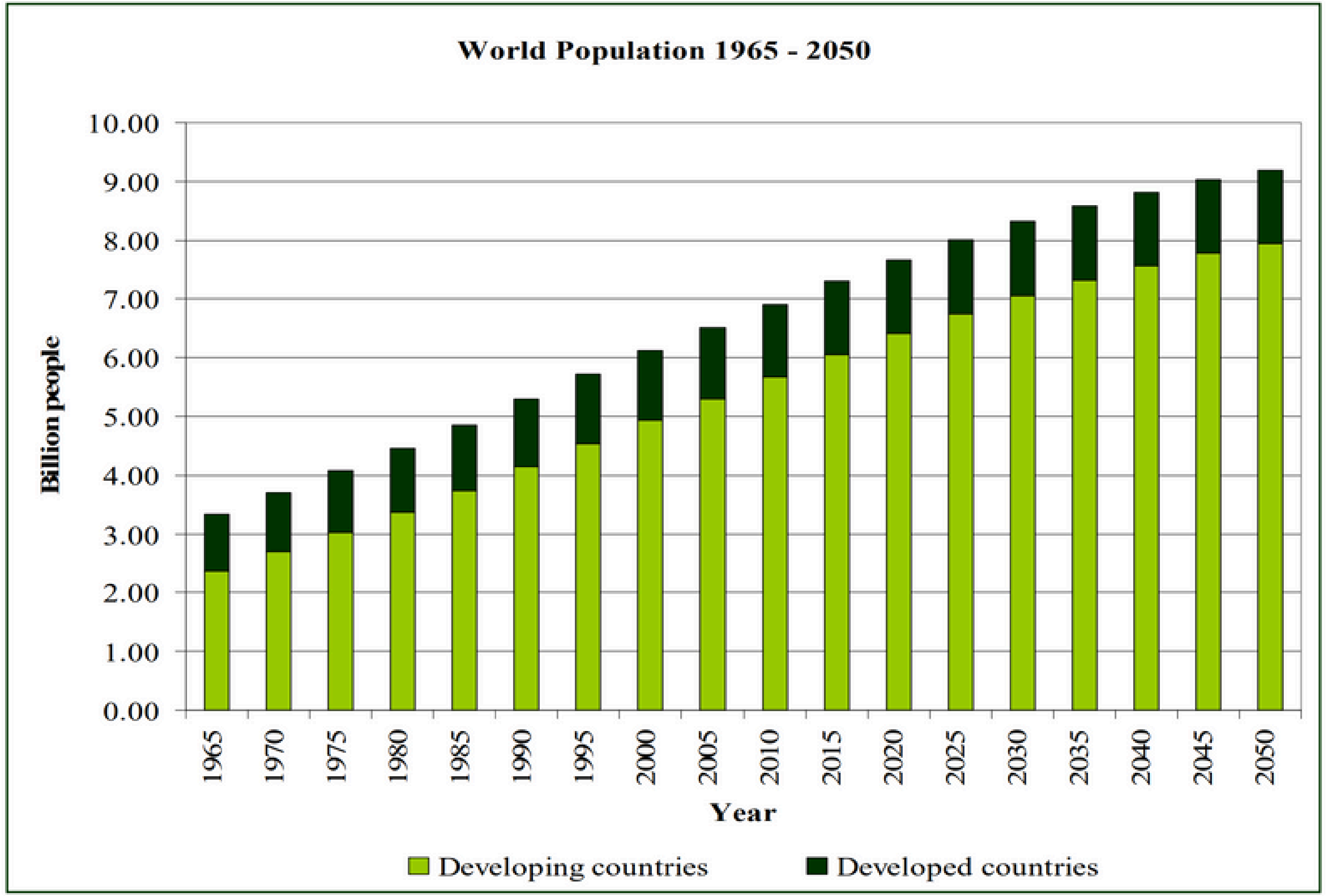
Overview



FAO

Big picture - big challenge

Population dynamics and food production

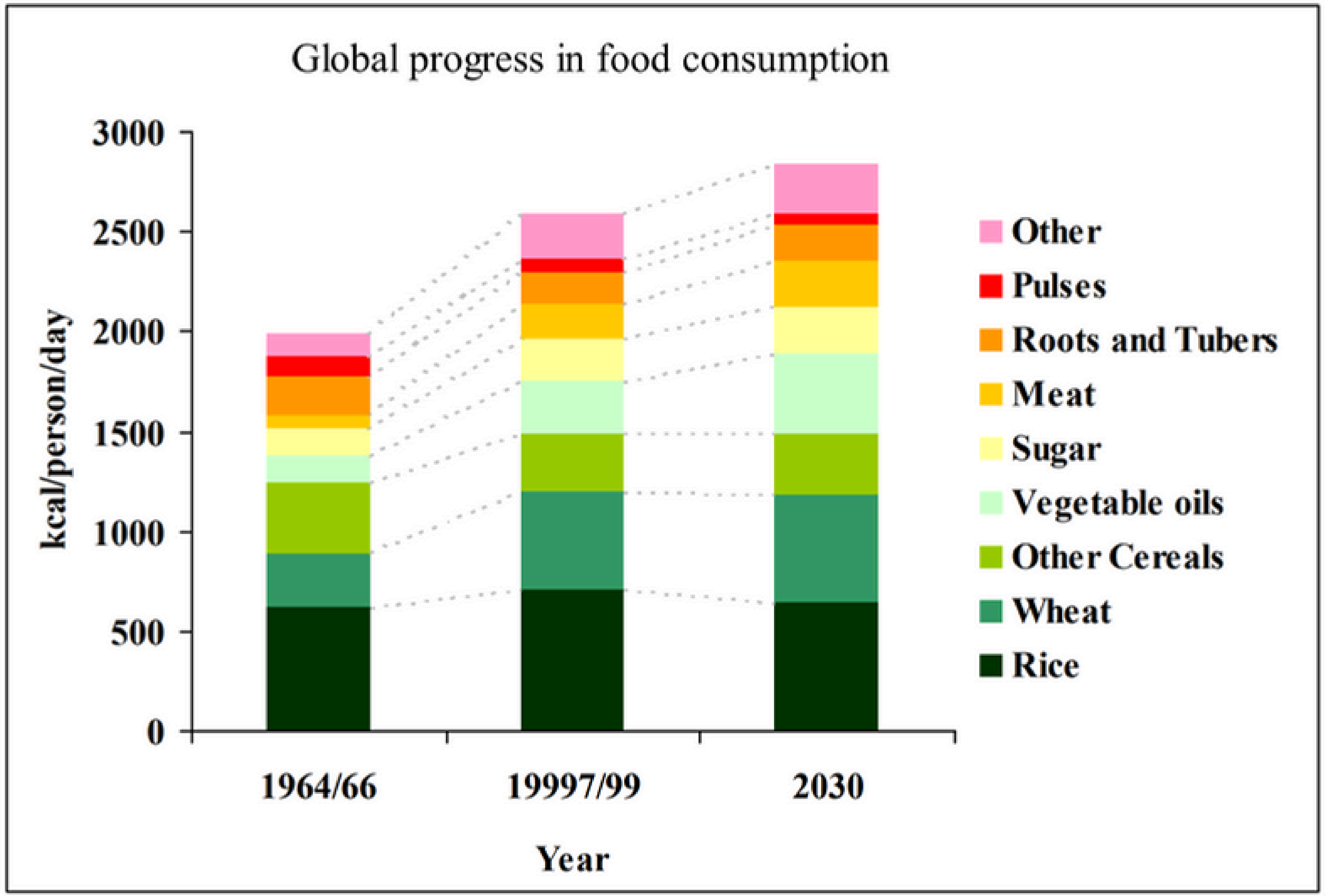


Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (2007)

FAO

Big picture - big challenge

Population dynamics and food production

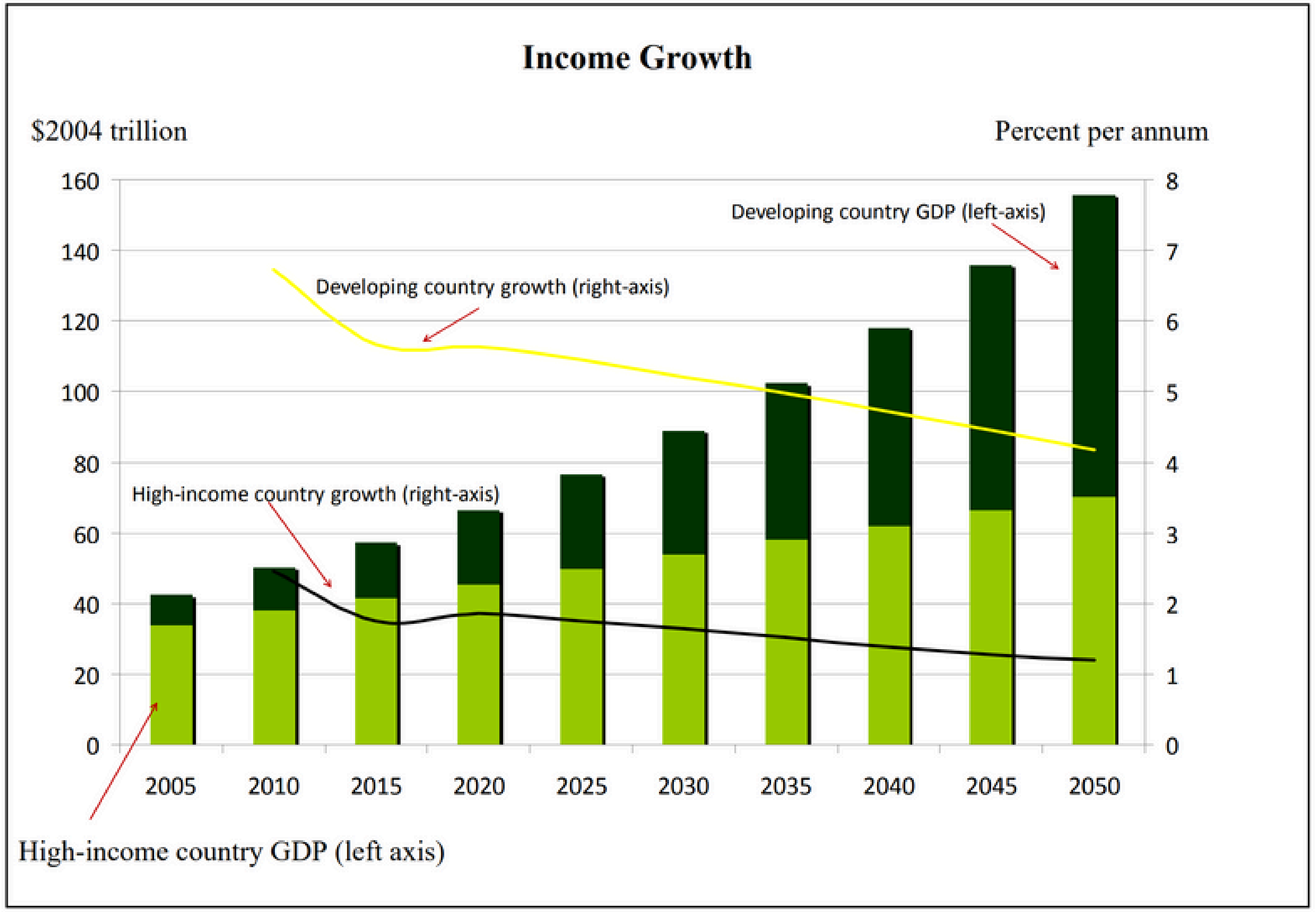


Source: FAO (2002)

FAO

Big picture - big challenge

Population dynamics and food production

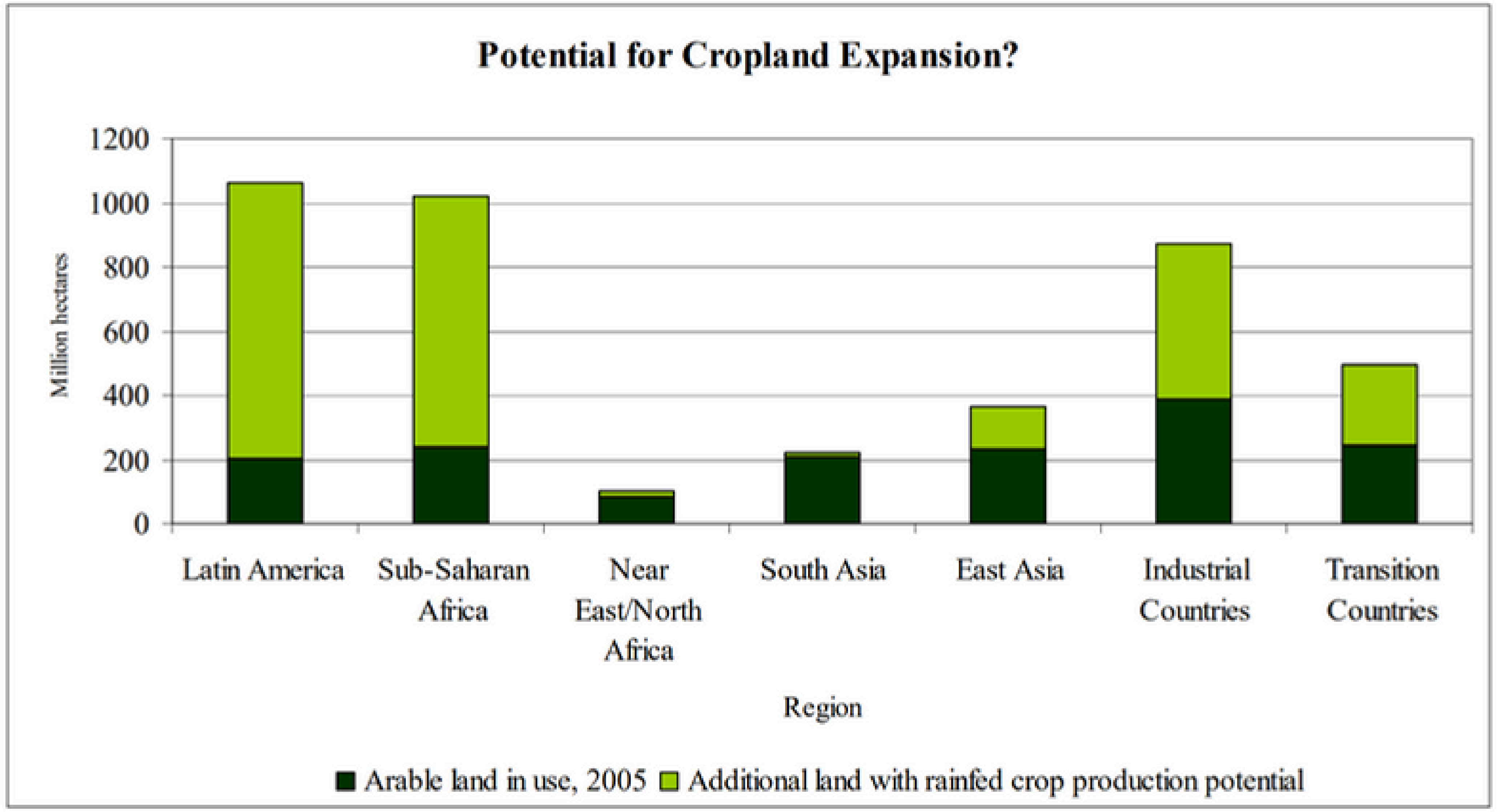


Source: Mensbrugghe et al. (2009)

FAO

Big picture - big challenge

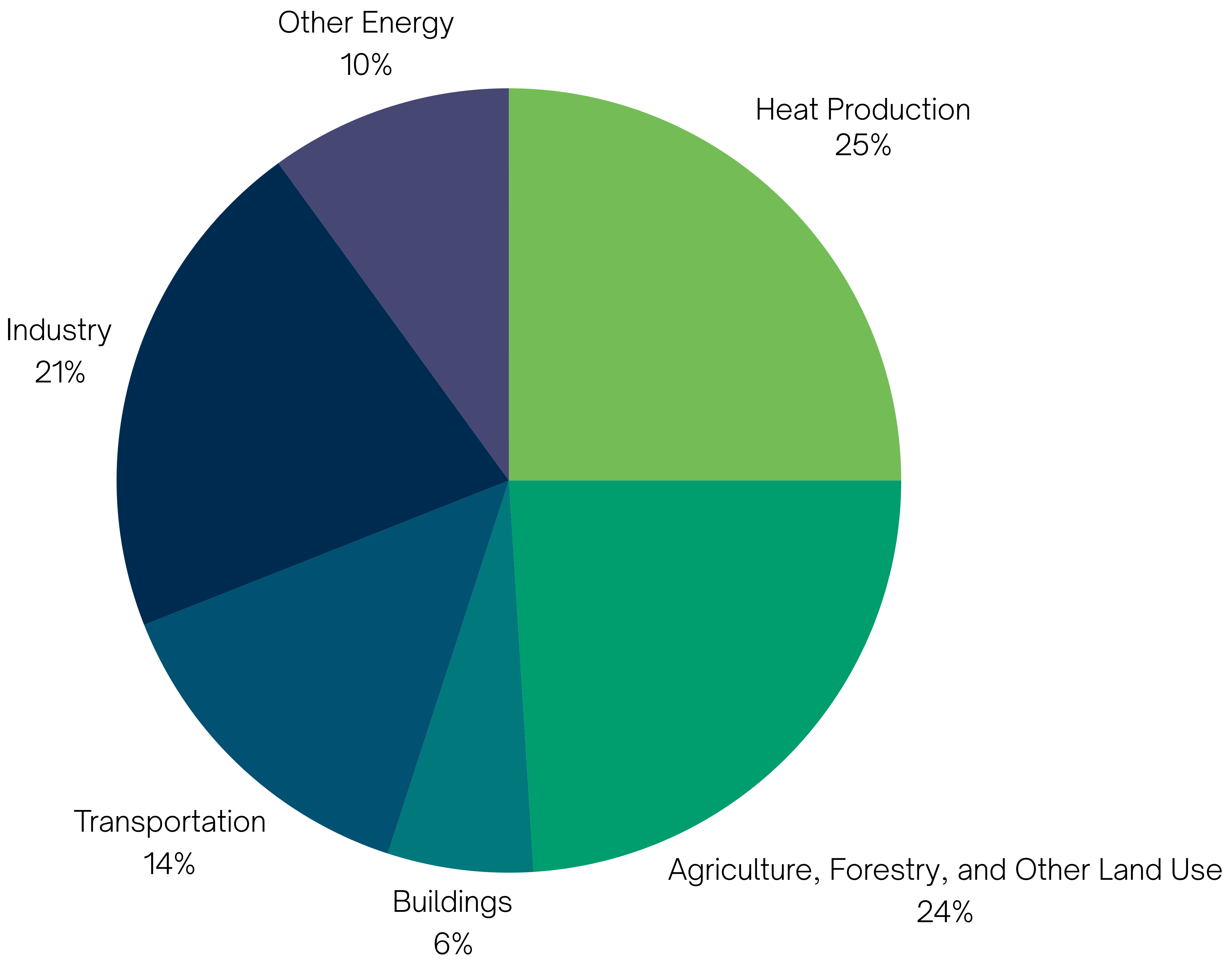
Population dynamics and food production



Source: Bruinsma (2009).

IPCC

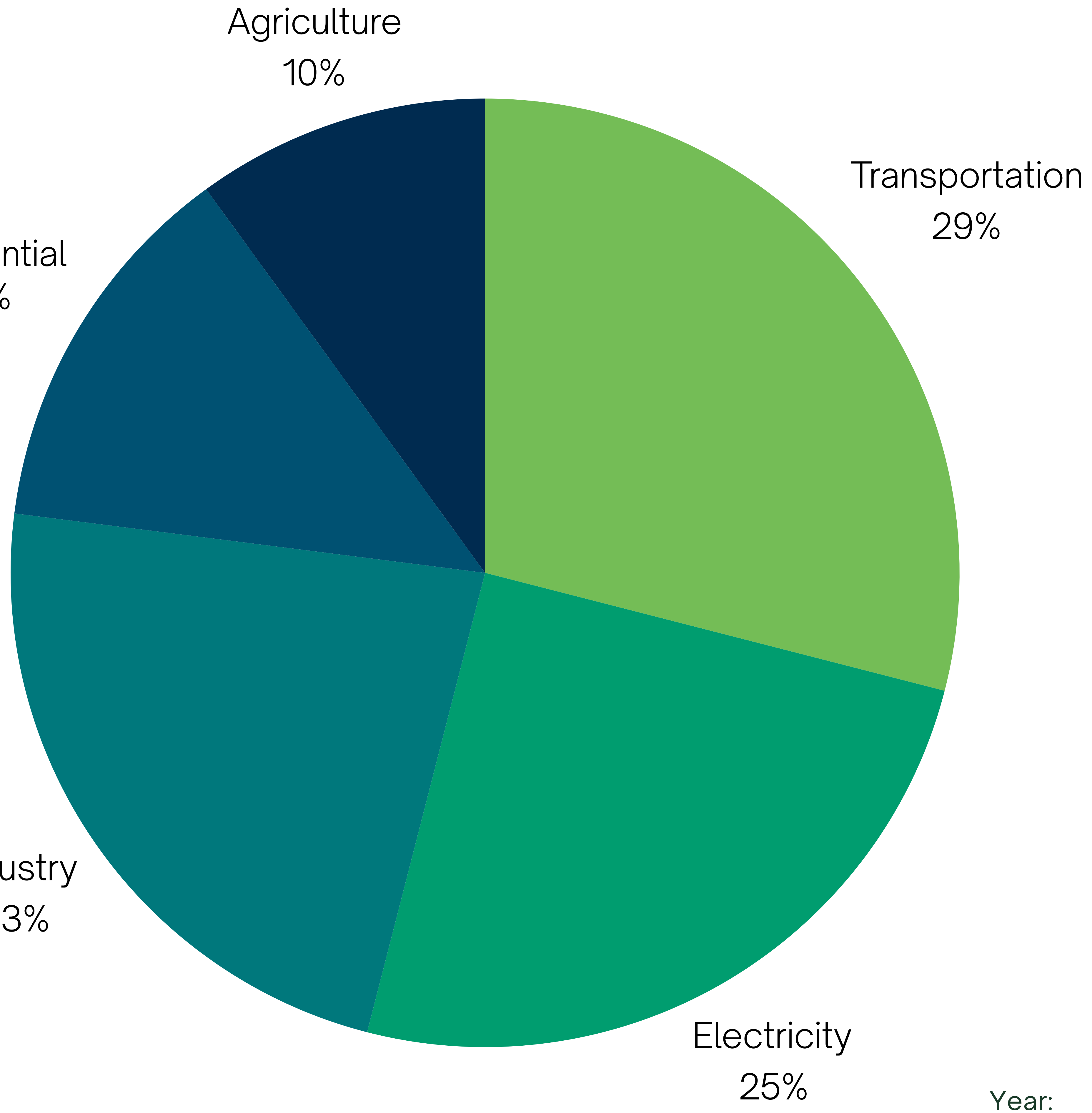
Global GHG Emissions by Economic Sector



Year:
2014

IPCC

Total US GHG emissions by economic sector in 2019

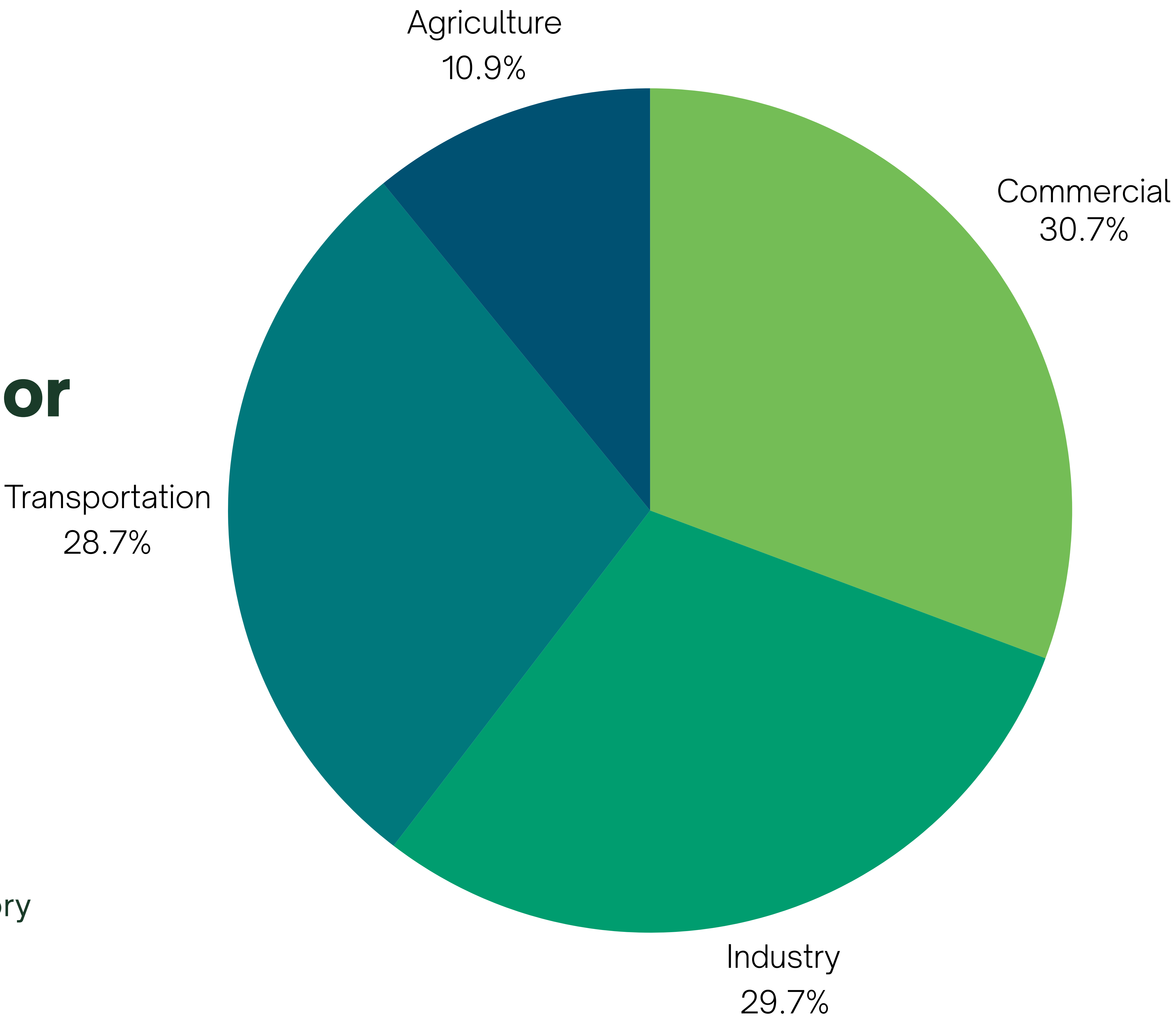


Total Emissions in 2019 = 6,558 Million Metric Tons of CO_2 equivalent. Percentage may not add up to 100% due to independent rounding

Year: 2019

IPCC

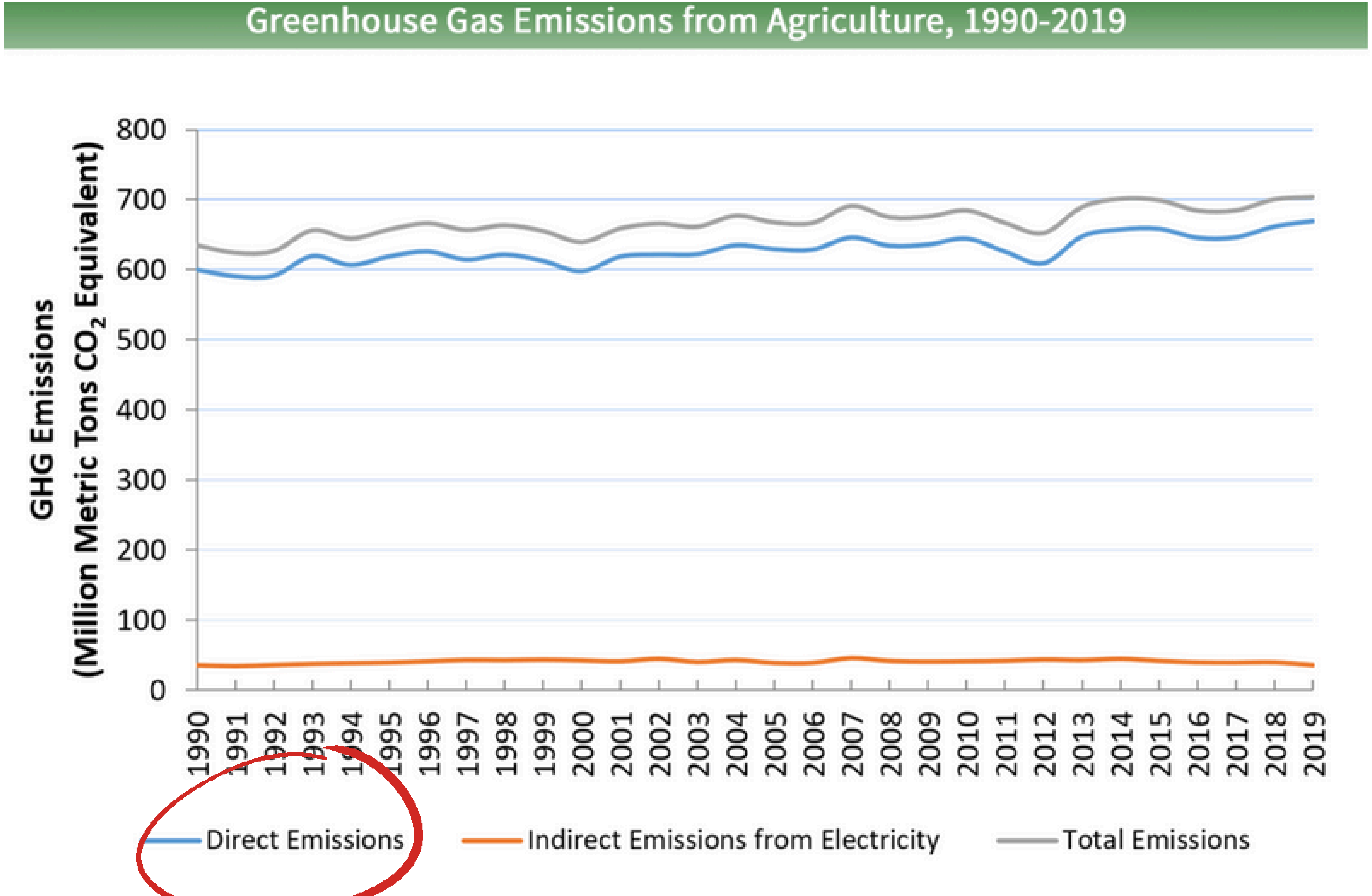
Total U.S. GHG Emissions by Sector with Electricity Distributed



All emission estimates from the Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019.

IPCC

Agriculture Sector Emissions



All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019.*

What are direct emissions in agriculture?

Carbon Dioxide

CO_2

- Carbon Cycle
- Liming
- Urea application

Methane

CH_4

- Carbon Cycle
- Enteric fermentation: Livestock (ruminants) digestive processes
- Manure management
- Crop burning

Nitrous Oxide

N_2O

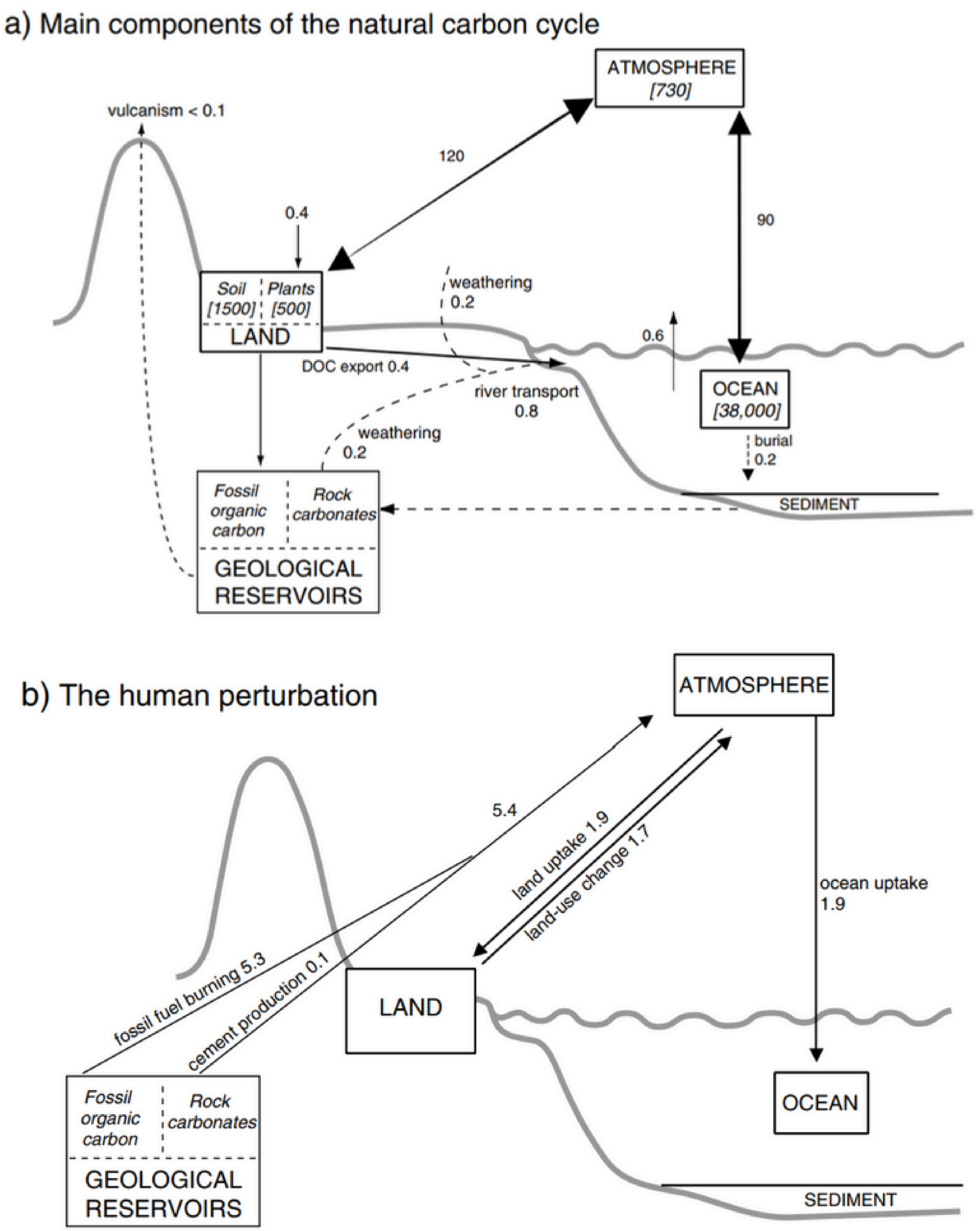
- Nitrogen Cycle
- Soil management practices
  - application of synthetic and organic fertilizers
  - growth of nitrogen-fixing crops
  - drainage of organic soils
  - irrigation practices
- Manure management
- Crop burning

IPCC

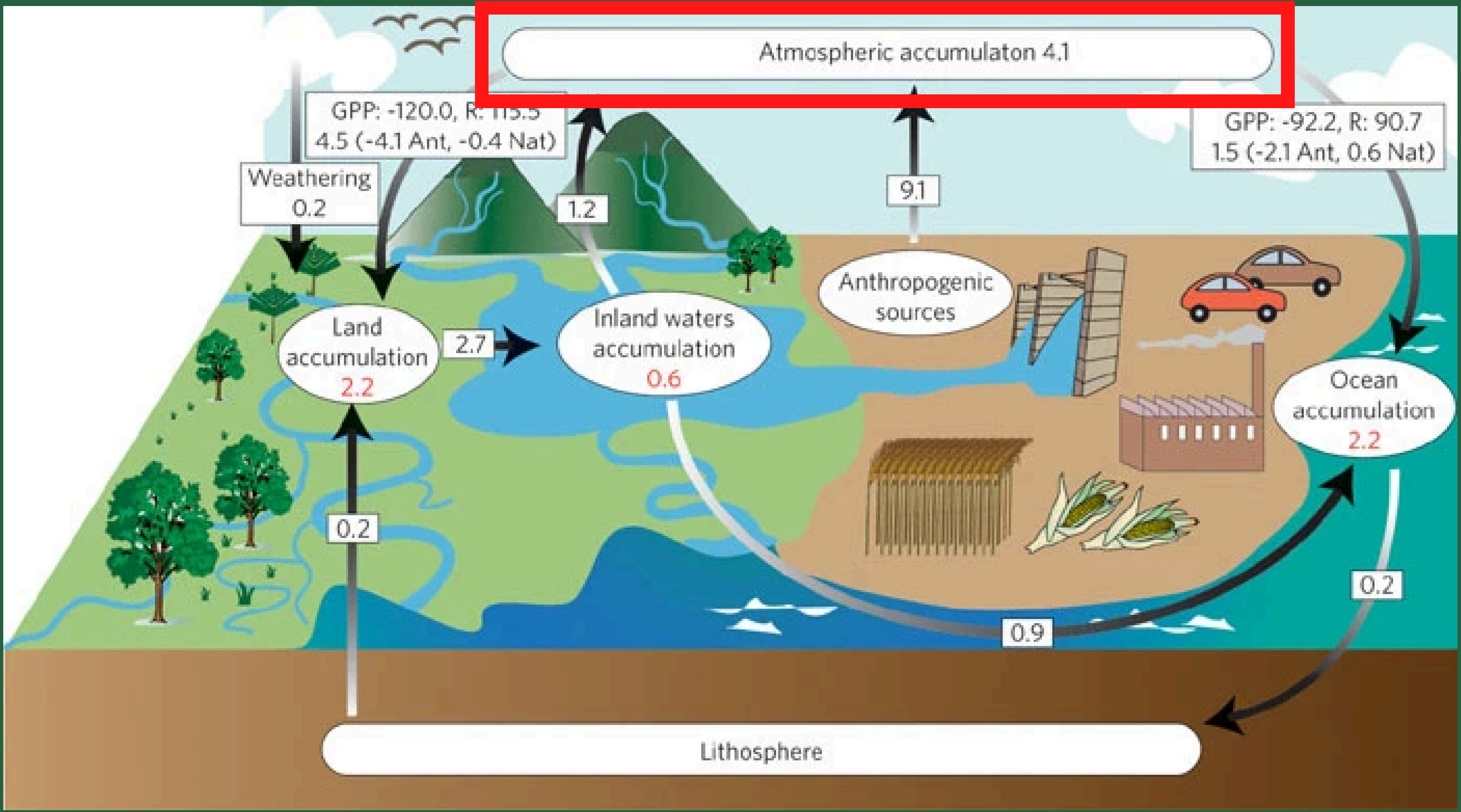
The Carbon Cycle

The carbon cycle dictates the flow of carbon on Earth. It has several components, drivers, and feedback loops.

There are three main sinks: the atmosphere, the oceans, and land. Long term carbon is also trapped in geological reservoirs.



Credit: IPCC

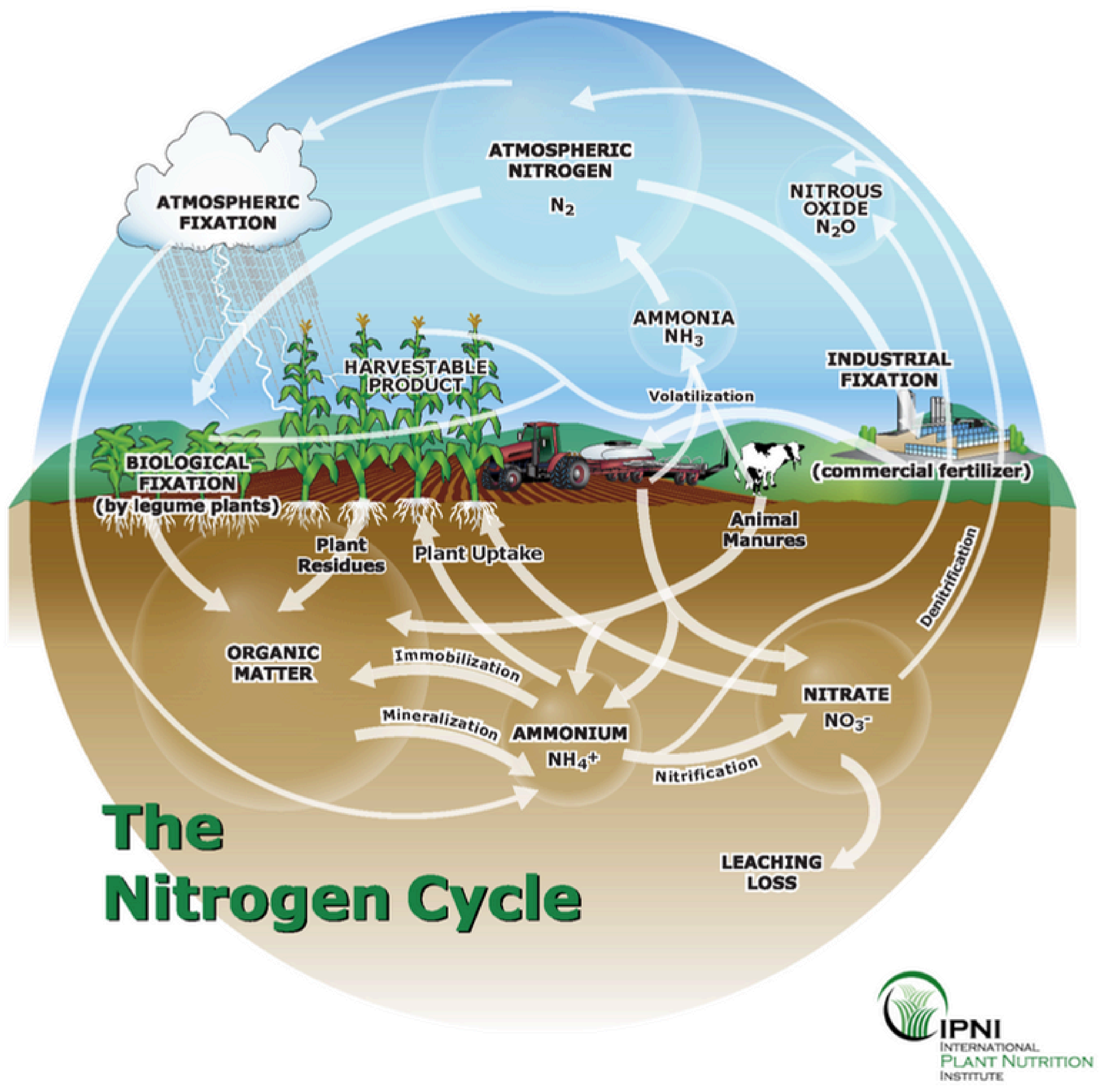


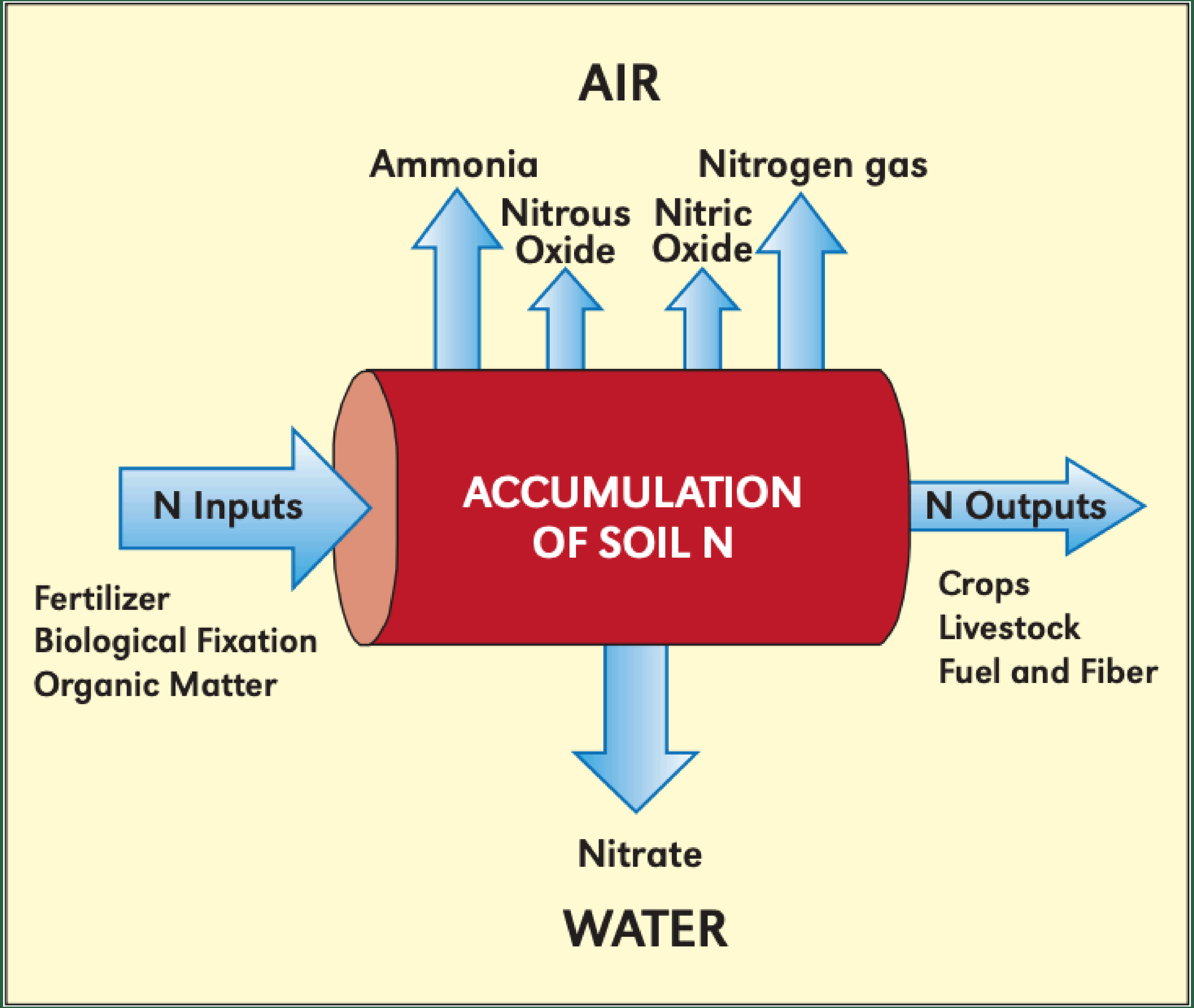
Battin, T., Luyssaert, S., Kaplan, L. et al. The boundless carbon cycle. Nature Geosci 2, 598–600 (2009). https://doi.org/10.1038/ngeo618

IPCC

The Nitrogen Cycle

- Nitrogen exists in the atmosphere as N2
- Nitrogen fixation - bacteria convert N2 into ammonia
    - Ammonia is useable by plants
- Nitrogen is a common limiting nutrient in agriculture
    - Fertilizer contains nitrogen --> runoff

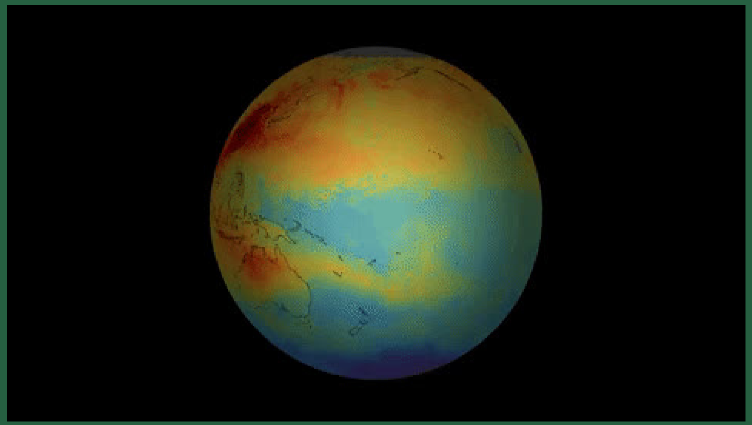



AIR
Ammonia
Nitrous Oxide
Nitric Oxide
Nitrogen gas
N Inputs
Fertilizer
Biological Fixation
Organic Matter
ACCUMULATION OF SOIL N
N Outputs
Crops
Livestock
Fuel and Fiber
Nitrate
WATER

IPNI

Part 2:

Global perspective



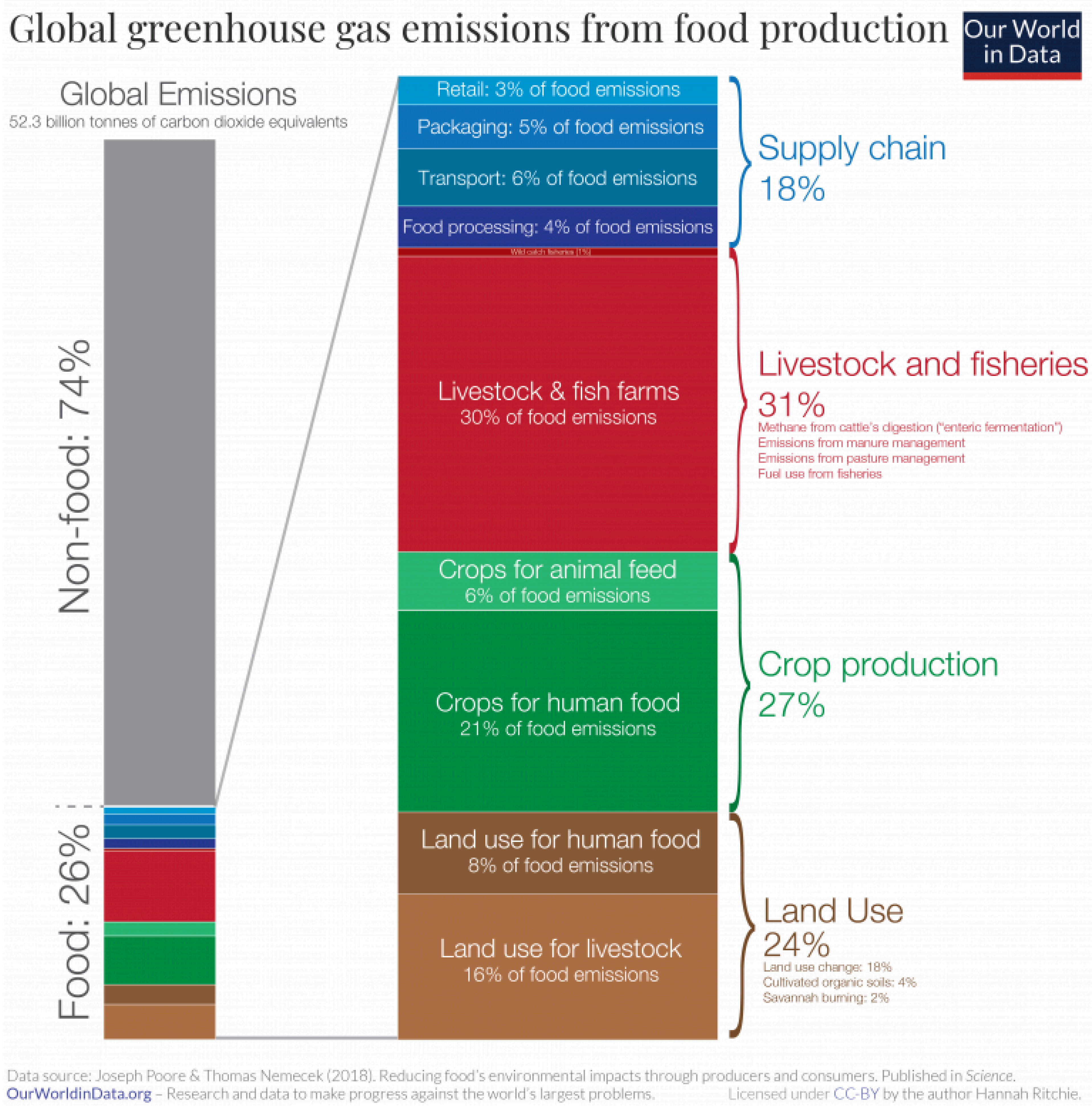
GHGs emissions distribution

Reducing food's environmental impacts through producers and consumers

Poore, J., & Nemecek, T. (2018)

Data were obtained from 1530 different studies spanning 139 authors, covering 38,700 commercially viable farms from 119 different countries.

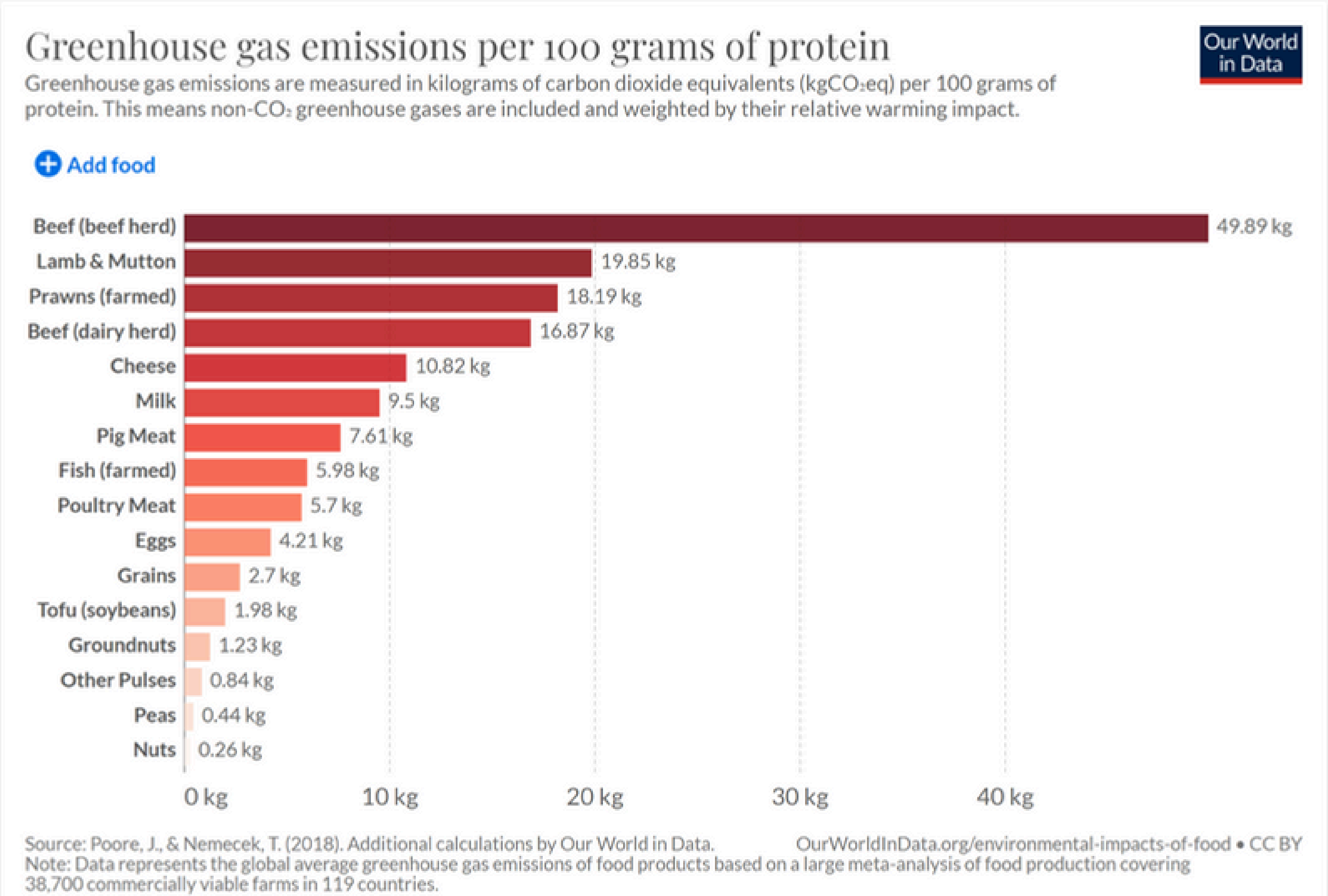
An approximate13.7 billion MtCO2(eq) are emitted from food production, with an additional 5% caused by non-food agriculture production and deforesetation.

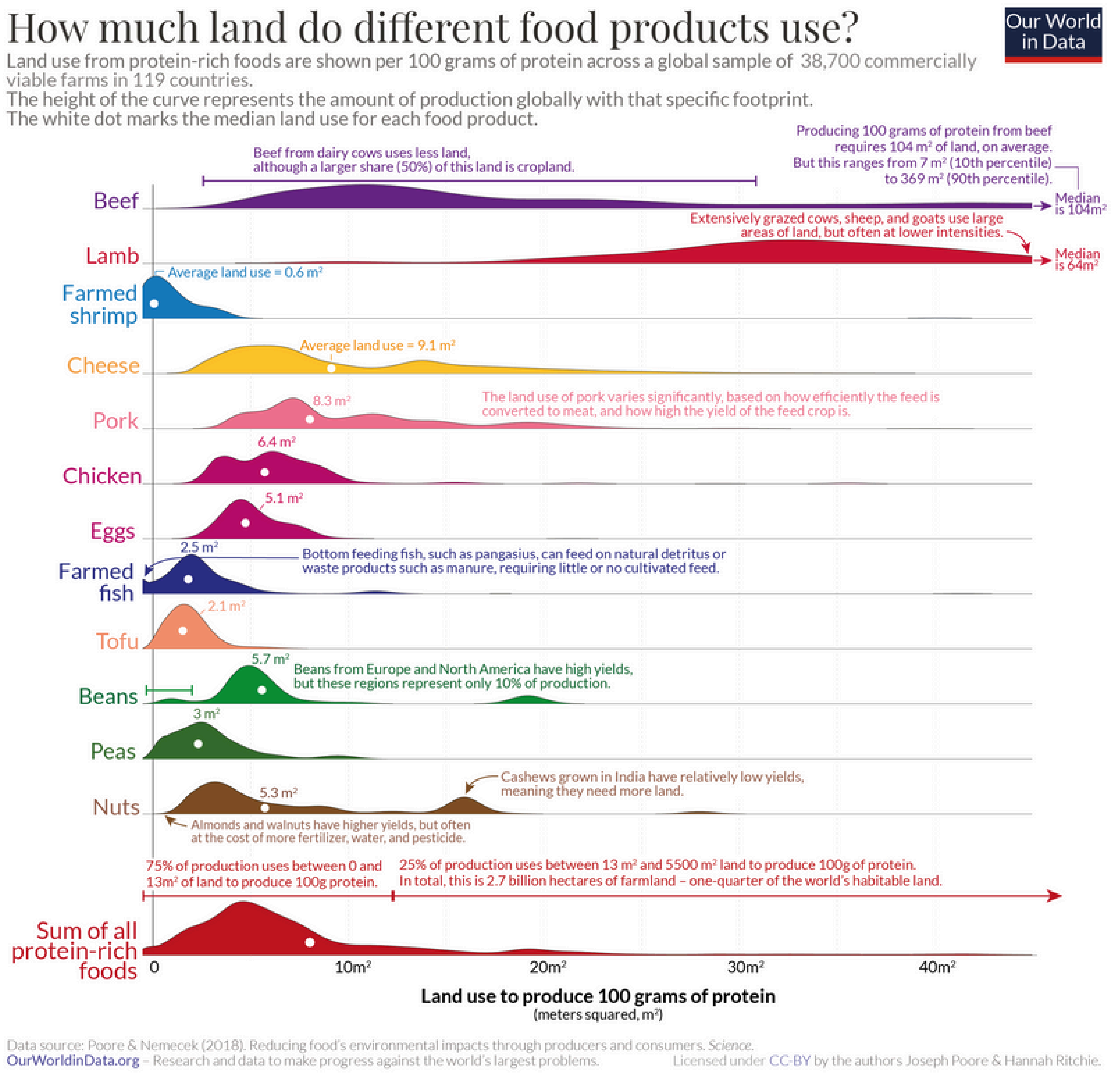


Land use, protein, and emissions

Reducing food's environmental impacts through producers and consumers

Poore, J., & Nemecek, T. (2018)





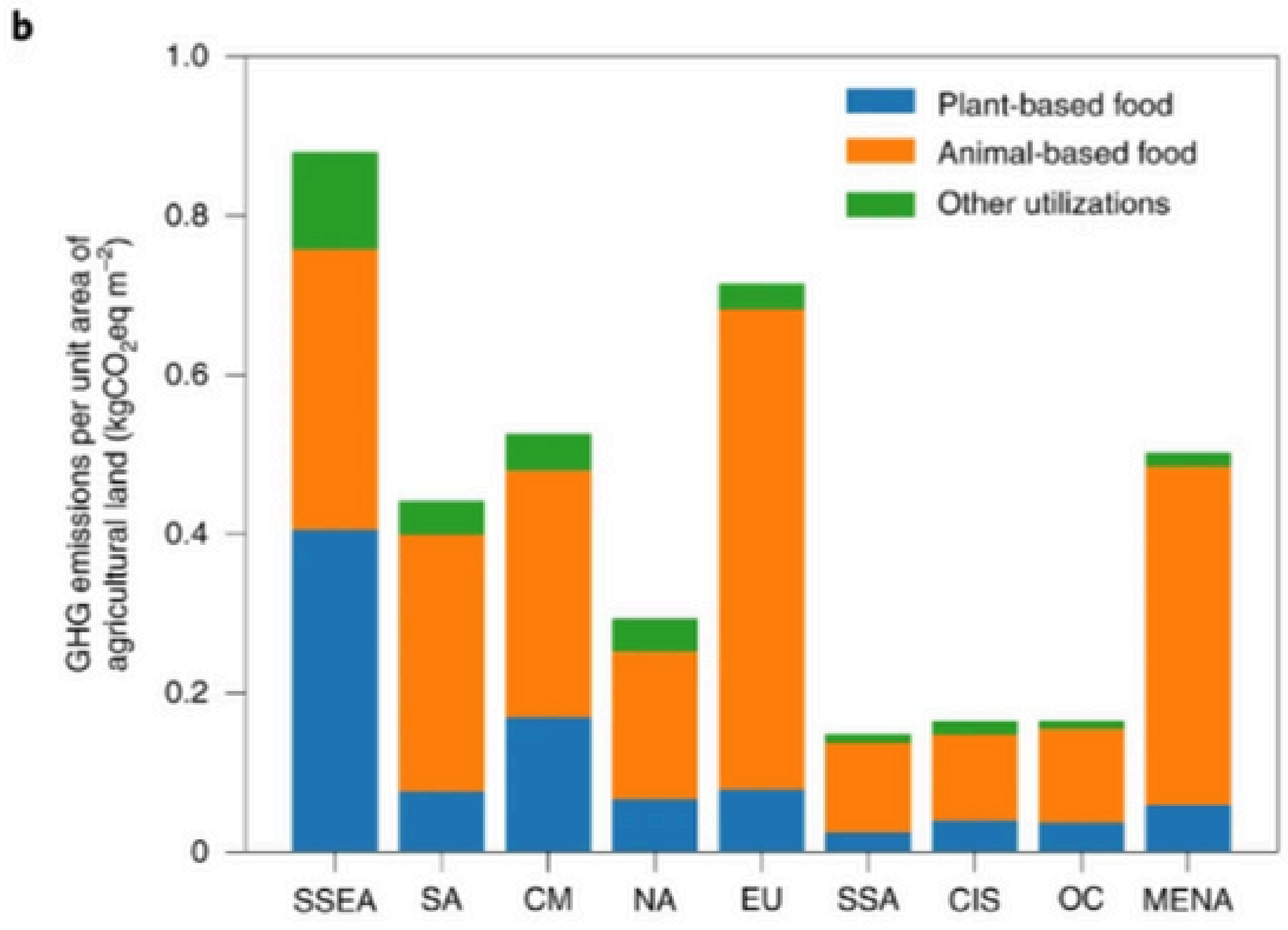
GHGs emissions distribution

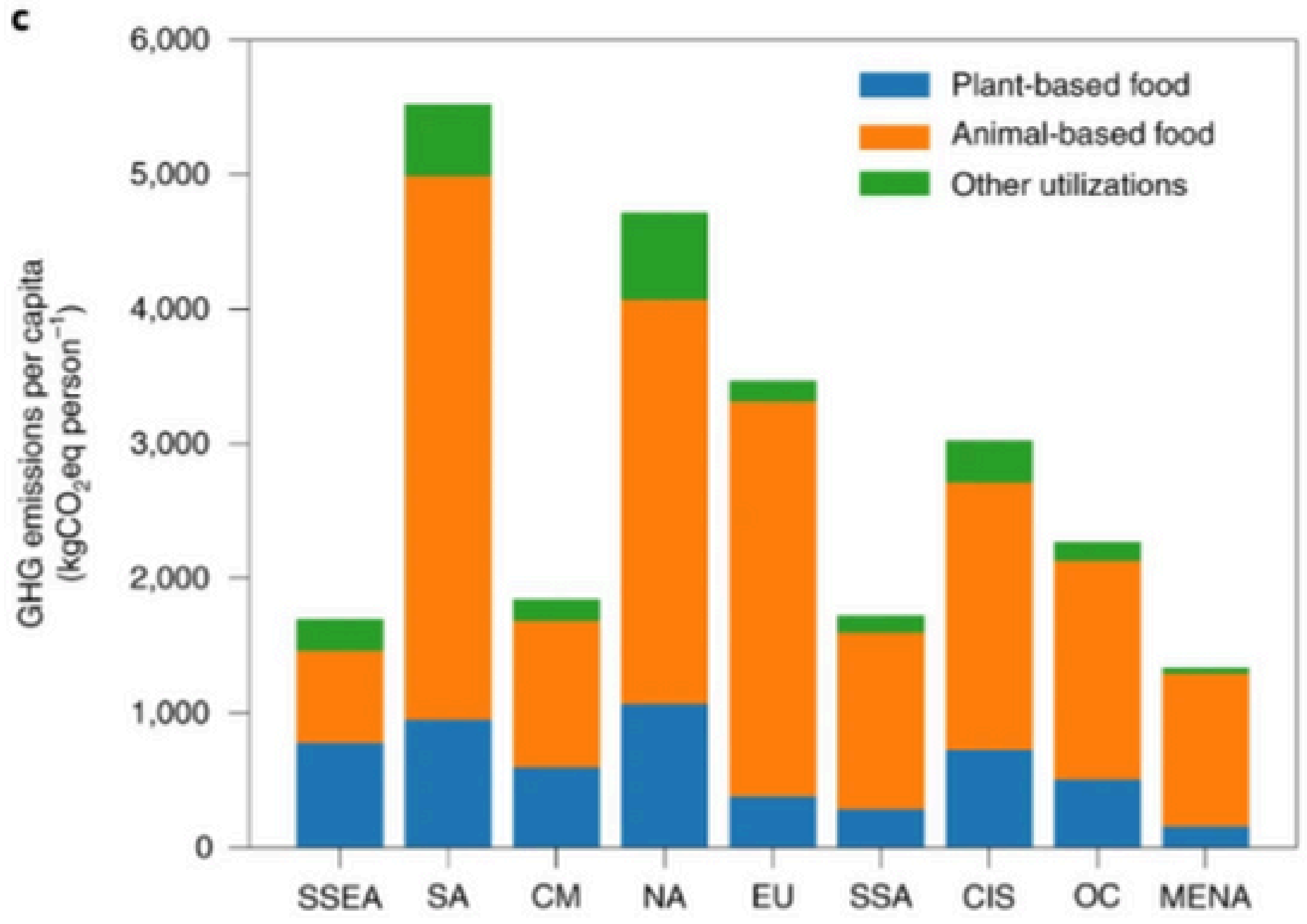
Global greenhouse gas emissions from animal-based foods are twice those of plant-based foods.

Xu, X., Sharma, P., Shu, S. et al. (2021)

This study found that GHGs emissions correspond to 17,318 ± 1,675 TgCO2eq yr−1, of which 57% come from the production of animal-based food (including livestock feed), 29% to plant-based foods, and 14% to other utilization. This represents roughly 35% - 37% of world emissions.

This represents 10% more than the estimates provided by IPCC, as well as those provided by the Poore and Nemecek study.





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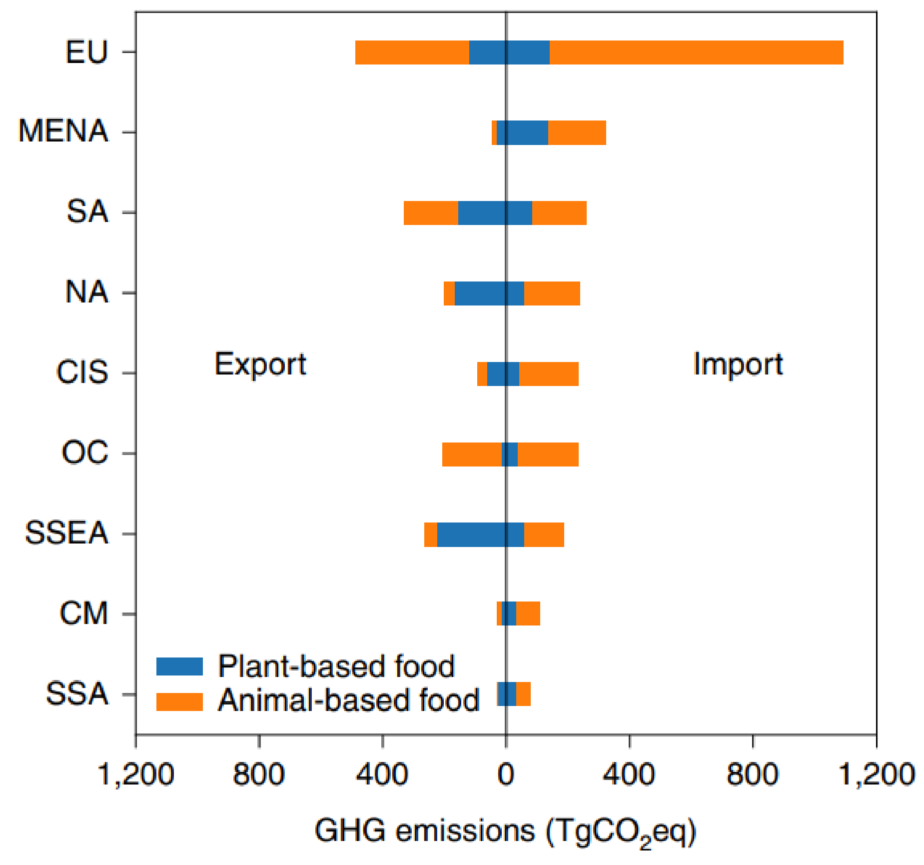


Fig. 5 | GHG emissions due to import and export of plant- and animal-based food in different regions. Animal-based food values include emissions from import and export of livestock feed.

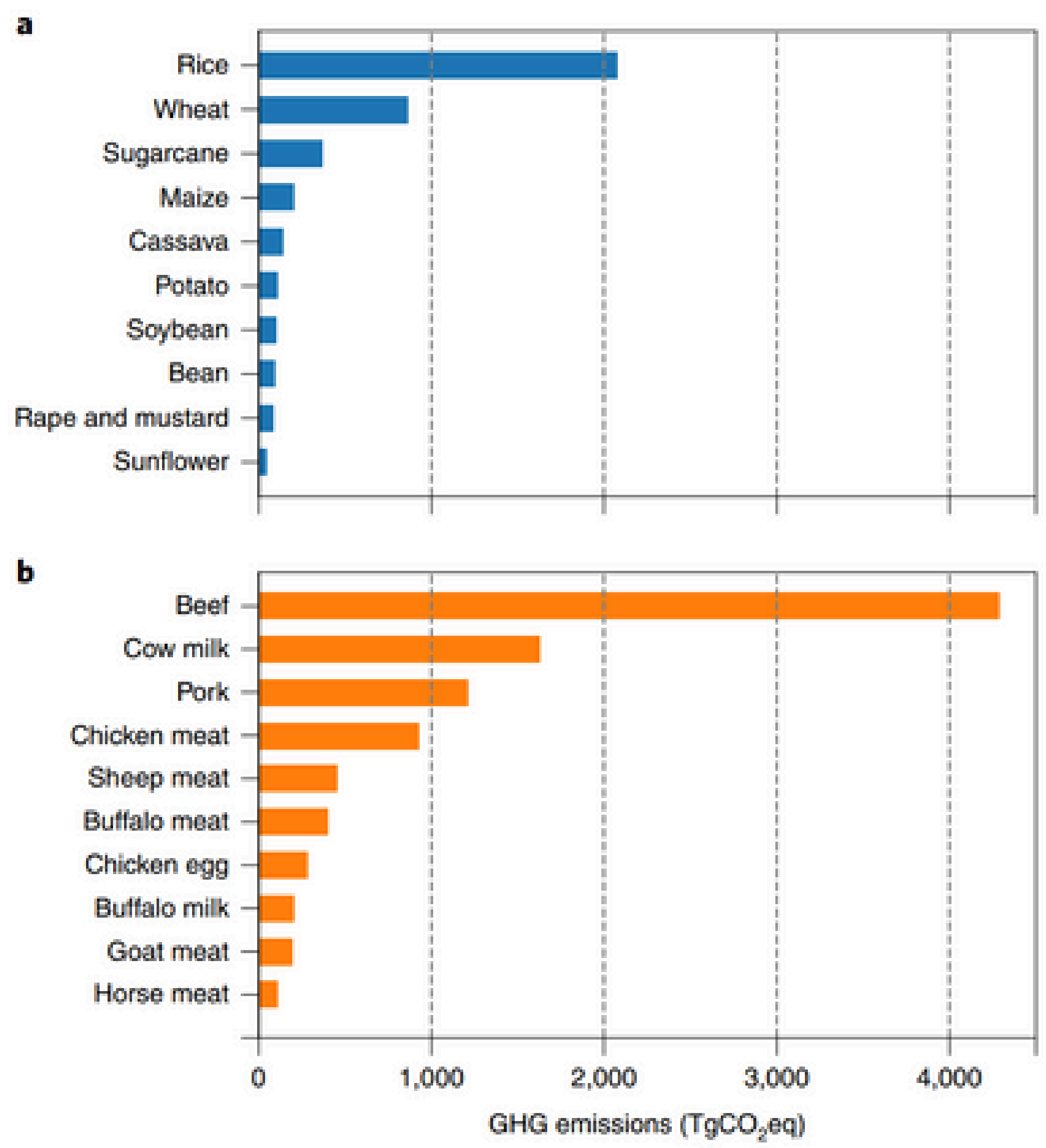


Fig. 3 | GHG emissions from the productions of top-contributing commodities. a, Top ten plant-based food commodities. **b**, Top ten animal-based food commodities.

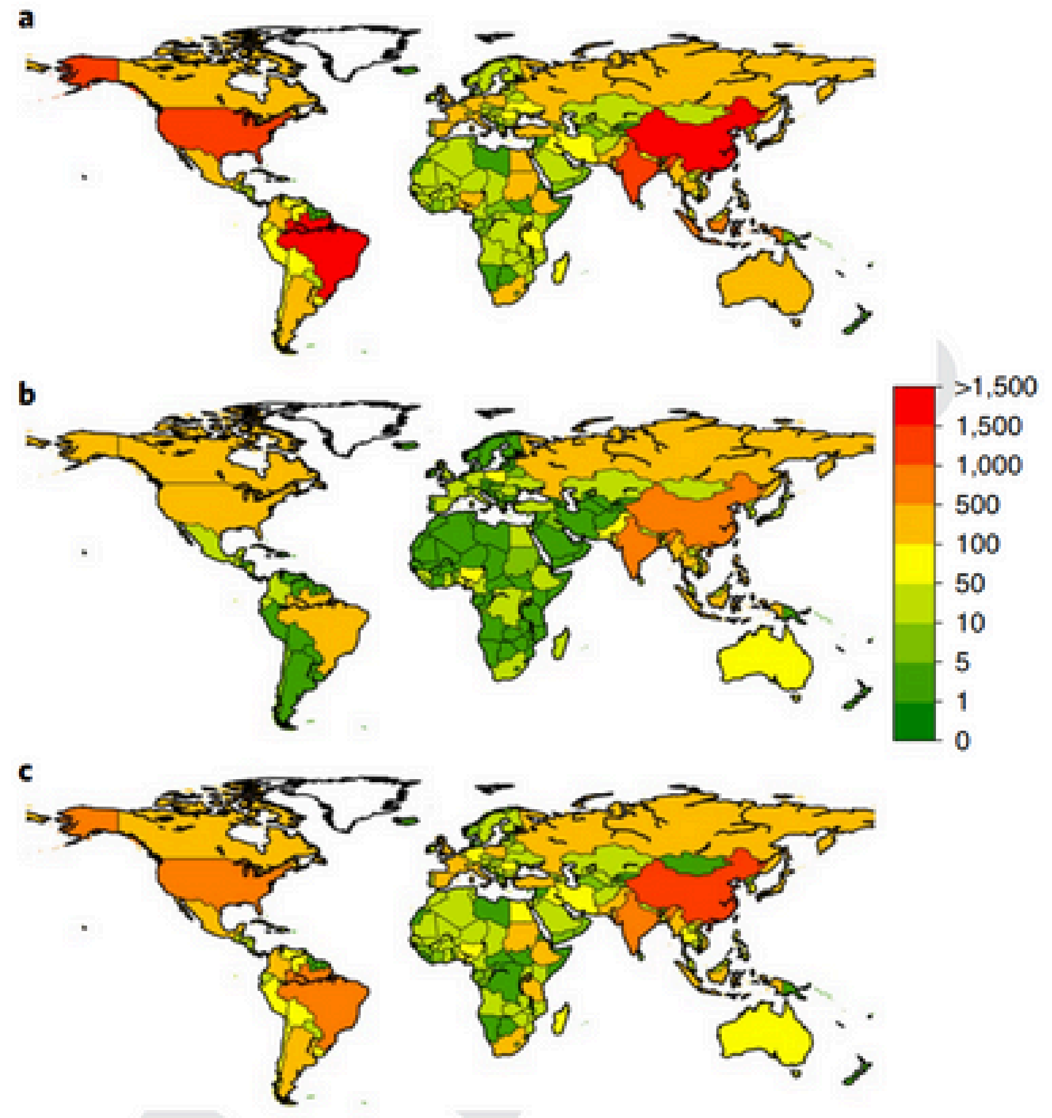


Fig. 4 | GHG emissions from food production at the country scale. a, Total emissions from food production. **b**, Emissions from plant-based food. **c**, Emissions from animal-based food. Values are expressed in $TgCO_2eq$.

Part 3:

Emissions, diet and the US

U.S. Agriculture Emissions

Cropland soils - N_2O

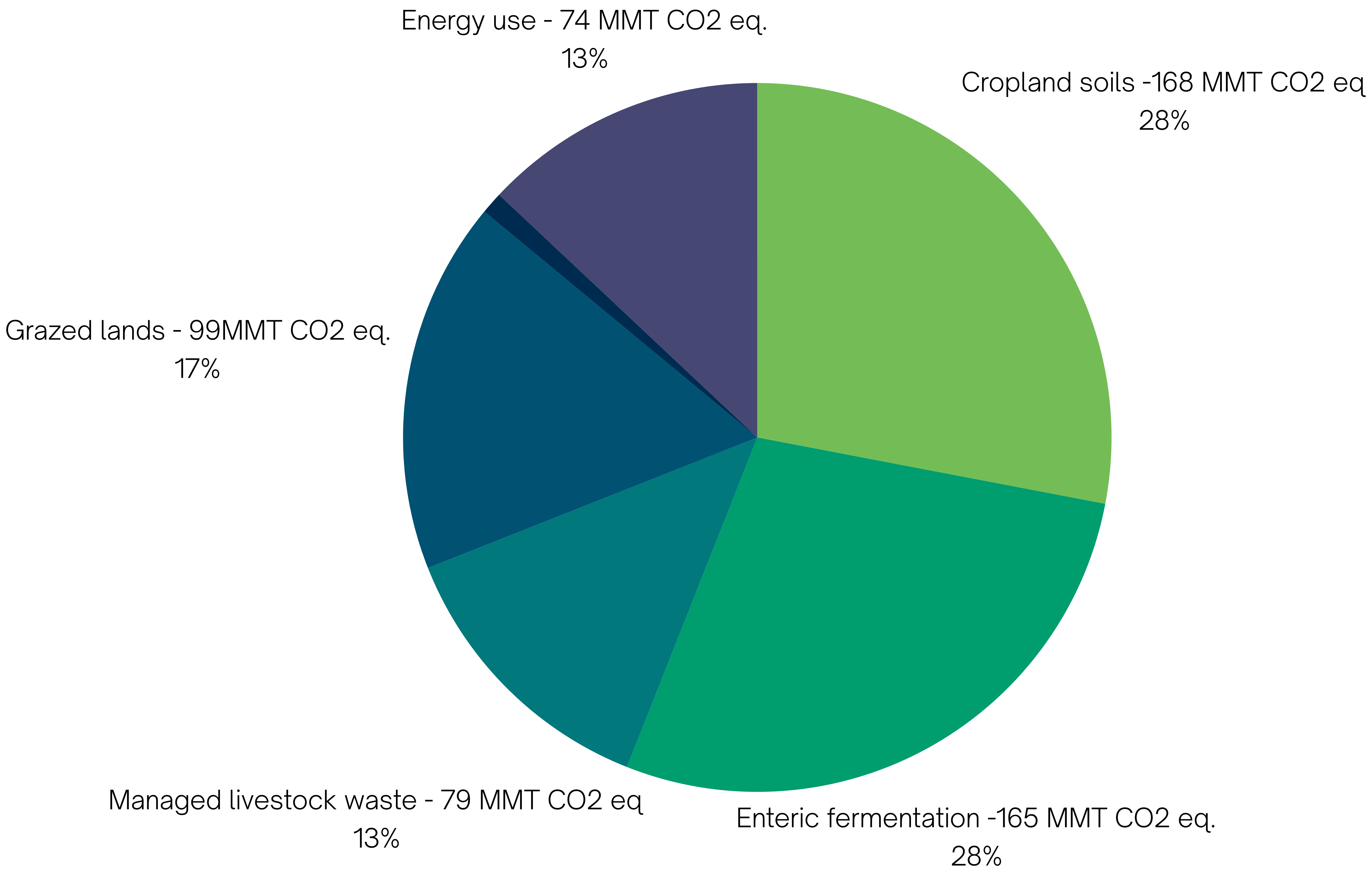
Enteric fermentation - CH_4

Managed Livestock Waste - CH_4, N_2O

Grazed lands - CH_4, N_2O

Rice cult. & residue burning - CH_4, N_2O

Energy Use - CO_2



Based on USDA 2013 Data

GHG emissions from different natural environments

CH_4			
Global source	**GHG emissions**	**Units**	**References**
Ocean	6-12	Tg CH_4 yr^{-1}	[13]–[15]
Inland Waters (e.g. lakes, ponds, reservoirs, streams, rivers)	209		[13], [15]–[17]
Wetlands (e.g. bogs, fens, swamps, marshes, floodplains)	142-284		[15]–[18]
Soils	9-55		[15]–[17], [19]
Total	463 (366-560)		
N_2O			
Global source	**GHG emissions**	**Units**	**References**
Ocean	2.5-4.5	Tg N yr^{-1}	[20], [21]
Inland Waters	0.3-0.4		[21]
Soils	6-7		[20], [21]
Total	10.4 (8.8-11.9)		

Althouse et al., 2022 (pending)

GHG emissions from soil: microbial processes associated with GHGs

Methanogenesis		
Biological Process	**Reaction(s)**	
Acetoclastic methanogenesis	$CH_3CHOOH \rightarrow CO_2 + CH_4$	(1)
Methylotrophic methanogenesis	$4CH_3OH \rightarrow 3CH_4 + CO_2 + 2H_2O$	(2)
Hydrogenotrophic methanogenesis	$4H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O$	(3)
Nitrification		
Oxidation of Ammonia to Nitrite (AOB)	$NH_3 + O_2 \rightarrow NO_2^- + 3H^+ + 2e^-$	(4)
Oxidation of Nitrate from Nitrite (NOB)	$NO_2^- + 0.5O_2 \rightarrow NO_3^- + 2H^+$	(5)
Complete nitrification	$NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$	(6)
Denitrification		
Pathways	$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$	(7)
Complete denitrification	$2NO^{3-} + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$	(8)

Althouse et al., 2022 (pending)

GHG emissions from crop production

Review of greenhouse gas emissions from crop production systems and fertilizer management effects
Snyder et al. (2009)

Comparison of selected agricultural cropping systems for net global warming potential (GWP)

Cropping system	GWP in CO_2 equivalents (kg ha^{-1} $year^{-1}$)							Food yield[a] (Gcal ha^{-1} $year^{-1}$)	Mean crop yields (t ha^{-1})		
	Soil C[b]	N fert.[c]	Lime	Fuel	N_2O	CH_4	Net GWP		Corn	Wheat	Soybean
Robertson et al. (2000)—Michigan (9-year study)											
Corn–soybean–wheat rotation											
Conventional tillage	0	270	230	160	520	−40	1140	12	5.3	3.2	2.1
No-till	−1100	270	340	120	560	−50	140	13	5.6	3.1	2.4
Low-input with legume cover crop	−400	90	190	200	600	−50	630	12	4.5	2.6	2.7
Organic with legume cover crop	−290	0	0	190	560	−50	410	9	3.3	1.6	2.7
Perennial crops											
Alfalfa	−1610	0	800	80	590	−60	−200				
Poplar	−1170	50	0	20	100	−50	−1050				
Late succession forest	0	0	0	0	210	−250	−40				
Adviento-Borbe et al. (2007)—Nebraska (6-year study: non-inversion deep till system)											
Continuous corn at BMP	−1613	807	220	1503	1173	−110	1980	48	14.0		
Continuous corn—intensive	−2273	1210	330	1833	2090	−110	3080	51	15.0		
Corn–soybean rotation at BMP	1100	293	220	1283	917	−73	3740	35	14.7		4.9
Corn–soybean rotation—intensive	−73	660	330	1613	1247	−37	3740	37	15.6		5.0

[a] Food energy calculated from crop yields and USDA national nutrient database http://riley.nal.usda.gov/NDL/index.html.
[b] Estimate of net soil C storage are based on change in soil C measured to a depth of 7.5 cm in the Michigan study and 30 cm in the Nebraska study. Shallower sampling depths tend to upwardly bias the C sequestration estimates in no-till systems.
[c] Estimated GWP associated with fertilizer N manufacture and transport was 4.51 kg CO_2 kg^{-1} N in the MI study and 4.05 in the Nebraska study.

GHG emissions from fertilizer

Review of greenhouse gas emissions from crop production systems and fertilizer management effects
Snyder et al. (2009)

Estimates of N2O emissions from cropland in the US, Canada and the world in 1995

Region	Area (million ha)	Fertilizer N applied (million t)	Animal manure N applied (million t)	N_2O-N emitted		
				Total (million t)	Fertilizer-induced[a]	
					Million t	% of total
Canada	46	1.58	0.21	0.067	0.016	24
U.S.	190	11.15	1.58	0.316	0.112	35
World	1436	73.48	20.66	3.150	0.735	23

[a] Estimated using IPCC emission factor of 1%.

Livestock and GHGs

Greenhouse Gas Emissions in the United States Food System: Current and Healthy Diet Scenarios

Claudia Hitaj, Sarah Rehkamp, Patrick Canning, and Christian J. Peters (2019)

units		soil management	enteric fermentation	manure management	fossil fuel combustion	total
grams of CO_2eq per gram of retail food weight	beef	22.05	18.26	1.38	4.96	46.66
	pork	1.77	0.31	3.23	9.46	14.77
	turkey	1.57	0.00	0.23	7.12	8.92
	chicken	1.61	0.00	0.23	5.92	7.76
	dairy	0.31	1.31	1.14	2.02	4.78
	eggs	0.88	0.00	0.62	2.29	3.79
grams of CO_2eq per gram of protein	beef	110.19	91.26	6.92	208.37	416.74
	pork	10.39	1.82	18.96	31.17	62.33
	turkey	7.25	0.00	1.05	8.31	16.61
	chicken	8.77	0.00	1.24	10.02	20.03
	dairy	5.33	22.32	19.31	46.97	93.93
	eggs	7.02	0.00	4.93	11.95	23.90

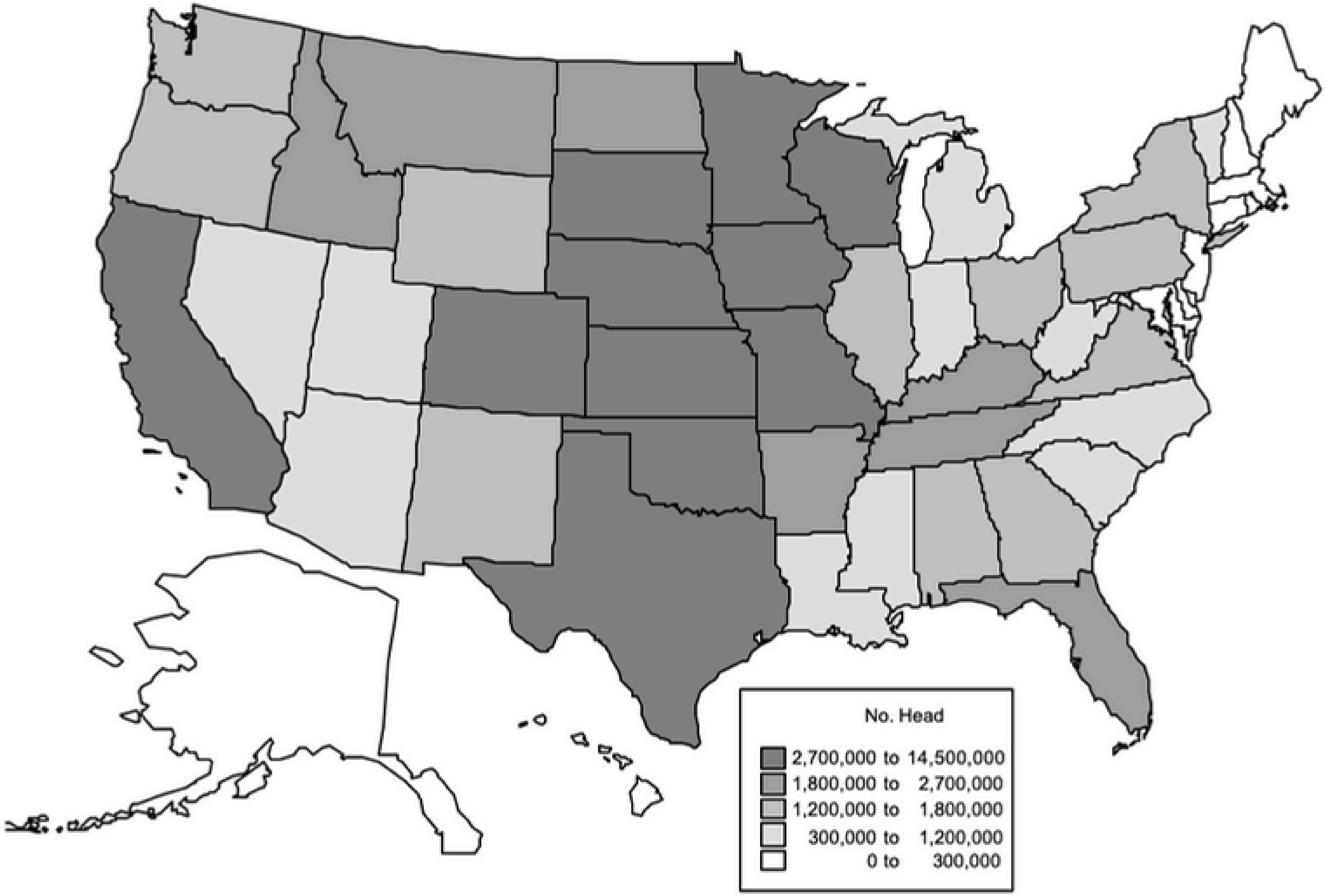
GHG emissions from livestock production for the Baseline Diet in grams CO2 eq per gram retail food weight and grams CO2 eq per gram of protein

Cattle and GHGs

Development of an Emissions Model to Estimate Methane from Enteric Fermentation in Cattle

Mangino J., Peterson K., and Jacobs, H. (2003)

US Cattle Population as of 2001



Cattle and GHGs

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Equation (1) $\text{DayEmit} = [GE \times Y_m] / [55.65 \text{ MJ/kg } CH_4]$

where

DayEmit	=	emission factor (kg CH_4/head/day)
GE	=	gross energy intake (MJ/head/day)
Y_m	=	methane conversion rate which is the fraction of gross energy in feed converted to methane (percent)

Cattle and GHGs

Development of an Emissions Model to Estimate Methane from Enteric Fermentation in Cattle

Mangino J., Peterson K., and Jacobs, H. (2003)

2001 U.S. methane emissions by cattle type (Gg)

Cattle Type	California	West	Northern Great Plains	South-central	Northeast	Midwest	South-east	Total[a]
Dairy	**208**	**192**	**60**	**65**	**234**	**426**	**97**	**1,282**
Cows	166	164	50	55	192	348	79	1,055
Replacements 0-12 months	9	6	2	2	9	17	4	48
Replacements 12-24 months	33	21	8	7	33	62	14	179
Beef[b]	**94**	**348**	**1,197**	**932**	**56**	**547**	**544**	**3,936**
Cows	58	236	682	654	38	351	473	2,492
Replacements 0-12 months	1	6	16	12	1	8	9	54
Replacements 12-24 months	5	24	60	45	4	28	34	200
Steer Stockers	14	35	152	81	6	67	17	372
Heifer Stockers	4	17	104	48	3	32	8	215
Feedlot Cattle	12	30	183	91	3	62	2	384
Bulls[b]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	219
Total	**302**	**540**	**1,257**	**996**	**290**	**973**	**642**	**5,218**

[a] Totals may not sum due to independent rounding.

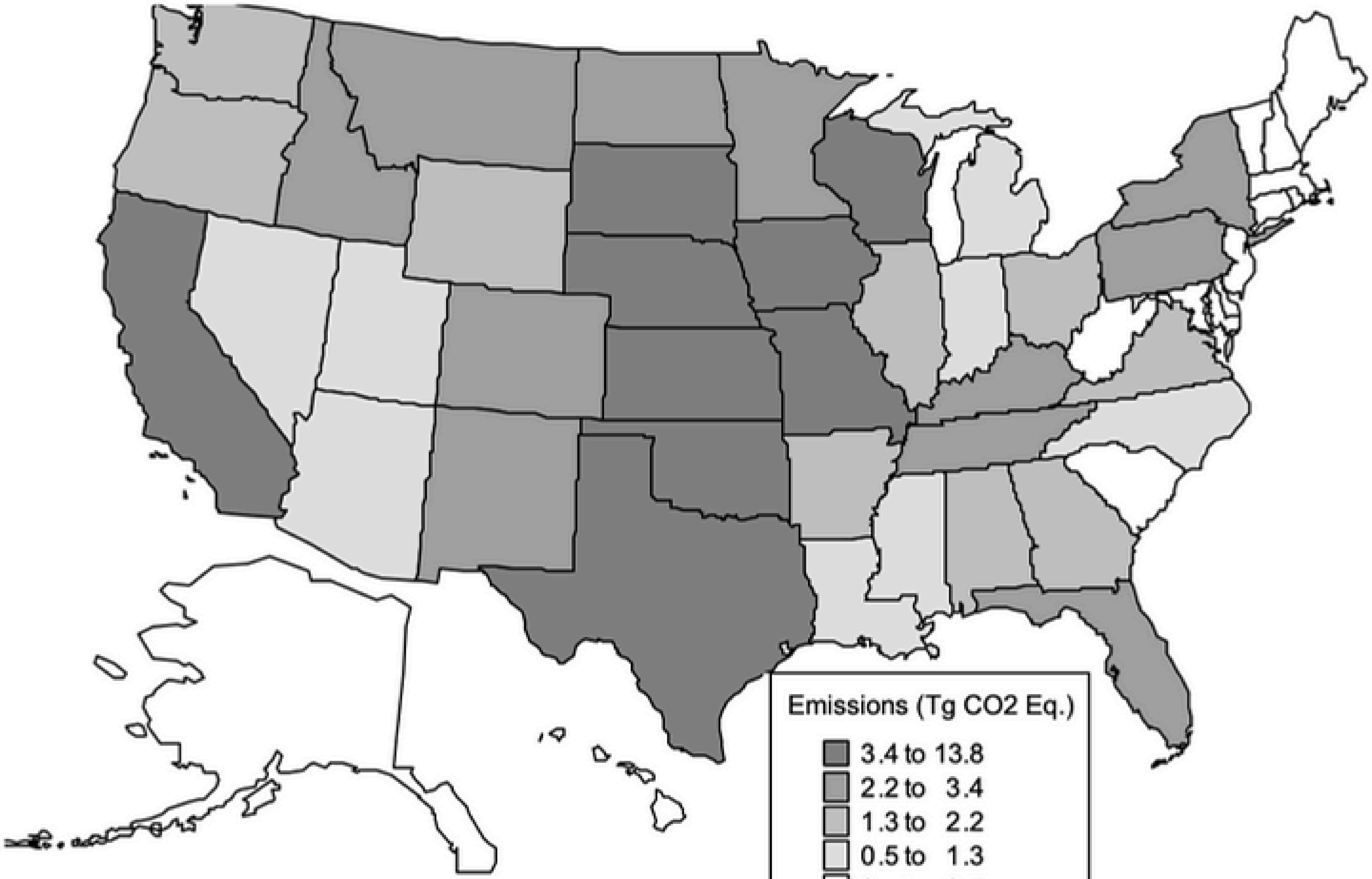
[b] Bull statistics were only modeled at the national level and are not included in the regional totals.

Cattle and GHGs

Development of an Emissions Model to Estimate Methane from Enteric Fermentation in Cattle

Mangino J., Peterson K., and Jacobs, H. (2003)

Methane emissions from cattle in the United States, 2001



How do our dietary choices impact emissions?

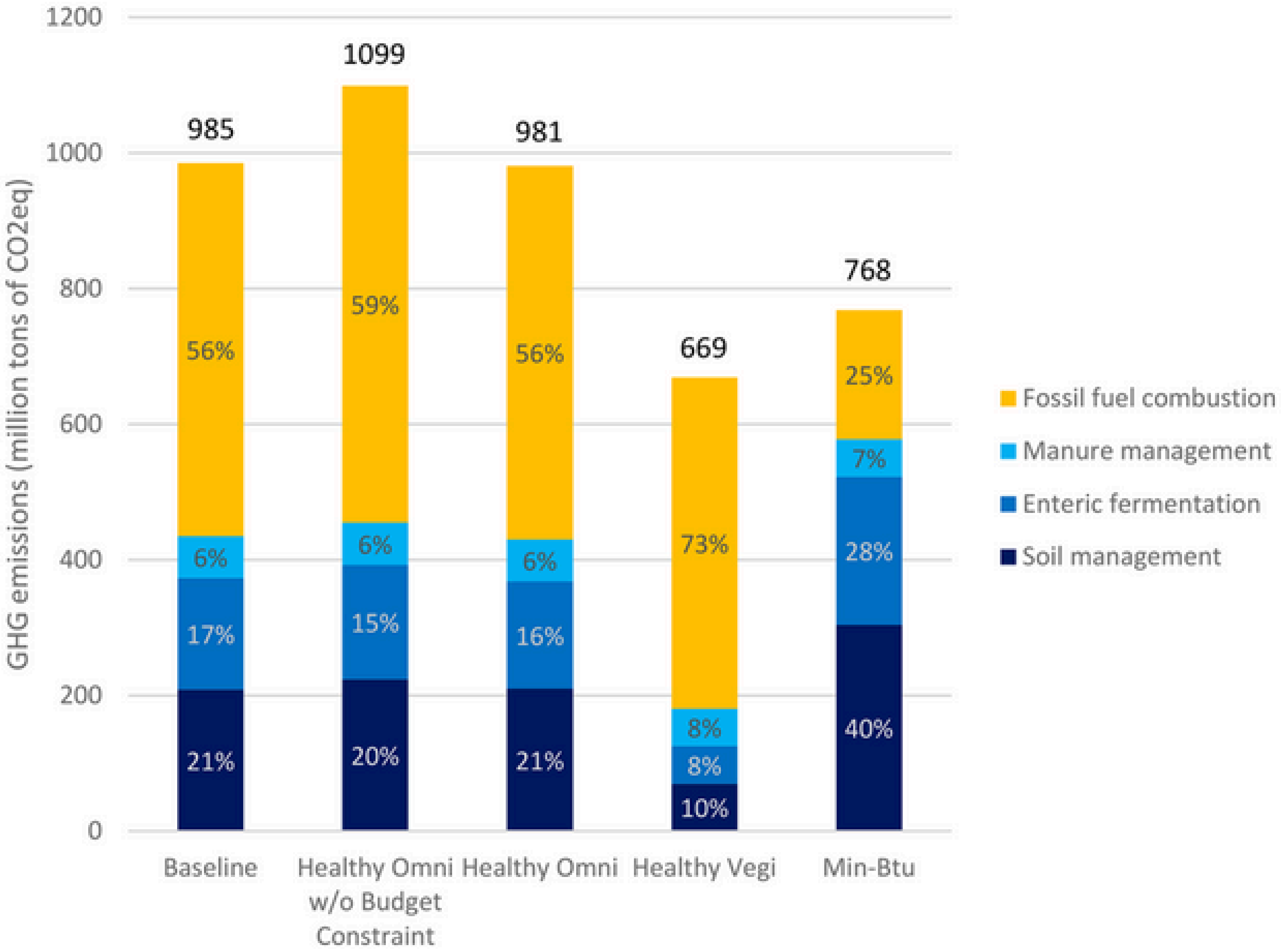
Emission Impacts from Dietary Choices

Greenhouse Gas Emissions in the United States Food System: Current and Healthy Diet Scenarios

Claudia Hitaj, Sarah Rehkamp, Patrick Canning, and Christian J. Peters (2019)

GHG emissions for different diet scenarios, organized by emissions

	model objective function	model constraints
healthy omni w/o budget constraint	minimize difference from baseline	calories, nutrients, USDA food patterns
healthy omni	minimize difference from baseline	calories, nutrients, USDA food patterns, cost
healthy vegi	minimize difference from baseline	calories, nutrients, lacto-ovo vegetarian adaptation of USDA food patterns, cost
min-Btu	minimize energy (Btu) in food production	calories, nutrients, USDA food patterns, cost



Greenhouse Gas Emissions in the United States Food System: Current and Healthy Diet Scenarios

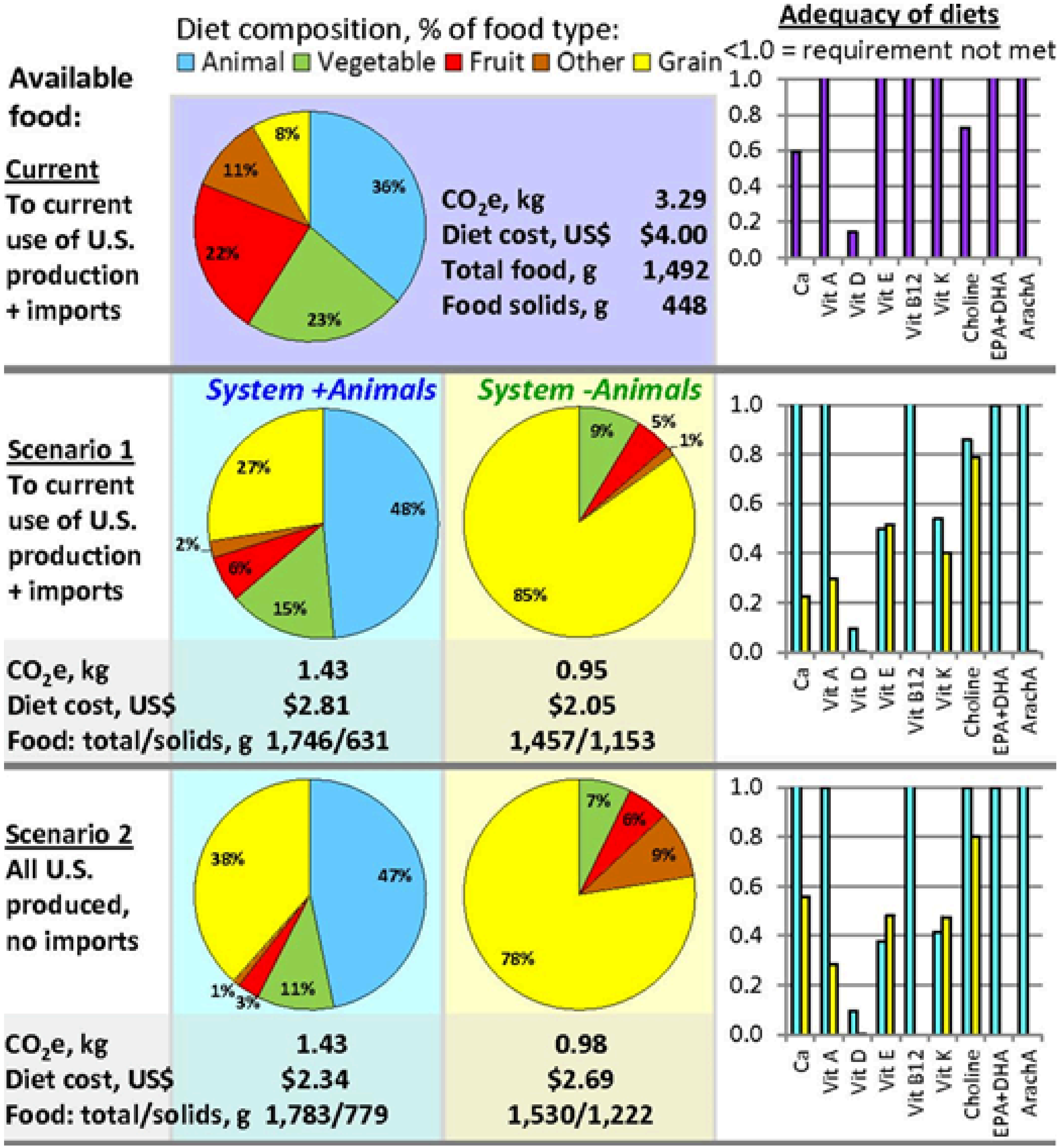
Claudia Hitaj, Sarah Rehkamp, Patrick Canning, and Christian J. Peters (2019)

GHG emissions for different diet scenarios, organized by food group

Emission Impacts from Dietary Choices

Nutritional and greenhouse gas impacts of removing animals from US agriculture.
White & Hall (2017)

Comparison of the daily diet composition, CO2e emissions, intake, cost, and nutrient adequacy of the current US diet compared with a series of optimized diets with and without (modeled) animal-derived foods

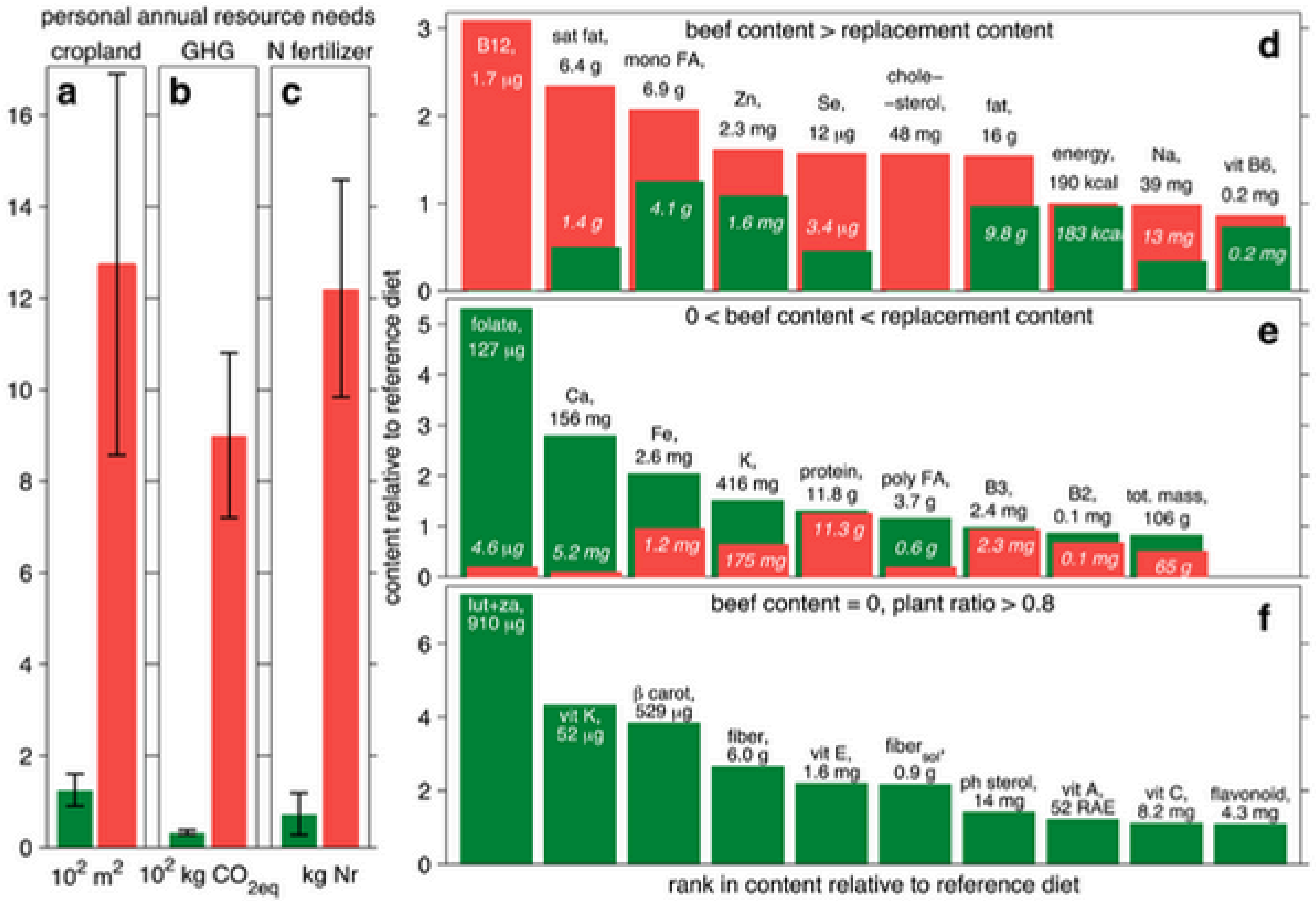


Bar graphs indicate dietary adequacy of specific nutrients by scenario; purple indicates current diet, blue indicates diet with animals, yellow indicates plants-only diet. “Other” represents nuts, legumes, fats, and sweeteners. ArachA, arachidonic acid.

Environmental Impacts of Beef Replacement

Environmentally Optimal, Nutritionally Aware Beef ReplacementPlant-Based Diets.

Eshel, G., et al. (2016)



Environmental attributes (a--c)

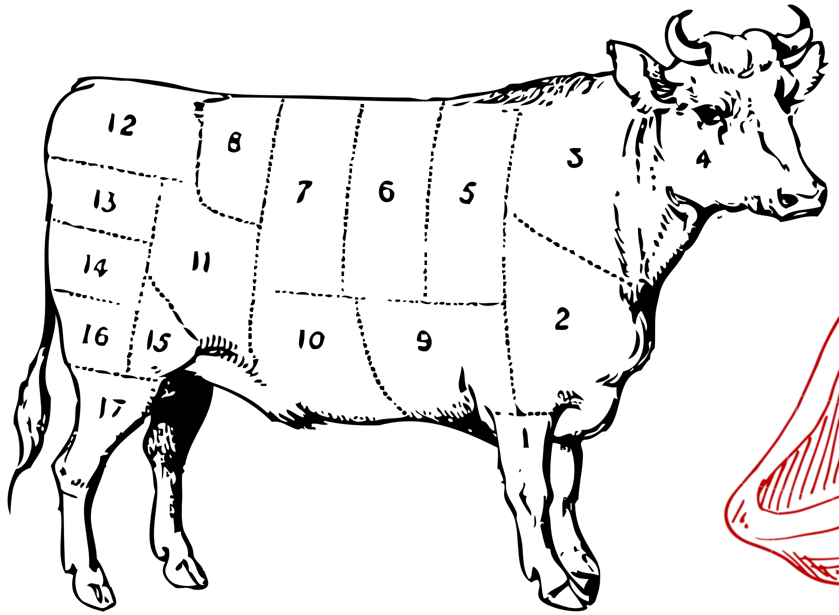
Nutritional attributes (d--f)

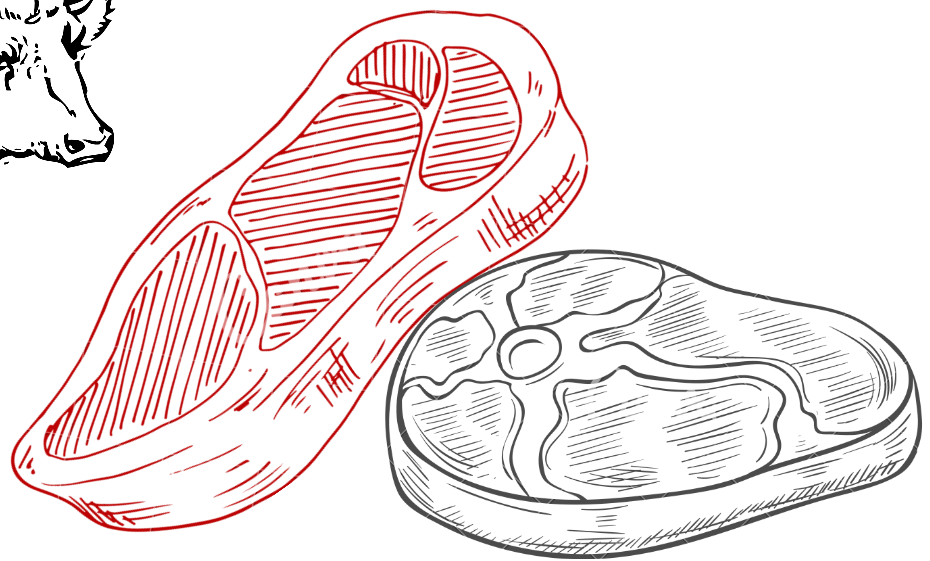
Plant based diet (green)

Beef portion of MAD (red)

Resource savings expected from a nationwide beef-to-plant dietary shift

High quality cropland	Rangeland	GHG emissions	Reactive nitrogen
91 million acres	771 million acres	278 million metric ton CO_2	3.7 million metric ton Nr





Environmentally Optimal, Nutritionally Aware Beef ReplacementPlant-Based Diets.
Eshel, G., et al. (2016)

Part 4:

Other emissions

What other emissions does agriculture emit?

Ammonia

NH3

- Plays significant role in PM2.5 formation
- Livestock, fertilizer, soils, crop burning

Aerosols

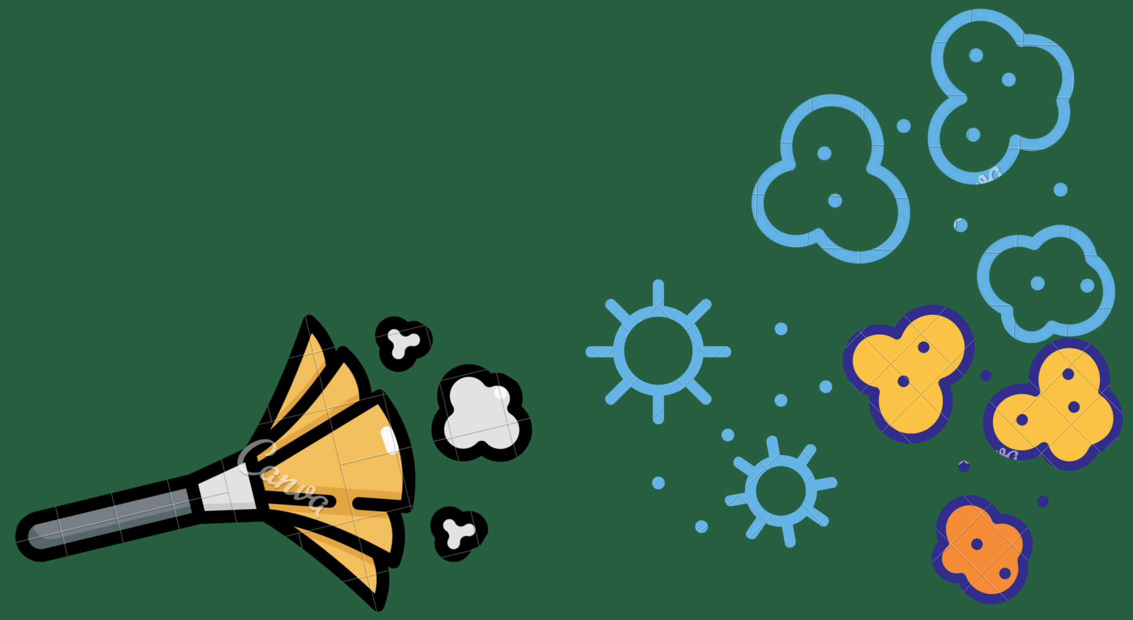
PM2.5

- Pollen, spores, salt spray, soil erosion, dust

Aerosols

PM10

- Pollen, spores, salt spray, soil erosion, dust



EPA

Livestock & Ammonia

Summary of ammonia emissions from U.S. Animal Husbandry Operations

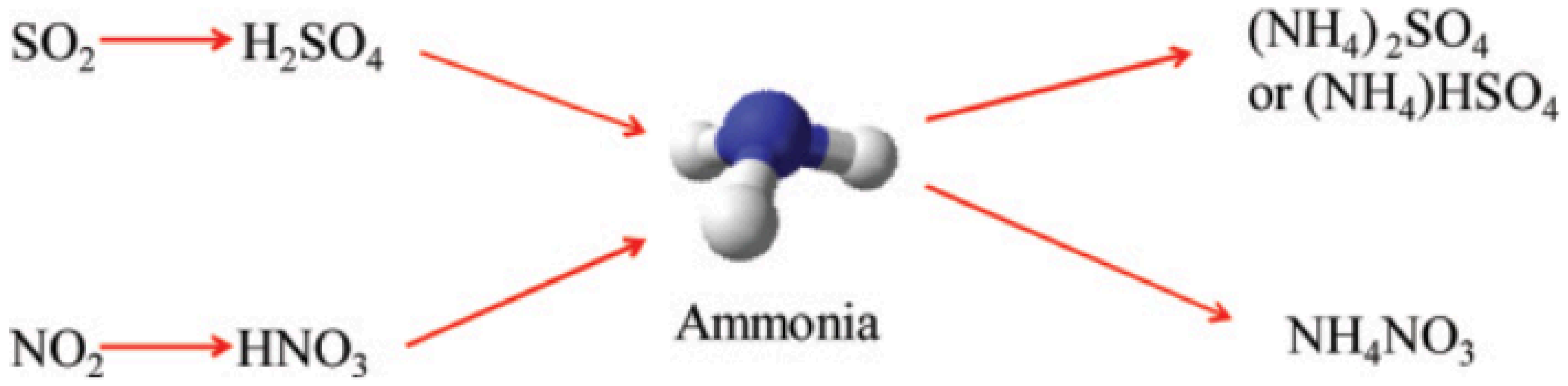
Animal Group	Ammonia Emissions (tons/year)				
	2002	2010	2015	2020	2030
Dairy[1]	558,094	565,892	547,874	545,155	546,666
Beef[2]	656,648	691,174	689,669	705,659	733,662
Poultry[3]	664,238	648,200	720,449	770,068	869,348
Swine[4]	429,468	485,223	512,458	529,288	518,082
Sheep	24,835	NE	NE	NE	NE
Goats[5]	14,028	NE	NE	NE	NE
Horses	71,285	NE	NE	NE	NE
Total	**2,418,595**	**2,390,489**	**2,470,449**	**2,550,171**	**2,667,758**

[1] Includes dairy cows and dairy heifers.
[2] Includes beef cattle, bulls, and calves.
[3] Includes chickens and turkeys.
[4] Includes breeding and market pigs.
[5] Includes milking and Angora goats.
NE- Not estimated

EPA 2004 Projections

Food Export and Associated NH3 Emissions

commodity	fraction exported[a] %	export value[a] billion US$	net export value[b] billion US $	NH_3 emissions[c] GgN a^{-1}
livestock		10.1	3.4	165
poultry	13%	2.8	2.1[d]	40
pork	12%	2.6	0.6	40
beef	7%	2.9	0.1	75
dairy	2%	1.8	0.6	10
crops		45	20.2	130
cotton	69%	3.8	0.8	15
soybeans	56%	10.5[e]	7	5
wheat	49%	5.5	2.7	45
rice	48%	1.3	0.5	5
feed, other grain	23%	5.3	1.3	20
corn	22%	7.3	3.4	35
fruits, vegetables, nuts	19%	11.2	4.5	<5
total		55.1[f]	23.5	295

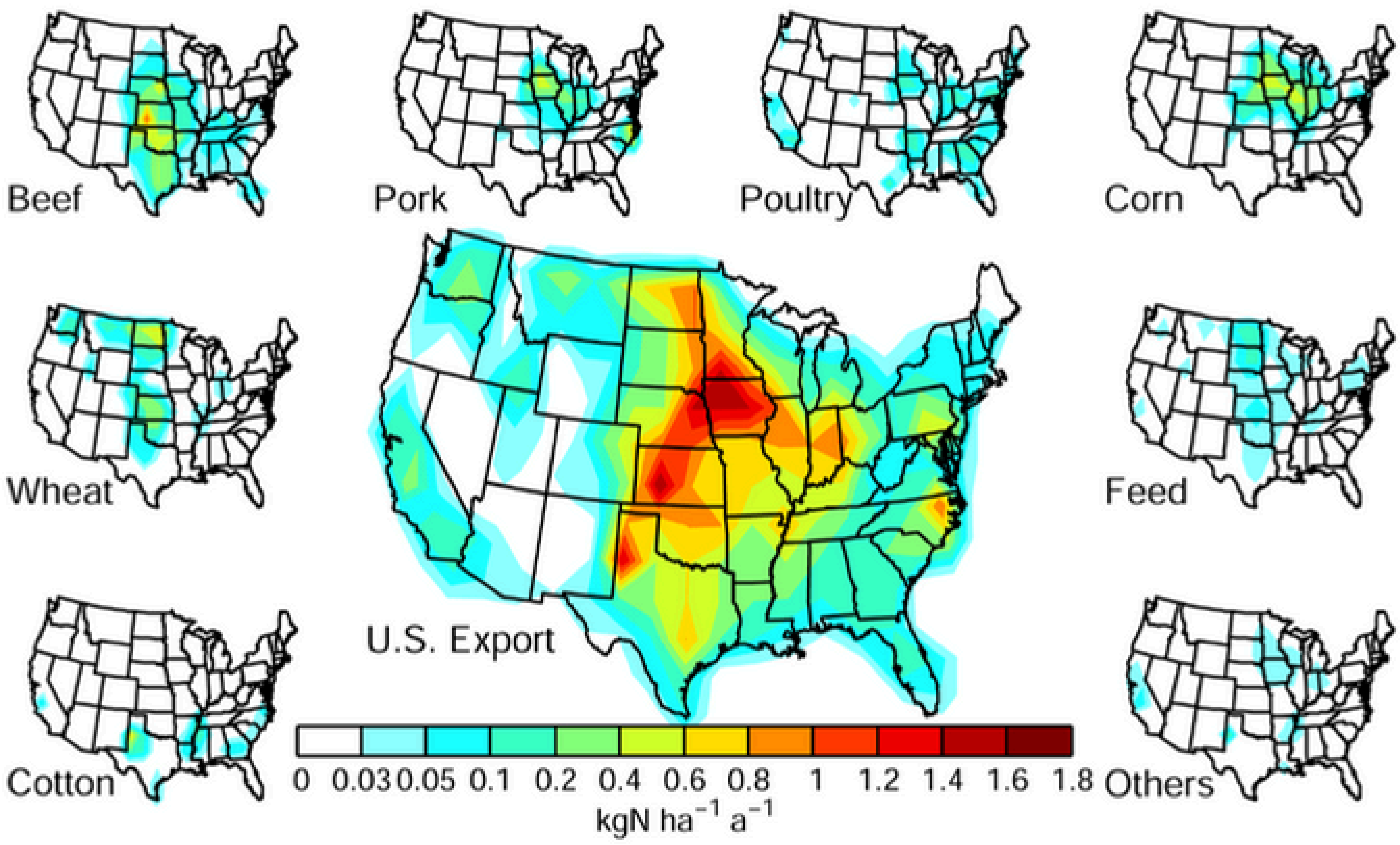


Main atmospheric reaction leading to PM2.5 formation from ammonia

Hidden Cost of U.S. Agricultural Exports: Particulate Matter fromAmmonia Emissions.
Fabien Paulot and Daniel J. Jacob (2014)

Technical note: Contribution of ammonia emitted from livestock to atmospheric fine particulate matter (PM2.5) in the United States
FA. N. Hristov (2011)

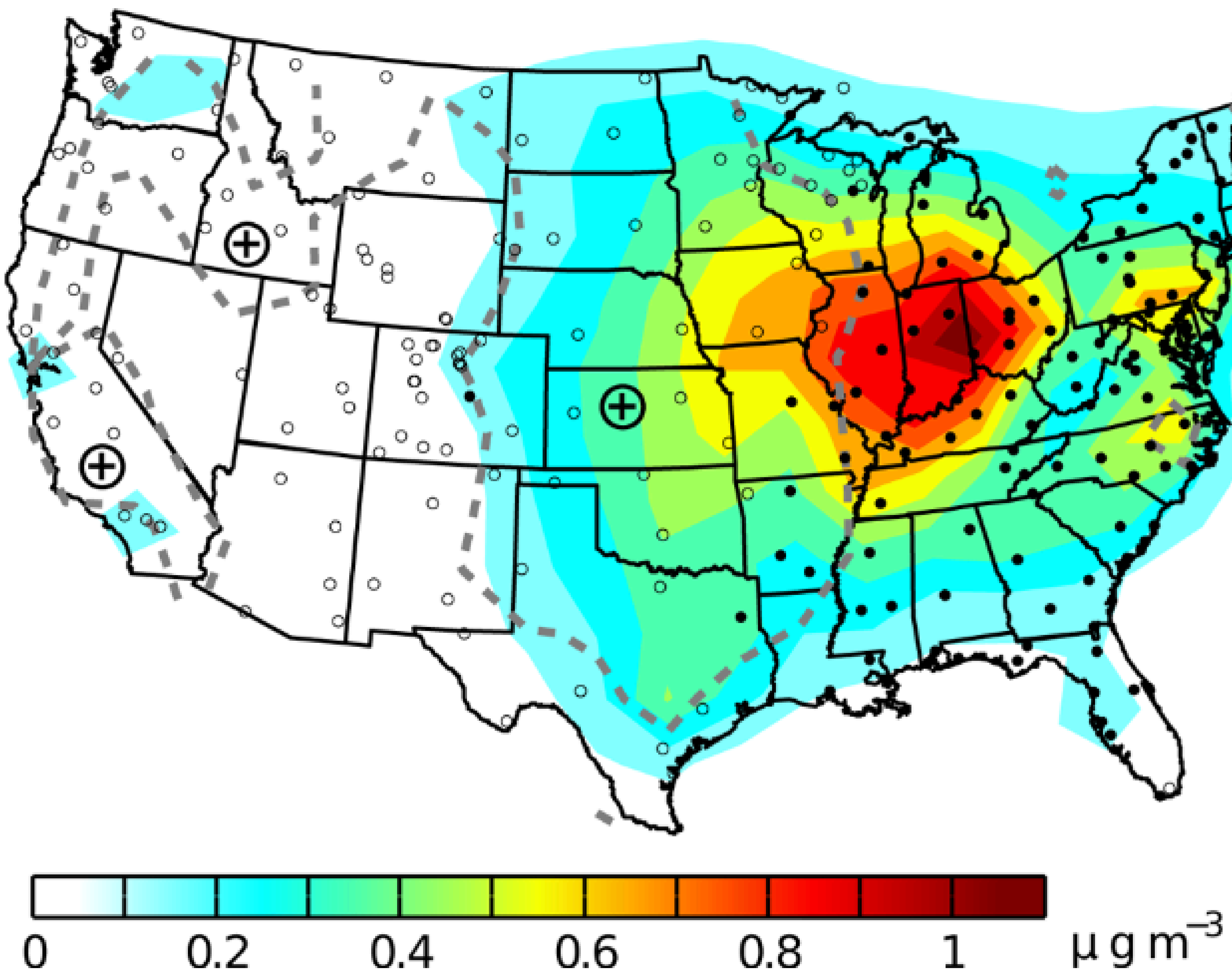
NH3 emissions associated with the production of exported food



Hidden Cost of U.S. Agricultural Exports: Particulate Matter from Ammonia Emissions.

Fabien Paulot and Daniel J. Jacob (2014)

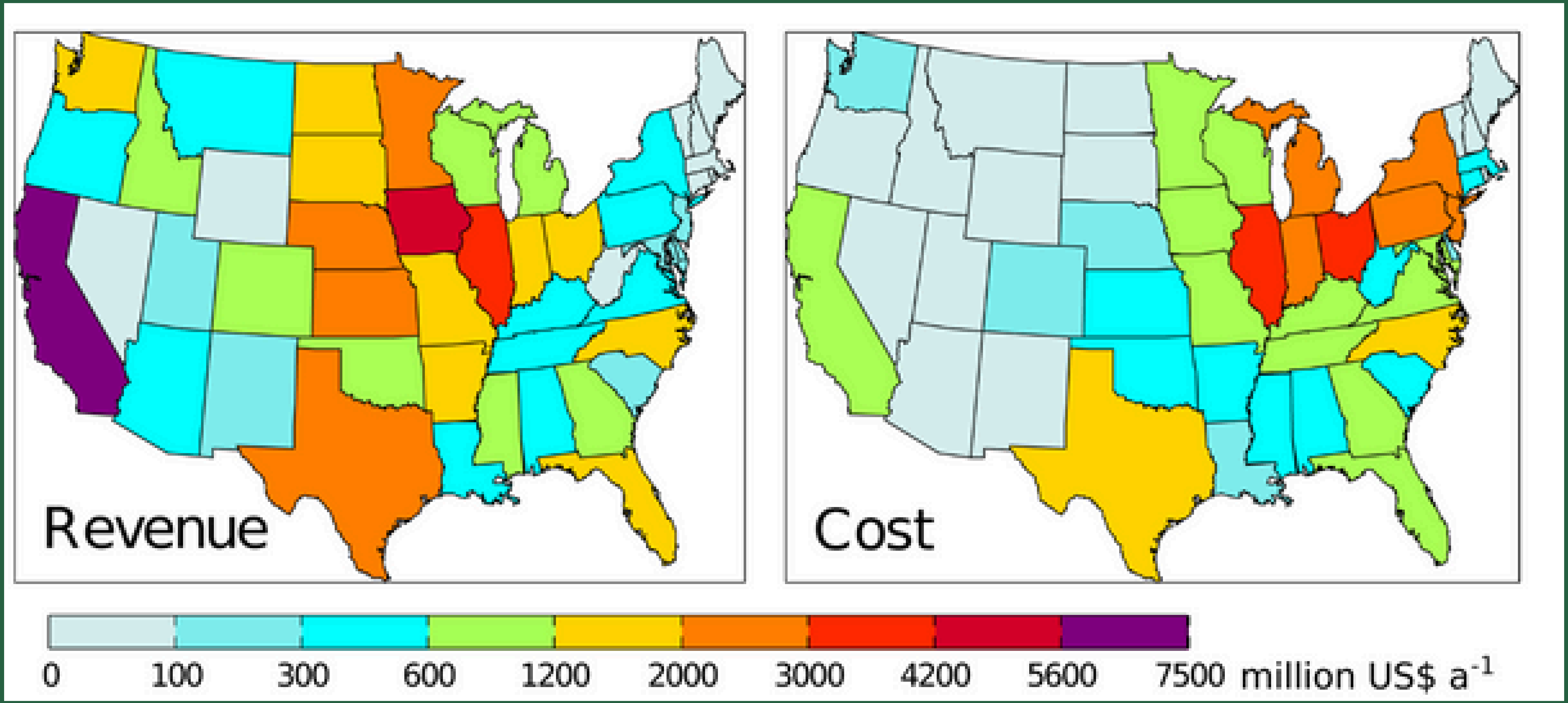
Impact of NH3 emissions from food export on annual mean surface PM2.5 concentrations



Hidden Cost of U.S. Agricultural Exports: Particulate Matter from Ammonia Emissions.

Fabien Paulot and Daniel J. Jacob (2014)

Comparison between annual gross revenue and health cost of agriculture export for individual states



Health cost driven by increased exposure to PM 2.5 due to NH3 emissions from agriculture export

Hidden Cost of U.S. Agricultural Exports: Particulate Matter from Ammonia Emissions.
Fabien Paulot and Daniel J. Jacob (2014)

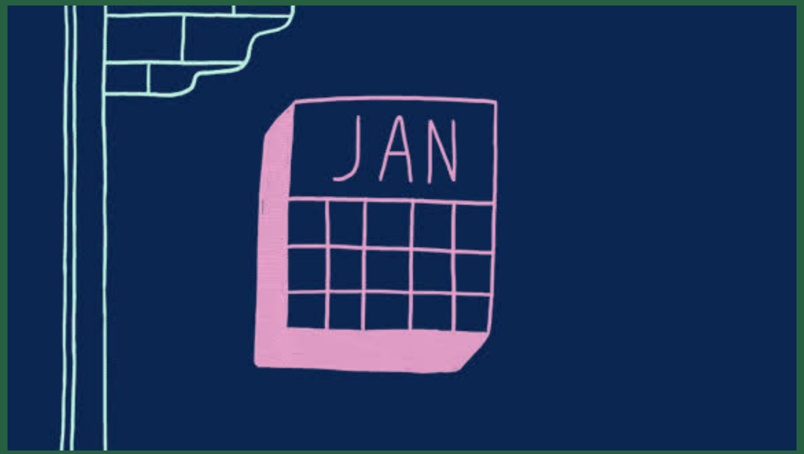
Knowlege Gap!

No PM emission guidelines to follow!

We need more research!

Part 5:

Future outlook



Proceedings of the Nutrition Society

'Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life'

U.N.

Main pillars of sustainable food security

Climate change and sustainable food production

Smith, P., & Gregory, P. (2013)

Food Utilization

- Nutritional value
- Social value
- Food safety

Food Access

- Affordability
- Allocation
- Preference

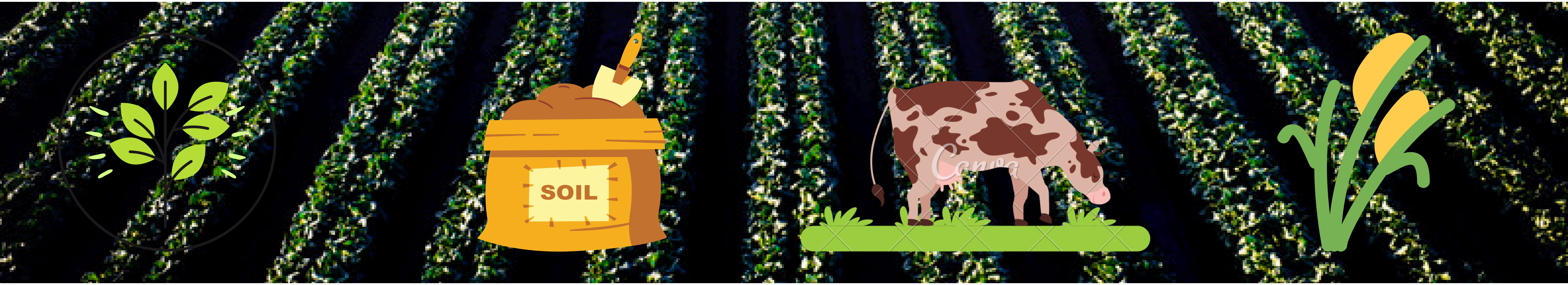
Food Availability

- Production
- Distribution
- Exchange

Solutions

Climate change and sustainable food production

Smith, P., & Gregory, P. (2013)



Cropland management

Mitigation potential up to about 1. 45 Pg CO2-eq/yr

Restoration of organic soils

Combined mitigation potential about 2. 0 Pg CO2-eq/yr

Grazing land management

Mitigation potential up to about 1. 35 Pg CO2-eq/yr

Improved water and rice management

About 0. 3 Pg CO2-eq/yr

Solutions

Climate change and sustainable food production

Smith, P., & Gregory, P. (2013)

Production-based measures

Can the projected crop yields required to sustain a population of nine billion be achieved and sustained?

Increased yield efficiency

Increased return on investment (energy)

Reduce meat consumption

Reduce waste

Consumption-based measures

We will need 70–100% more food by 2050

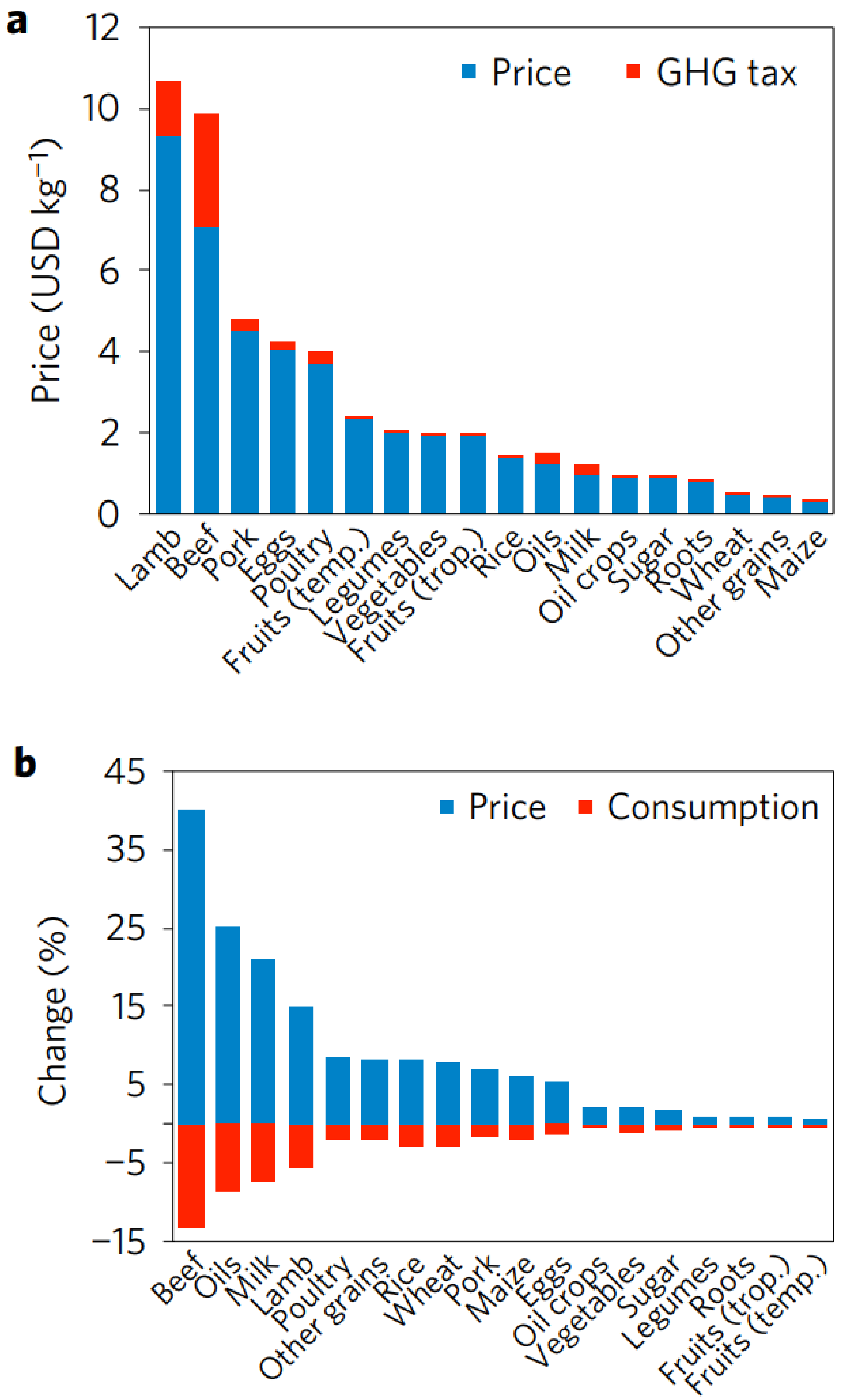
GHG and food taxation

Mitigation potential and global health impacts from emissions pricing of food commodities

Springmann, M., Mason-D'Croz, D., Robinson, S. et al (2017)

The climate change mitigation potential provided by this paper is about 1 GtCO2e, which is roughly 9% of food-related GHG emissions (more than the current emissions of global aviation)

Furthermore, levying GHG taxes on all food commodities led to 107,000 potentially prevented deaths (95% confidence interval (CI), 95,000–118,000) globally in 2020



GHG emissions in California

Greenhouse Gas Mitigation Opportunities in California Agriculture: Science and Economics Summary

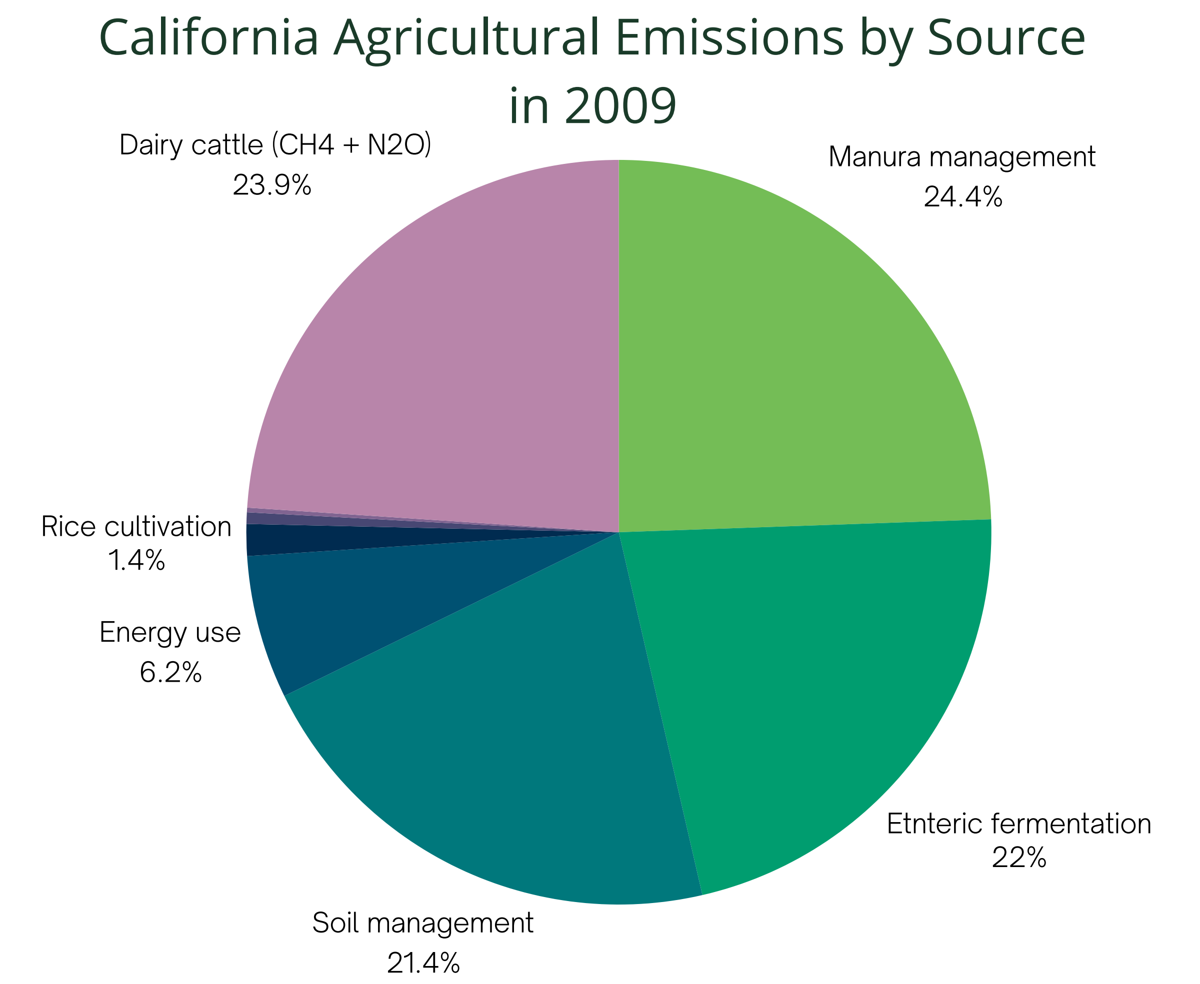
Vegh, T., Olander, L., & Murray, B. (2014).

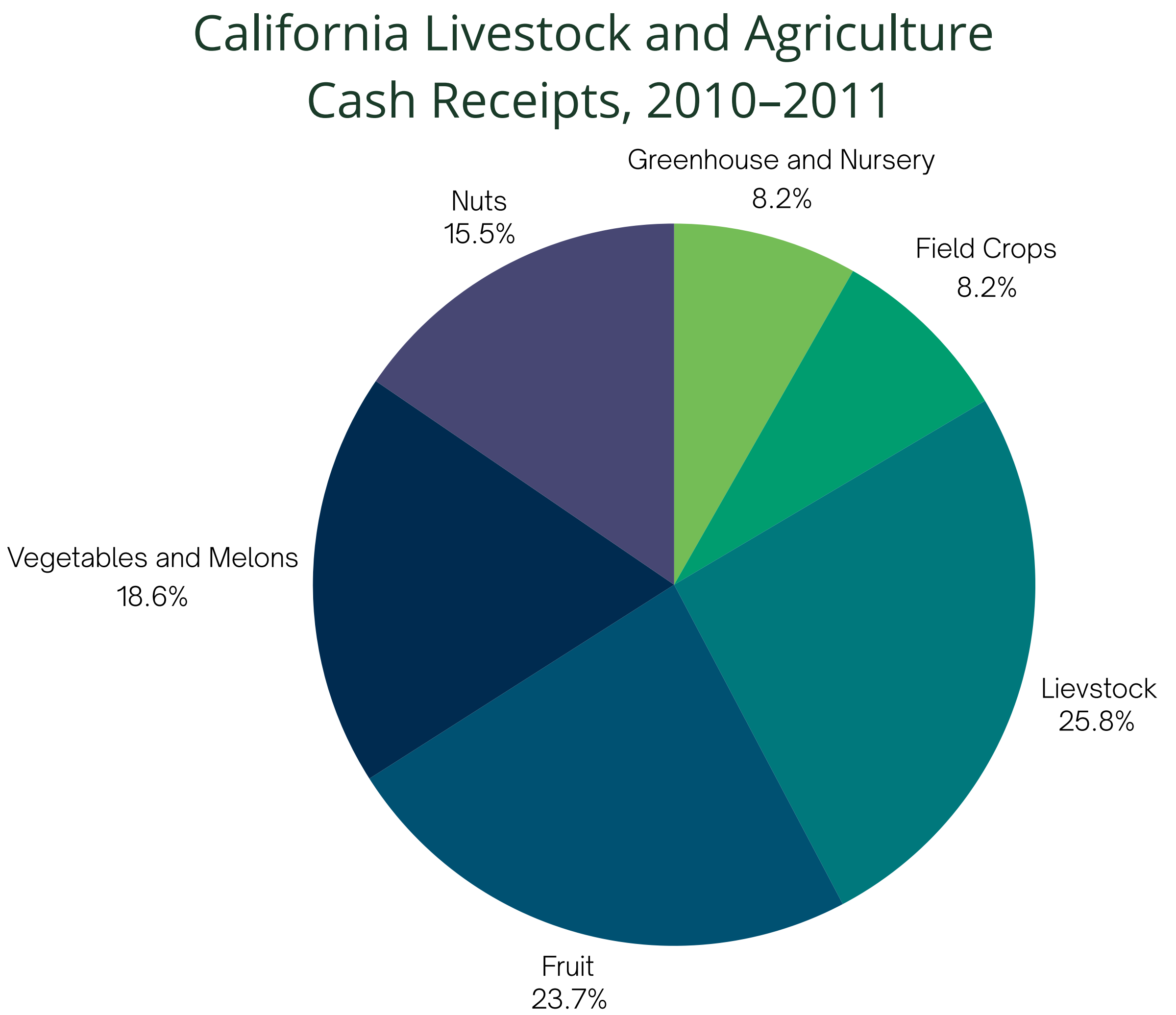
Improved Manure Management

Dairy Enteric Emissions Reduction

Cropping Systems

Rangeland Systems





Thank you!

Questions?

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