Supplementary Information

A. Additional Results

Table S1: Decomposition of Baseline Dietary Costs by Product

	Beef	Dairy	Sheep-Goat	Pork	Poultry	Eggs
Contribution to Total Dietary Costs	$45.93	$37.02	$0.32	$3.95	$4.20	$1.12

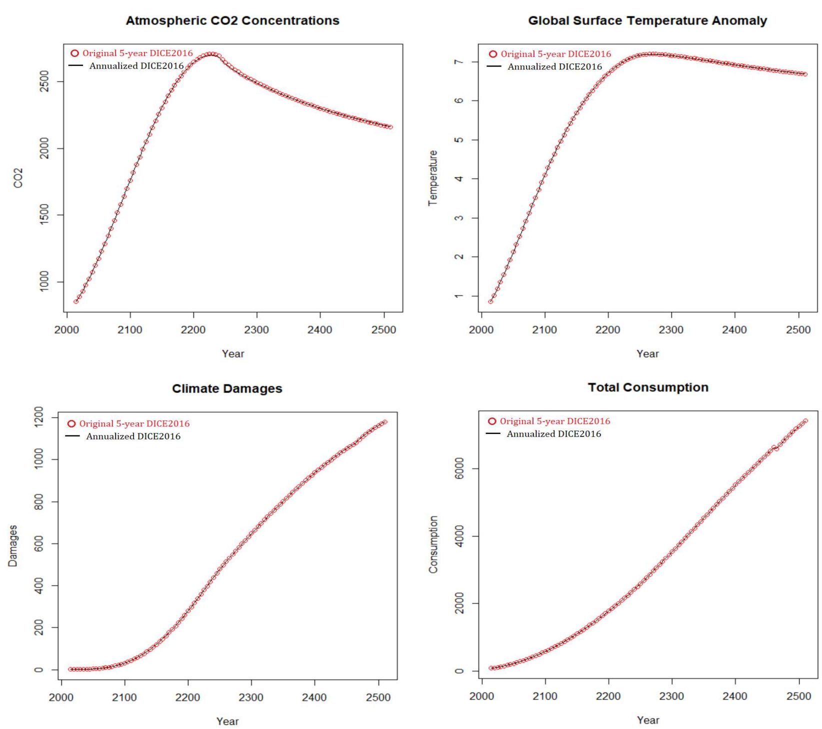
Notes: Decomposition of dietary cost estimate in baseline parameterization ($92; row 1, col 2, Table 1) by product.

Table S2: Robustness of Baseline Results to Original FAIR Parameterization

Discount Rate	Global systemwide	S.A.D.	Vegetarian	Beef	Dairy	Sheep-Goat	Pork	Poultry	Eggs
	Billions	Annual Per Capita		Per Serving					
Benchmark	$233	$80	$33	$0.18	$0.08	$0.09	$0.03	$0.01	$0.01
Stern	$691	$248	$107	$0.50	$0.26	$0.22	$0.08	$0.05	$0.05
2.5%	$569	$194	$84	$0.40	$0.20	$0.19	$0.06	$0.03	$0.04
3%	$406	$139	$59	$0.29	$0.14	$0.14	$0.04	$0.02	$0.02
5%	$179	$61	$25	$0.14	$0.06	$0.08	$0.02	$0.01	$0.01

Notes: Reproduction of Table 1 without changes to the two FAIR parameters modified in main analysis.

Figure S1: DICE2016 Replication at Annual Frequency



Notes: Replication of DICE2016 using annualized implementation.

B. Model with Increasing Per Capita Meat Consumption

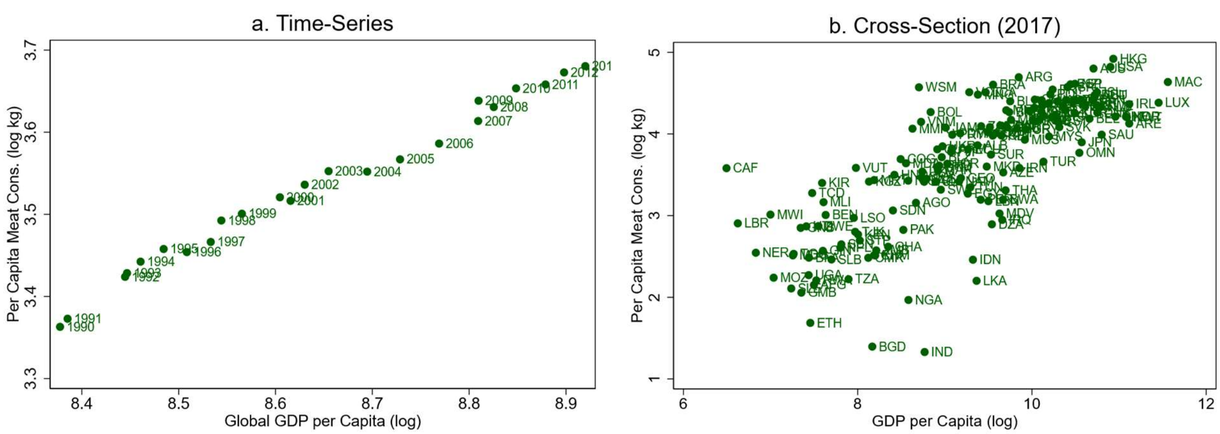
Our model is subject to many well-studied uncertainties present in the climate economics literature. A key uncertainty, however, that is unique to our model is the evolution of global per capita meat consumption. In this section, we discuss this assumption and the results from alternative assumptions on this evolution.

The assumption employed throughout the paper is that of fixed per capita meat consumption; animal agriculture grows only because of population growth. We first note that this is likely a conservative assumption relative both to historical trends (Figure S2) as well as projections used by other studies relying on agricultural emissions.[13]

Meat consumption is highly correlated with income, both in the aggregate over time as well as in a cross section of countries in a single year (2017). In fact, the log-log regression using either source of variation returns an elasticity of about 0.5: for every 1 percent increase in GDP per capita, meat consumption per capita is predicted to rise by 0.5 percent. Because the DICE model implies substantial increases in global income, allowing for a non-zero elasticity produces large increases in per capita meat consumption.

Applying this correlation to the DICE model's economic growth results in per capita meat consumption growth that is higher than is found using more sophisticated projections. However, using an elasticity half this size (0.25) implies values in the general range of these more sophisticated projections (namely, FAO projections[51] that exist for the year 2050). Using this value allows us to preserve the transparency of an elasticity-based approach while projecting values that are consistent with past work. Formally, in each year, we allow per capita meat consumption to rise at one-quarter of the rate of economic growth for the next 100 years, after which meat consumption growth plateaus.

Figure S2: Meat Consumption vs. Per Capita Income



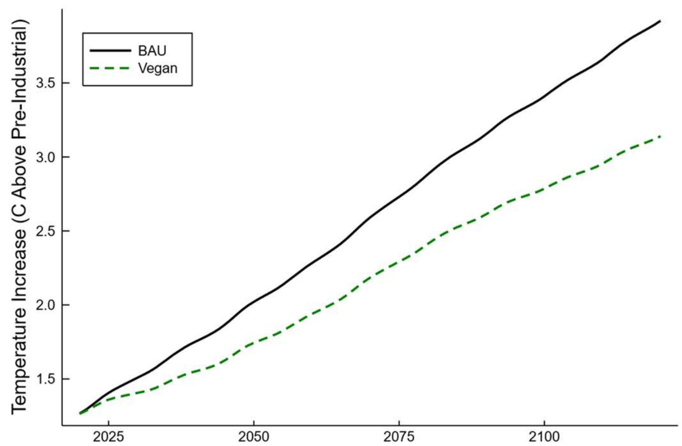
Source: United Nations FAOSTAT, World Bank Development Indicators

This assumption plays a major role in two of the main results: total projected climate effects of animal agriculture (Figure 1) and the opportunity costs (Figure 2). The total projected warming effects in this version of the model are 0.8 degrees rather than the 0.5 degrees with a zero-income elasticity (Figure S3). It is important to note that because DICE-FARM is calibrated to match DICE's BAU scenario, increasing per capita meat consumption will not change the BAU outcome. Instead, the model now brings more of the "exogenous" RCP emissions under the umbrella of dietary emissions, hence leading to larger effects of eliminating such emissions (see section A for model calibration details).

For a similar reason, the opportunity cost grows as well. Recall, this is a measure of the benefits of percent reductions (perhaps thought of as "rates of veganism or vegetarianism"). The larger per capita consumption is projected to be, the larger are the benefits from increasing the rate of reductions in this sector. The benefits of reducing agricultural emissions are 3.2 percentage points for every 10-percentage point reduction; more than 50% larger in this version of the model (Figure S4; slopes).

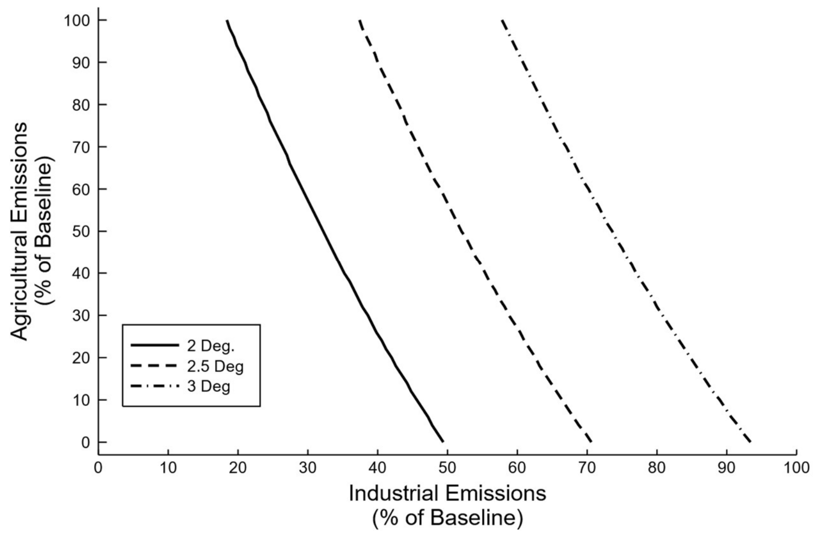
This version of the model produces realistic results, and the larger effects should be considered. The baseline case is chosen with conservative assumptions to highlight that even under best-case dietary scenarios, there are significant climate policy implications. However, declining emissions intensity of future production would be a counter-veiling force against rising per capita consumption. Technological progress—like large-scale use of sustainable livestock management practices or sweeping innovations in automated farming technologies and livestock genetics—may change this trade-off. Recent gene-editing techniques that directly reduce emissions from livestock[52] or potentially indirectly through improved animal health[53,54] demonstrate promise, though none have been commercialized or scaled, consumer acceptance of genetically engineered foods is far from universal[55,56], and such methods can result in unintended technological regress.[57] In sum, while uncertainty remains in the evolution of total emissions from animal agriculture, our main results are not driven by outlying assumptions about business as usual agriculture emissions.

Figure S3: Total Climate Effects of Animal Agriculture Under Per Capita Consumption Growth



Notes: Replication of Figure 1 (left panel) with increases in per capita meat consumption. BAU temperature in DICE is held fixed by construction; only the contribution of animal agriculture is therefore affected (see *Methods*).

Figure S4: Opportunity Cost Under Per Capita Meat Consumption Growth



Notes: Replication of Figure 2 with increases in per capita meat consumption. When a larger share of total non-industrial emissions is calibrated to be dietary emissions, efforts to reduce these emissions have larger payouts.

C. Global Livestock Environmental Assessment Model (GLEAM) Version 2.0

Model Overview

GLEAM 2.0 is a process-based model that uses a life-cycle assessment (LCA) approach to estimate total emissions from major global livestock supply chains. It covers 11 major livestock commodities: meat and milk from buffalos, cattle, sheep, and goats; meat and eggs from chickens; and meat from pigs. There are eight production systems in total. Three of these systems are for cattle (grassland (i.e., open grazing), feedlot, and mixed); two are for buffalo, sheep, and goats (grassland and mixed); three are for pigs (backyard, intermediate, and industrial); and three are for chickens (backyard, broilers, and layers). These systems are further classified according to one of three agro-ecological zones[58]: humid, temperate, and arid[59].

Underlying GLEAM 2.0 are six modules that replicate the major blocks in the livestock supply chain: herd, feed ration and intake, animal emissions, manure, feed emissions, and allocation. A summary of the ''inputs' and 'outputs' from these six modules are provided in Table S3. Starting with the herd module (1), data inputs on total animal population and herd parameters are used to calculate herd structure and dynamics, which flow to the feed ration and intake module (2). These inputs are combined with crop yields, nutritional value of feedstuffs, and animal energy requirements, along with other intermediate calculations, to calculate ration composition and nutrition and the animal's energy requirements and feed intake. The animal emissions module (3) next takes data about manure management systems and intermediate calculations on feed intake and the digestibility and nitrogen content of rations to output excretion rates, total manure emissions, and enteric methane production.

Many of the GHG emissions calculations are next performed in the feed emissions module (5). Raw inputs to this module include crop yields, energy use values, fertilizer application rates, and various emissions factors. Combined with intermediate calculations about nitrogen use efficiency and cohort feed intake, the feed emissions module computes total emissions per kg of dry matter for eight categories of animal management activities, as well as total herd emissions. The final step is the allocation module (6), which generates total commodity production and emissions by source and then allocates these to products and commodities.[59]

An overview of the livestock production systems modeled in GLEAM 2.0 are given in Table S4. These systems vary most substantially based on feeding method (e.g., grassland systems entail livestock grazing on pasture and rangeland) and type and condition of housing.[59] Many developed countries use feedlot systems for cattle and other ruminant production, in combination with industrial methods for pigmeat and advanced systems for broilers and layers. In contrast, less developed countries tend to use grassland and mixed systems for ruminants and backyard systems for pigs and chickens.[30].

GHG Emissions from Global Animal Agriculture

Among livestock and commodities of animal origin, cattle are the main contributor to agricultural GHG emissions, accounting for 62.2% (5.0 Gt C02-e) of total sector emissions. Another 10.1% (0.819 Gt C02-e) arises from pigmeat, followed by 9.8% (790 Gt CO2-e) from chicken meat and eggs. Meat and milk from buffalos comprise 9.5% (766 Gt C02-e) of emissions, while these same commodities from sheep and goat make up 7.4% (596 Gt C02-e). Other poultry products and non-edible output account for the remaining 1% of emissions from global agriculture.[24]

Aggregate emissions by animal and commodity reflect a number of complex conditions. These conditions include, among others, herd size, weight, and health; content and quality of feed rations; land use change associated with cropland and pastureland; processing, storage, and transportation of commodities; and production systems and management efficiency—all of which vary by region, country, and sub-national areas.[1]

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[1] GLEAM 2.0 incorporates parameters on the attributes of herds, manure, feed, land-use change, animal productivity, and post-farm operations. These parameters are associated with various levels of spatial aggregation: 10 km x 10 km grid, sub-national, national, regional, and global. Parameters with the highest

Aggregate animal-based emissions can be more meaningfully compared across animal types, commodities, and production systems through use of emissions intensities (Table S5).[2] To ensure consistent aggregation across greenhouse gases and commodity types (e.g., meat, milk, and eggs), emissions intensities are defined as kg C02-equivalents per kg protein. A combination of Tier 1 and Tier 2 methods[60] are used in the calculations underlying GLEAM's emissions factors. Meat from cattle and buffalo are among the most intensive animal products, though substantial differences exist based on production method and region. Sheep and goat meat produce relatively less emissions per kilogram of protein but are similarly intensive commodities. Milk production is less intensive than meat production across all systems. Owing to management practices and production efficiency, sheep milk is among the most intensive dairy products, while cow's milk is the least intensive. Pigmeat and chicken meat are the least intensive meat products, while eggs are the least intensive of any commodity.

Regional variation in emissions intensities per kilogram of protein across the 10 GLEAM 2.0 regions are provided in Table S6. Meat production from cattle are among the most intensive and least efficient in South Asia, Latin America and the Caribbean, and Sub-Saharan Africa. Buffalo meat production is the most intensive in East Asia and Southeast Asia, a common source of protein among countries comprising this region. Near East and North Africa countries are the most emissions-intensive producers of sheep meat, while Sub-Saharan African countries produce the most emissions-intensive goat meat. Per kilogram of protein, pig meat produces the highest emissions in South Asian nations. Cow's milk and buffalo milk are less emissions-intensive than milk from sheep and goats. East Asia tends to have the highest emissions per kilogram of protein from chickens—for both meat and eggs.

The emissions intensities used in DICE-FARM are displayed in Table S7, Panel A. These intensities represent an average across animal products, production systems, and regions. The composition of the average global diet and standard American diet, by product, are in Table S7, Panel B.

Major Sources of Agricultural GHG Emissions

Among each livestock supply chain, there are 12 major sources of emissions. These sources of emissions vary by GLEAM module and activity (Table S8).[3]

Enteric fermentation is the single largest source (44%) of agricultural emissions.[24] Anaerobic fermentation—in which bacteria decompose organic matter into methane, carbon dioxide, and hydrogen—occurs naturally in wetlands, rice patties, and the digestive tracts of mammals with multi-chambered stomachs, ruminants. Enteric methane production from mammals is directly proportional to the content, quality, and volume of feed; animal size and growth rate; and environmental temperature.[61] Among the world's predominant livestock, buffalo and cattle are considered large ruminants, while sheep and goats are considered small ruminants. In contrast, pigs and chickens are monogastric animals with simple single-chambered stomachs.[59] Cattle emit the majority of enteric methane (77%), followed by buffalos (13%), and sheep and goats (10%).[30]

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level of aggregation (grid) are: herd sizes, crop yields, harvested areas, nitrogen crop residues, and annual mean temperatures. Parameters with the lowest level of aggregation (global) are: nitrogen loss rates; digestibility, nitrogen, and energy content of feeds; energy used in field operations and transportation; transportation distances, and fat and protein content of livestock commodities.

[2] GLEAM 2.0 also offers emissions intensities that vary based on 10 regions: East Asia and Southeast Asia, Eastern Europe, Latin America and the Caribbean, Near East and North Africa, North America, Oceania, Russian Federation, South Asia, Sub-Saharan Africa, and Western Europe. For space considerations Table S5 reports global emissions intensities that aggregates across 236 countries underlying GLEAM 2.0.

[3] GLEAM 2.0 omits several kinds of emissions along supply chains that are deemed to be marginal. These include emissions from N_20 losses from changes in carbon stocks; biomass burning; biological fixation; changes in carbon stocks from land use under constant management; production of cleaning agents, antibiotics, and other pharmaceuticals; waste water treatment post-farm; emissions from other animal waste; slaughter by-products; energy use and waste disposal at the retail point and beyond.

Emissions from the production, processing, and transportation of livestock feed are the second- largest source of emissions from global animal agriculture, comprising 41% of total sector emissions.[24] A substantial share of livestock feed is derived from feed crops, which require the manufacture, transportation, and application of pesticides and fertilizers (the latter derived from nitrogen, potassium, and/or phosphorous). Feed processing and transportation also generate carbon dioxide. Land use change resulting in expanded pastureland and cropland dedicated to soy and palm kernel cake production emit further carbon dioxide. Nitrous oxide is emitted from nitrogenous fertilizers applied to feed crops and through the direct application of manure on pastureland and feed crops.[59]

Manure storage and processing, excluding application and deposit, accounts for 10% of sector level emissions. These emissions are methane, mainly from volatile solids, and nitrous oxide—either directly emitted or indirectly emitted from N20 volatilization or leaching.[24]

Energy consumption from on-farm and post-farm sources comprise the remaining 5% of emissions.[24] Energy is used directly to run agricultural equipment (e.g., tractors, irrigation systems, milking machines, ventilation, and cooling devices) and is also embodied in capital assets (e.g., animal housing and storage facilities for feed and manure). Additional energy use results from processing, packaging, and transporting livestock commodities to retail points.[59]

Table S3: GLEAM 2.0 Sequential Model Structure

Module	Inputs: Raw Data	Inputs: Intermediate Calculations	Output (Calculation)
Herd	Total animal population Herd parameters	None None	Herd structure and dynamics
Feed Ration & Intake	Crop yields Nutritional value of feedstuffs Animal energy requirements coefficients	Number of animals per cohort Average bodyweights Growth rates	Ration composition Nutritional values Animal's energy requirements Animals' feed intake
Animal Emissions	Share of manure management systems Emissions factors for manure systems Bo coefficients	Feed intake at cohort level Average digestibility of ration Average N content of ration	Animal's nitrogen and volatile solids excretion rate Total herd's manure emissions (N20, CH4) Total herd's enteric fermentation emissions (CH4)
Manure	Arable and grassland area Nitrogen loss rates	Nitrogen excretion	Manure application rate to arable land and pasture
Feed Emissions	Crop yields Emissions factors for N20 Energy use in field operations Emissions factors for feed processing and transportation Emissions factors for fertilizer and pesticide production Synthetic fertilizer application rates Emissions factors for land-use change	kg N per ha Feed intake at cohort level	Totalization of herd's emissions by source Emissions per kg of dry matter for: N20 from applied and deposited manure N20 from fertilizer and crop residue C02 from field operations C02 from fertilizer and pesticides production C02 from processing and transportation C02 from feed blending C02 from land-use change CH4 from rice cultivation
Allocation	Carcass to bone-free meat Dressing percentages Fiber yield Product price Protein content of meat, milk, and eggs Emissions factors for direct energy, indirect energy use Post-farm activities	Total animal emissions Total feed emissions	Total production of meat, milk, and eggs Total emissions by source Emission allocations to products Emissions intensities per commodity

Source: FAO GLEAM Version 2.0 Model Description[59]

Table S4: GLEAM 2.0 Livestock Production Systems

Production System	Animal	Housing	Characteristics
Grassland (or grazing)	Cattle, Buffalo, Sheep, Goats	—	Areas dominated by pasture or rangeland with growing periods < 60 days and low human density (< 20 people km^{-2}). At least 10% of dry matter feed is farm-produced and annual average stocking rates are < 10 livestock units ha^{-1}.
Mixed	Cattle, Buffalo, Sheep, Goats	—	Areas dominated by cropland with growing periods > 60 days and greater human density (> 20 people km^{-2}). At least 10% of dry matter feed is from crop by-products and/or stubble, or > 10% of production value comes from non-livestock farming.
Feedlots	Cattle	Generally, fully enclosed areas to facilitate feeding process	Fully market-oriented with animals being fed specialized diet consisting of high-energy, protein-rich rations for typically 6-9 months
Backyard	Pigs	Partially enclosed with either no floor or pavement made with local materials; roof and support made with local materials.	Subsistence-driven with low capital and output for local markets; feed contains maximum 20% of purchased non-local feed, with typically large shares of swill, scavenging, and locally sourced feeds
Intermediate	Pigs	Partially enclosed with either no walls or made with local materials; solid concrete floor; steel roof and support	Fully market-oriented with medium capital inputs, though with reduced level of herd performance; locally sourced feed comprises 30-50% of rations
Industrial	Pigs	Fully enclosed with slatted concrete floor; steel roof and support; walls made of either brick, concrete, steel, or wood	Fully market-oriented with high capital inputs and high overall herd performance; feed is either purchased and made from non-local materials or intensively produced from feed crops on farm
Backyard	Chickens	Simple housing from local materials with scrap wire netting walls and scrap iron roof	Output (meat and eggs) are intended for subsistence or local markets; 20-40% of diet consists of swill and scavenging, with locally produced feed making up 60-80% of diet
Layers	Chickens	Variety of cage, barn, and free-range systems with automatic feed and water provision	Fully market-oriented with high capital inputs and high overall flock performance; feed is either purchased and made from non-local materials or intensively produced from feed crops on farm
Broilers	Chickens	Loosely housed on litter with automatic feed and water provision	Fully market-oriented with high capital inputs and high overall flock performance; feed is either purchased and made from non-local materials or intensively produced from feed crops on farm

Source: FAO GLEAM Version 2.0 Model Description[59]

Table S5: GLEAM 2.0 Global GHG Emissions Intensities by Animal, Commodity, and Production System

		Production System								
Animal	Commodity	Aggregated	Grassland	Mixed	Feedlot	Backyard	Intermediate	Industrial	Layers	Broilers
Cattle	Aggregated	160.3	206.3	138.7	93.2	—	—	—	—	—
	Milk	86.7	95.0	81.9	—	—	—	—	—	—
	Meat	295.4	433.8	265.0	93.2	—	—	—	—	—
Buffalo	Aggregated	179.4	219.8	172.5	—	—	—	—	—	—
	Milk	139.7	159.7	136.6	—	—	—	—	—	—
	Meat	404.0	440.1	394.5	—	—	—	—	—	—
Sheep	Aggregated	189.0	236.7	146.4	—	—	—	—	—	—
	Milk	164.9	221.9	116.2	—	—	—	—	—	—
	Meat	200.8	243.7	161.5	—	—	—	—	—	—
Goats	Aggregated	171.8	199.4	155.8	—	—	—	—	—	—
	Milk	130.7	165.8	113.8	—	—	—	—	—	—
	Meat	201.6	219.4	189.9	—	—	—	—	—	—
Pigs	Aggregated	55.0	—	—	—	—	—	—	—	—
	Meat	—	—	—	—	50.6	69.1	52.7	—	—
Chicken	Aggregated	33.8	—	—	—	30.4	—	—	34.4	33.7
	Eggs	31.4	—	—	—	28.0	—	—	31.7	—
	Meat	35.3	—	—	—	37.1	—	—	59.1	33.7

Source: FAO GLEAM Version 2.0[62]
Note: All emissions intensities are expressed in kg C02-eq per kg protein. Variability in emissions intensities are greatest among producers of ruminant livestock. This variation is largely a function of agro-ecological conditions, livestock and feed crop production practices, and supply chain management.[59]

Table S6: Regional Variability in GLEAM 2.0 GHG Emissions Intensities Aggregated by Animal

	Cattle		Buffalo		Sheep		Goats		Pigs	Chickens	
Region	**Milk**	**Meat**	**Milk**	**Meat**	**Milk**	**Meat**	**Milk**	**Meat**	**Meat**	**Eggs**	**Meat**
East Asia and Southeast Asia[1]	77.9	331.9	252.8	554.8	125.8	214.0	212.2	161.6	62.8	39.8	51.2
Eastern Europe[2]	47.8	104.2	103.0	183.9	82.2	71.3	49.4	96.8	44.2	16.4	20.6
Latin America and the Caribbean[3]	108.7	413.0	115.8	233.7	280.7	219.8	141.9	172.7	54.6	28.1	32.0
Near East and North Africa[4]	164.8	277.4	131.5	371.8	282.7	306.9	234.9	200.3	68.8	23.5	35.8
North America[5]	56.9	147.7	60.2	59.6	0.0	217.2	52.7	119.1	36.5	16.4	21.3
Oceania[6]	57.0	196.7	0.0	0.0	0.0	120.4	232.5	130.8	81.3	21.4	35.2
Russian Federation[7]	48.5	97.1	0.0	246.0	104.5	166.7	54.8	51.7	36.1	12.5	21.6
South Asia[8]	140.5	529.1	135.7	378.6	187.4	302.8	111.5	231.4	75.9	25.9	37.5
Sub-Saharan Africa[9]	191.3	410.5	0.0	0.0	140.3	207.2	144.5	285.4	54.1	24.9	38.8
Western Europe[10]	47.2	128.0	69.8	79.1	69.8	109.1	60.7	73.2	50.0	21.7	31.0

Source: FAO GLEAM Version 2.0[62]

Note: All emissions intensities are expressed in kg C02-eq per kg protein. GLEAM 2.0 classifies the following countries according to these regions:

1. East Asia and Southeast Asia: Brunei Darussalam, Cambodia, China, Christmas Island, Democratic People's Republic of Korea, Hong Kong, Indonesia, Japan, Lao People's Democratic Republic, Macau, Malaysia, Mongolia, Myanmar, Philippines, Republic of Korea, Singapore, Thailand, Timor-Leste, Vietnam
2. Eastern Europe: Belarus, Bulgaria, Czech Republic, Hungary, Moldova, Poland, Romania, Slovakia, Ukraine
3. Latin America and the Caribbean: Anguilla, Antigua and Barbuda, Argentina, Aruba, Bahamas, Barbados, Belize, Brazil, British Virgin Islands, Cayman Islands, Chile, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Falkland Islands (Malvinas), French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, United States Virgin Islands, Uruguay, Venezuela
4. Near East and North Africa: Algeria, Armenia, Azerbaijan, Bahrain, Cyprus, Egypt, Gaza Strip, Georgia, Iraq, Israel, Jordan, Kazakhstan, Kuwait, Kyrgyzstan, Lebanon, Morocco, Oman, Qatar, Republic of Sudan, Saudi Arabia, South Sudan, State of Libya, Syrian Arab Republic, Tajikistan, Tunisia, Turkey, Turkmenistan, United Arab Emirates, Uzbekistan, West Bank, Western Sahara, Yemen
5. North America: Bermuda, Canada, Greenland, United States of America
6. Oceania: American Samoa, Australia, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Nauru, New Caledonia, New Zealand, Niue, Norfolk Island, Northern Mariana Islands, Palau, Papua New Guinea, Pitcairn, Saint Pierre et Miquelon, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wake Island, Wallis and Futuna
7. Russian Federation: Russian Federation
8. South Asia: Afghanistan, Bangladesh, Bhutan, British Indian Territory, India, Iran, Maldives, Nepal, Pakistan, Sri Lanka
9. Sub-Saharan Africa: Angola, Benin, Botswana, Burkina Faso, Burundi, Cote d'Ivore, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mayotte, Mozambique, Namibia. Niger, Nigeria, Rwanda, Reunion, Saint Helena, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
10. Western Europe: Albania, Andorra, Austria, Belgium, Bosnia and Herzegovina, Croatia, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Greece, Guernsey, Iceland, Ireland, Isle of Man, Italy, Jersey, Latvia, Liechtenstein, Lithuania, Luxembourg, Madeira Islands, Malta, Monaco, Montenegro, Netherlands, Norway, Portugal, Republic of Serbia, San Marino, Slovenia, Spain, Svalbard and Jan Mayen Islands, Sweden, Switzerland, Yugoslav Republic of Macedonia (former), United Kingdom

Table S7: GLEAM 2.0 GHG Emissions Intensities and Diets Used in DICE-FARM

A. Emissions Intensities by Gas-Animal Product

	Greenhouse Gas		
Animal product	**CO_2**	**CH_4**	**N_2O**
Beef	65.1	6.5	0.22
Dairy	14.6	2.1	0.22
Sheep-Goat	20.0	4.5	0.02
Pork	25.1	0.70	0.03
Poultry	25.6	0.02	0.02
Eggs	20.1	0.07	0.03

Source: FAO GLEAM Version 2.0[62]
Note: All emissions intensities are expressed in kg per kg protein.

B. Diets for Global Model Calibration and SC-AP

	Kg Protein Consumed	
Animal product	**Global**	**American**
Beef	1.4	4.5
Dairy	2.6	8.0
Sheep-Goat	0.4	0.1
Pork	2.0	2.7
Poultry	2.0	6.5
Eggs	1.3	1.6

Source: FAO GLEAM Version 2.0[62]
Note: Global consumption calibrated to per capita consumption averaged worldwide; American diet used to compute SC-AP in Table 1.

Table S8: GLEAM 2.0 Emissions Sources

Source	Module	GHG	Description
Feed	Feed	C02	Field operations, fertilizer and pesticide production, processing and transportation, blending and pelting
Land Use Change from Producing or Importing Soy and Palm	Feed	C02	Expansion of soybean production and palm oil plantations
Land Use Change from Pasture Expansion	Feed	C02	Expansion of pastureland for livestock forage
Fertilizer and Crop Residues	Feed	N20	Direct and indirect emissions from applied synthetic nitrogenous fertilizers and crop residues decomposition
Applied and Deposited Manure	Feed	CH4	Direct and indirect emissions from manure deposited on field and used as organic fertilizer
Feed	Feed	CH4	Cultivation of rice used as feed
Enteric Fermentation	Manure	CH4	Direct emissions from enteric fermentation among ruminant animals
Manure Management	Manure	CH4	Emissions arising from storage and management of manure
Manure Management	Manure	N20	Emissions arising from storage and management of manure
Direct Energy Use	Energy & Post-Farm	C02	On-farm energy use for heating, cooling, ventilation, and other operations
Indirect Energy Use	Energy & Post-Farm	C02	On-farm energy use embodied in capital assets like farm buildings and equipment
Post-Farm	Energy & Post-Farm	C02	Emissions from processing and transportation of commodities

Source: FAO GLEAM Version 2.0 Model Description[59]
Note: GLEAM 2.0 considers land use change from soybean products in Brazil, Argentina, and Paraguay. Palm kernel cake production is expanded in Indonesia and Malaysia. GLEAM 2.0 assumes pasture expansion comes from deforestation, which is only quantified for Latin America.

D. Global Production Costs of Animal-Based Foods

Above, we calculate that the social climate cost of 20-g servings of beef, dairy, and sheep-goat protein are 36%, 26%, and 21% of each product's total production costs (private plus social cost), respectively. Underlying these estimates are production-weighted prices of animal products averaged across countries in the GLEAM 2.0 base year, 2010.

International data on per-ton farmgate prices and total production quantities are taken from FAO (6). For each animal product in each country, the farmgate price is multiplied by a weight, where the weight is equal to production in that country divided by the sum of global production. The average production-weighted price is thus the sum of each country's weighted price. For year 2010, the following sample sizes (number of countries) are available from FAO for each animal product: beef (102), milk (98), sheep (85), and goat (60).

To calculate the combined private production cost of sheep-goats, the production-weighted price of goat meat is multiplied by (1/3) and then added to the production-weighted price of sheep meat, multiplied by (2/3). These latter ratios were chosen because, of the total global consumption of sheep and goat meat, goat has comprised roughly one-third the total quantity in at least ten of the most recent years for which data is available.[6] Therefore, the combined production-weighted price represents the fact that sheep meat is consumed in larger quantities than goat meat.

After converting metric tons to pounds, the following factors are used to convert one pound of animal product to grams protein: 117 (beef), 15.1 (milk), 112 (sheep), and 123 (goat).

The averaged global production costs per 20 g serving are therefore: $0.32 (beef), $0.26 (milk), sheep ($0.42), and goat ($0.36).

SI References

51. Alexandratos, N. & Bruinsma, J. *World agriculture towards 2030/2050: the 2012 revision.* Food and Agriculture Organization of the United Nations (FAO) (2012).
52. Wallace, R. J. *et al.* A heritable subset of the core rumen microbiome dictates dairy cow productivity and emissions. *Sci. Adv.* **5**, eaav8391 (2019).
53. Carlson, D. F. *et al.* Production of hornless dairy cattle from genome-edited cell lines. *Nat. Biotechnol.* **34**, 479–481 (2016).
54. Burkard, C. *et al.* Pigs Lacking the Scavenger Receptor Cysteine-Rich Domain 5 of CD163 Are Resistant to Porcine Reproductive and Respiratory Syndrome Virus 1 Infection. *J. Virol.* **92**, e00415-18, /jvi/92/16/e00415-18.atom (2018).
55. Fernbach, P. M., Light, N., Scott, S. E., Inbar, Y. & Rozin, P. Extreme opponents of genetically modified foods know the least but think they know the most. *Nat. Hum. Behav.* **3**, 251–256 (2019).
56. Kolodinsky, J. & Lusk, J. L. Mandatory labels can improve attitudes toward genetically engineered food. *Sci. Adv.* **4**, eaaq1413 (2018).
57. Norris, A. L. *et al.* Template plasmid integration in germline genome-edited cattle. *Nat. Biotechnol.* **38**, 163–164 (2020).
58. Seré, C. & Steinfeld, H. *World livestock production systems.* Food and Agriculture Organization of the United Nations (FAO) (1996).
59. *Global Livestock Environmental Assessment Model: Version 2.0: Model Description.* Food and Agriculture Organization of the United Nations (FAO) (2018).
60. *Volume 4: Agriculture, Forestry, and Other Land Uses*. Intergovernmental Panel on Climate Change (IPCC) (2006).
61. *Reducing Enteric Methane for Improving Food Security and Livelihoods.* Food and Agriculture Organization of the United Nations (FAO) (2016).
62. *Global Livestock Environmental Assessment Model: Version 2.0: Public Data Release*. Food and Agriculture Organization of the United Nations (FAO) (2018).