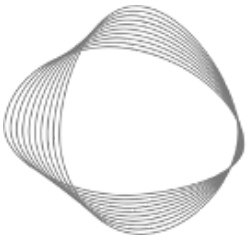
Agriculture sector: Country-level Enteric fermentation and Manure Management Emissions Estimates from Cattle Feedlots and Dairies



CLIMATE TRACE

Aaron Davitt[1,2], Gabriela Volpato[1,2], and Christy Lewis[1,2]
1) WattTime, 2) Climate TRACE

1. Introduction

According to the Food and Agriculture Organization (FAO) data (FAOSTAT), beef and dairy milk production systems are the largest contributors of greenhouse gas (GHG) emissions in the livestock sector, representing more than 60% of emissions in the sector and 14.5% of all anthropogenic sources (FAO 2013). Beef and dairy sector emissions are driven by two sources. The primary source is enteric fermentation emissions which consists of methane (CH_4) gas produced in the digestive systems of ruminants and to a lesser extent non-ruminants. The secondary source is GHG emissions from manure management, producing both methane (CH_4) and nitrous oxide (N_2O) emissions via aerobic and anaerobic decomposition of livestock manure, including the microbially-driven processes of nitrification and denitrification (Waldrip et al., 2016; Waldrip et al., 2020). These emissions occur within manure storage facilities common to beef and dairy systems, as well as in-field where manure has been applied, or deposited by livestock.

FAOSTAT is the current source for global cattle information, which provides emissions and stocks (populations total) at the country-level under the domains "Emissions from Enteric fermentation and Emissions from Manure Management" and "Crops and livestock products", respectively (https://www.fao.org/). In the FAOSTAT domain "Emissions from Enteric fermentation and manure management", emissions are broken down by item or by the cattle type: "Cattle, dairy" and "Cattle, non-dairy". The "Cattle, dairy" and "Cattle, non-dairy" types include the total number of animals of the genus *Bos* used for milk or meat production for human consumption, respectively (https://www.fao.org/). However, FAOSTAT also reports cattle populations in the domain "Crops and livestock products" which is broken into cattle types: "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" (beef and veal) and "Milk animals, Raw milk of cattle". Each domain differs in recency of years reported and when the domains' version updates occur with "Crops and livestock products" has more up-to-date information. Because of different version updates and years reported, there is a lack of consistency across FAOSTAT reporting domains, described further in section 2.1.1.

The Climate TRACE coalition seeks to provide the most up-to-date information on country-level beef and dairy emissions globally. Livestock production and processing data tend to be reported and available from FAOSTAT sooner than FAOSTAT's emissions data. In order to produce more timely emissions data, an approach was developed to use the most recently updated FAOSTAT cattle data in the "Crops and livestock products" domain and Intergovernmental Panel on Climate Change (IPCC) emissions factors (EFs) to estimate enteric fermentation and manure management emissions estimates for years 2015 to 2022.

2. Materials and Methods

The approach employed to estimate country-level feedlot and dairy emissions used FAOSTAT cattle populations data from the domain "Crops and livestock products" and applied IPCC EFs and equations from The IPCC Chapter 10: Emissions from Livestock and Manure Management and Chapter 11: N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application were used to estimate emissions **(**IPCC 2006a; IPCC 2006b). Figure 1 gives an overview of the approach.

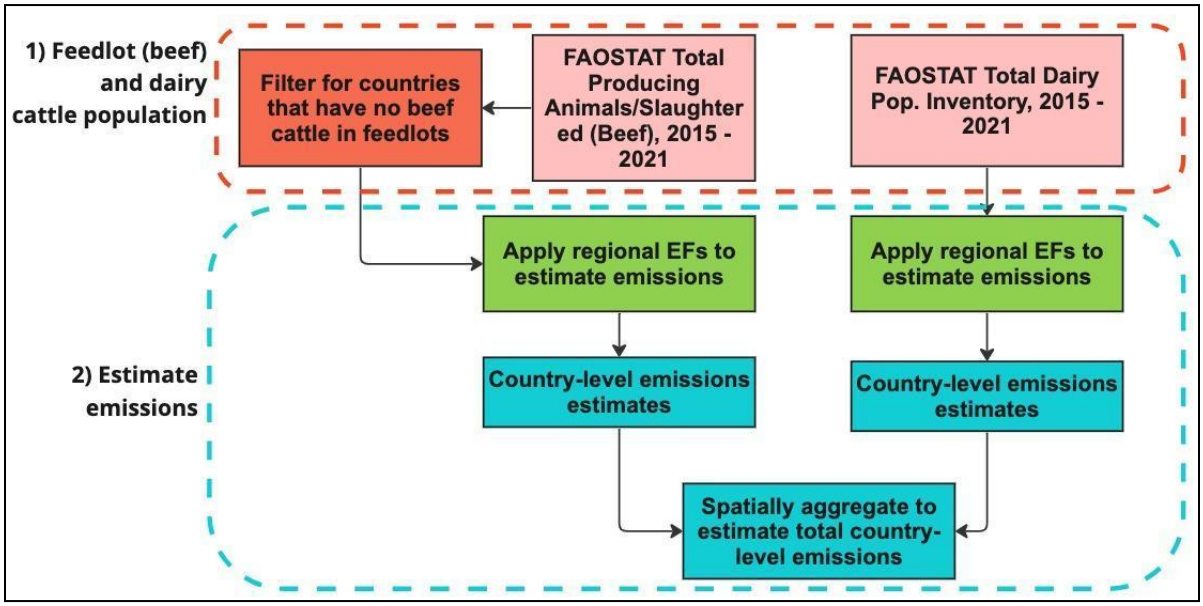


Figure 1 Flowchart depicting the FAOSTAT data used to estimate country-level feedlot and dairy emissions. More information described in text below.

2.1 Datasets employed

The approach used FAOSTAT cattle stocks items- "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" (beef and veal) and "Milk animals, Raw milk of cattle"- reported under the "Crops and livestock products" domain. Default regional EFs were applied to the data to estimate enteric fermentation and manure management emissions for years 2015 to 2022.

FAOSTAT data for years 2015 to 2021 were accessed with the year 2022 forward-filled with 2021 data. At the time of this study, the "Crops and livestock products" domain was selected since it provided the most recent cattle data, up to date as of March 24, 2023 (accessed August 1, 2023), whereas the domain "Emissions from Enteric fermentation and Emissions from Manure Management" was updated November 4, 2022. Additionally, the more recent version provided updated "Flag" and "Flag Descriptions" where reported country-level data that has an "Estimated value" was updated to "Official figure". This provides some level of confidence in a country's reported data (see Table 5 for examples of these flags).

2.1.1 FAOSTAT "Crops and Livestock" domain - identifying feedlot and dairy populations

According to the FAOSTAT Methodology, the Crops and Livestock item "Producing Animals/Slaughtered" refers to "All data shown relate to total meat production, that is, from both commercial and farm slaughter." For item "Milk animals" this is defined as "Data on cow milk production relate to total production of whole fresh milk" (FAOSTAT, 2023). As such, we treated the reported numbers for each item as representing beef and dairy cattle meant for production in each country.

We opted to not use the "Cattle, dairy" and "Cattle, non-dairy" items since these data only provided population totals up to 2020. Additionally, the "Cattle, non-dairy" item does not represent cattle only meant for meat production. Table 1 highlights this where the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) cattle subtypes were totaled and matched the FAOSTAT "Cattle, non-dairy" population totals for years 2018 to 2021. The USDA NASS reported other cattle types - stockers, heifers, steers, and bulls - when providing numbers to FAOSTAT which reports these as "Cattle, non-dairy" (Table 1). These other cattle types are used as replacement for cattle on feedlots or to replenish the cattle population. The stockers, heifers, steers, and bulls can be considered foraging on pasture or grasslands to fatten up to the desired weight so they can be finished in feedlots (McKinley et al., 2004; Endres and Schwartzkopf-Genswein, 2018; Hayek and Garrett, 2018; Aubuchon, 2021). These other cattle types were not considered for emission estimates in this sector and were reported in Climate TRACE sectors "Emissions from Enteric Fermentation and Manure Left on Pasture from Cattle" since we consider these cattle types on pasture.

To have a more representative cattle population for meat production, the same mapping exercise was applied to "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" (Table 2). By breaking down the USDA NASS data cattle types meant for slaughter, the "CATTLE, CALVES - SLAUGHTERED" and "CATTLE, GE 500 LBS - SLAUGHTERED" were identified as the cattle types meant for meat production and reported to FAOSTAT. Table 2 highlights this and shows the years 2018 and 2019 matching FAOSTAT "Producing

Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled". Only two years, 2020 and 2021, had slightly different totals. This could be due to U.S. states revising their county data after USDA NASS initial release which is not later updated in FAOSTAT (U.S. National Agricultural Statistics Service, 2018).

Therefore, we assumed other countries with "Cattle, non-dairy" populations included other cattle types in this category and the "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" were more representative of cattle meant for meat production in some type of facility, hereafter called *feedlots*. For FAOSTAT "Milk animals, Raw milk of cattle", the reported values were treated as representing cows processed for milk production in some type of facility, hereafter called *dairies*.

Table 1 USDA NASS cattle types mapped to FAOSTAT "Cattle, non-dairy" population for years 2018 to 2021. Note, FAOSTAT did not report 2021 data at the time of this writing.

Year	Data Item	Value	Year	Data Item	Value
2018	CATTLE, BULLS, GE 500 LBS - INVENTORY	2,252,300	***2020***	CATTLE, BULLS, GE 500 LBS - INVENTORY	2,237,400
	CATTLE, CALVES - INVENTORY	14,401,400		CATTLE, CALVES - INVENTORY	14,309,000
	CATTLE, COWS, BEEF - INVENTORY	31,466,200		CATTLE, COWS, BEEF - INVENTORY	31,338,700
	CATTLE, HEIFERS, GE 500 LBS - INVENTORY	20,217,800		CATTLE, HEIFERS, GE 500 LBS - INVENTORY	20,024,400
	CATTLE, STEERS, GE 500 LBS - INVENTORY	16,528,200		CATTLE, STEERS, GE 500 LBS - INVENTORY	16,541,200
	Total USDA NASS "non-dairy" =	***84,865,900***		***Total USDA NASS "non-dairy" =***	***84,450,700***
	FAOSTAT Cattle, non-dairy =	***84,865,900***		***FAOSTAT Cattle, non-dairy =***	***84,450,700***
2019	CATTLE, BULLS, GE 500 LBS - INVENTORY	2,253,000	***2021***	CATTLE, BULLS, GE 500 LBS - INVENTORY	2,210,500
	CATTLE, CALVES - INVENTORY	14,539,900		CATTLE, CALVES - INVENTORY	14,305,100
	CATTLE, COWS, BEEF - INVENTORY	31,690,700		CATTLE, COWS, BEEF - INVENTORY	30,843,600
	CATTLE, HEIFERS, GE 500 LBS - INVENTORY	20,210,000		CATTLE, HEIFERS, GE 500 LBS - INVENTORY	20,200,100
	CATTLE, STEERS, GE 500 LBS - INVENTORY	16,757,700		CATTLE, STEERS, GE 500 LBS - INVENTORY	16,787,800
	Total USDA NASS "non-dairy" =	***85,451,300***		***Total USDA NASS "non-dairy" =***	***84,347,100***
	FAOSTAT Cattle, non-dairy =	***85,451,300***		***FAOSTAT Cattle, non-dairy =***	***N/A***

Table 2 FAOSTAT "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" totals compared to USDA NASS slaughtered cattle population for years 2018 to 2021. USDA slaughtered population is the summation of "CATTLE, CALVES - SLAUGHTERED" and "CATTLE, GE 500 LBS - SLAUGHTERED". Year's differences with positive values indicates FAOSTAT reporting higher beef cattle slaughtered, negative numbers indicate USDA NASS reporting higher beef cattle slaughter, and zero values indicate matching reported values.

Any non-zero value in the difference row suggests a reporting entity updated their values since last submission.

Year	Database	Element (FAOSTAT) or Data Item (USDA NASS) and Unit	Value
2018	FAOSTAT Crops and livestock products	Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled (An)	33,703,400
	USDA NASS	CATTLE, CALVES - SLAUGHTERED, MEASURED IN HEAD	603,600
	USDA NASS	CATTLE, GE 500 LBS - SLAUGHTERED, MEASURED IN HEAD	33,099,800
		Difference (FAOSTAT - USDA NASS) =	***0***
2019	FAOSTAT Crops and livestock products	Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled (An)	34,264,800
	USDA NASS	CATTLE, CALVES - SLAUGHTERED, MEASURED IN HEAD	608,900
	USDA NASS	CATTLE, GE 500 LBS - SLAUGHTERED, MEASURED IN HEAD	33,655,900
		Difference (FAOSTAT - USDA NASS) =	***0***
2020	FAOSTAT Crops and livestock products	Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled (An)	33,366,100
	USDA NASS	CATTLE, CALVES - SLAUGHTERED, MEASURED IN HEAD	479,800
	USDA NASS	CATTLE, GE 500 LBS - SLAUGHTERED, MEASURED IN HEAD	32,885,300
		Difference (FAOSTAT - USDA NASS) =	***1,000***
2021	FAOSTAT Crops and livestock products	Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled (An)	34,360,000
	USDA NASS	CATTLE, CALVES - SLAUGHTERED, MEASURED IN HEAD	413,500
	USDA NASS	CATTLE, GE 500 LBS - SLAUGHTERED, MEASURED IN HEAD	33,946,600
		Difference (FAOSTAT - USDA NASS) =	***-100***

2.1.2 IPCC emission factors

EFs from The IPCC Chapter 10: Emissions from Livestock and Manure Management and Chapter 11: N_2O Emissions from Managed Soils, and CO_2 Emissions from Lime and Urea Application were used to estimate emissions **(**IPCC 2006a; IPCC 2006b). Cattle emissions are produced by enteric fermentation, producing CH_4, and manure management, producing CH_4 and N_2O. To estimate CH_4 and N_2O emissions, the IPCC Tier 1 approach was applied with a Tier 2 approach included for Indirect N_2O emissions due to leaching from manure management systems. For dairies and feedlots that lacked detailed manure management systems, assumptions were applied, discussed further in section 2.2.

The default IPCC “Other Cattle” and “Dairy Cows” EFs based on region, temperature and manure management systems was applied to “Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled” and “Milk animals, Raw milk of cattle” populations, respectively.

2.1.3 Temperature data

Manure management methane emissions are affected by the number of animals and the temperature (IPCC, 2006a). To reflect temperature's influence, the average annual temperature for each country was produced from the ERA5-Land Monthly Aggregated from the European Centre for Medium-Range Weather Forecasts (ECMWF) Climate Reanalysis via Google Earth Engine (Muñoz Sabater, J., 2019). The specific image collection accessed was "ECMWF/ERA5_LAND/MONTHLY_AGGR", which provided a monthly "temperature_2m" band. The Global Administrative Areas (GADM) project (Version 4.1 released on 16 July 2022) was modified by Climate TRACE and country boundaries were used to filter each month's "temperature_2m" values to within each country's national boundary and averaged to generate annual average temperatures for years 2015 to 2022. Countries with Arctic regions (i.e., Canada, U.S., and Russia) had these temperature values included in the annual average.

Each country's temperature value was used to determine the IPCC EF to use by year in Table 10.14, "Manure management methane emission factors by temperature" (IPCC 2006a). More information on the GADM employed can be found in the Supplementary section

2.2 Country-level emissions estimates

To estimate country-level enteric fermentation CH_4 and manure management CH_4 and N_2O emissions, IPCC equations and default regional "Other Cattle" and "Dairy Cows" EFs were applied to "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" and "Milk animals, Raw milk of cattle" populations, respectively. Table 3 lists the equations used. Once the emissions for each cattle type were calculated, each emission was summed to produce a total country-level.

Table 3 IPCC equations and descriptions for country-level emissions estimates.

IPCC Equation	Description
EQ 10.19	ENTERIC FERMENTATION EMISSIONS FROM A LIVESTOCK CATEGORY
EQ 10.22	CH_4 EMISSIONS FROM MANURE MANAGEMENT
EQ 10.25	DIRECT N_2O EMISSIONS FROM MANURE MANAGEMENT

EQ 10.26	N LOSSES DUE TO VOLATILISATION FROM MANURE MANAGEMENT
EQ 10.27	INDIRECT N_2O EMISSIONS DUE TO VOLATILISATION OF N FROM MANURE MANAGEMENT
EQ 10.28	N LOSSES DUE TO LEACHING FROM MANURE MANAGEMENT SYSTEMS
EQ 10.29	INDIRECT N_2O EMISSIONS DUE TO LEACHING FROM MANURE MANAGEMENT

A modification was made to EFs in Table 10A-4 "Manure Region Management System Usage (MS%)" for regions with "Other" column values. There is no clear explanation to what the "Other" column represents in relation to manure management practices or emissions. Therefore, the "Other" manure management percentage was assigned to the most common, or the highest percentage, manure management system in that region. An example of this is shown in Table 4. As a result, the most dominant manure management system percentage is higher than what was reported in IPCC CH. 10. Lastly, the "Pasture/Range/Paddock" and "Burned for Fuel" categories were not included in the country-level emissions estimates for this sector and were reported in the Climate TRACE sectors "Emissions from Enteric Fermentation and Manure Left on Pasture from Cattle" and "other-energy-use" or "Other Energy Use", respectively.

Table 4 An example of adjusting Manure Management System (MMS) Usage (MS%) to include "Other" category type. Bold italicized values in the rows indicate what MS% were combined.

	Manure Management System (MMS) Usage (MS%)									**Adjusted MMS Usage**
Region	*Lagoon*	*Liquid/ Slurry*	*Solid Storage*	*Drylot*	*Pasture/ Range/ Paddock*	*Daily Spread*	*Digester*	*Burned for Fuel*	*Other*	*Liquid/ Slurry + Other*
North America	15.00	***27.00***	26.30	0.00	10.80	18.40	0.00	0.00	***2.60***	***27.00 + 2.60 = 29.60***

Region	*Lagoon*	*Liquid/ Slurry*	*Solid Storage*	*Drylot*	*Pasture/ Range/ Paddock*	*Daily Spread*	*Digester*	*Burned for Fuel*	*Other*	*Solid Storage + Other*
Western Europe	0.00	35.70	***36.80***	0.00	20.00	7.00	0.00	0.00	***0.50***	***36.80 + 0.50 = 37.30***

2.2.1 Countries with no feedlot emissions estimates

Some countries had their "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" populations set to zero for all years or some years (Table S1). Meaning, no feedlot emissions at the country-level were generated. This is due to FAOSTAT reporting "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" population larger than the country's reported "Cattle, non-dairy" population. This may be due to FAOSTAT defining, "Total meat production includes meat from animals slaughtered in countries, irrespective of their origin" (FAOSTAT, 2023). Foreign imports could have increased the slaughtered population to higher values relative to the "Cattle, non-dairy" population, which may not have been updated to reflect this change. Table 5 provides Ukraine and Egypt as examples of different values being reported. This can be seen in the version updates for "Crops and livestock products" domain updated March 24, 2023, whereas the "Emissions from Enteric fermentation and Emissions from Manure Management" was updated November 4, 2022.

A representative cattle population for meat production could not be identified for specific countries and years listed in Table S1 since the Producing Animals/Slaughtered" population should be less than the "Cattle, non-dairy" population, as this would indicate other cattle populations types - stockers, heifers, steers, and bulls - used to replenish the cattle population or foraging on pasture (see section 2.1.1). Therefore, feedlot emissions for these countries were not generated, only dairy emissions. Instead, these countries had their "Producing Animals/Slaughtered" populations reported in the Climate TRACE sector "Emissions from Enteric Fermentation and Manure Left on Pasture from Cattle" since they were considered to be foraging on pasture.

Table 5 Egypt and Ukraine examples of "Milk Animals" compared to "Cattle, dairy" populations (top table) and "Producing Animals/Slaughtered" with larger populations relative to "Cattle, non-dairy" population (bottom table). Negative difference values indicate "Producing Animals/Slaughtered" or "Milk Animals" reporting higher populations than "Cattle, non-dairy" or "Cattle, dairy". Flags are included with each value: A = Official figure, I = Imputed value, and E = Estimated value.

Region	Year	Cattle, dairy	Milk Animals, Raw milk of cattle	Difference
Egypt	2018	1,581,467 (E)	1,582,132 (I)	-665
	2019	1,658,564 (E)	1,739,730 (I)	-81,166
	2020	1,418,355 (E)	1,727,509 (E)	-309,154
Ukraine	2018	1,995,800 (E)	1,995,800 (A)	0

Region	Year	Cattle, dairy	Milk Animals, Raw milk of cattle	Difference
Egypt	2018	1,581,467 (E)	1,582,132 (I)	-665
	2019	1,658,564 (E)	1,739,730 (I)	-81,166
	2020	1,418,355 (E)	1,727,509 (E)	-309,154
	2019	1,898,300 (E)	1,898,300 (A)	0
	2020	1,765,600 (E)	1,765,600 (A)	0

Region	Year	Cattle, non-dairy	Producing animals/slaughtered, Meat of cattle with the bone, fresh or chilled	Difference
Egypt	2018	2,797,533 (E)	1,145,000 (A)	1,652,533
	2019	1,150,436 (E)	1,386,000 (A)	-235,564
	2020	993,334 (E)	1,245,000 (A)	-251,666
Ukraine	2018	1,535,000 (E)	2,145,900 (A)	-610,900
	2019	1,434,600 (E)	2,127,500 (A)	-692,900
	2020	1,326,400 (E)	1,987,600 (A)	-661,200

2.3 Emission data produced

Country-level enteric fermentation CH_4 and manure management CH_4 and N_2O emissions estimates were generated and reported as separate sub-sectors on the Climate TRACE website (climatetrace.org). To generate CO_2 equivalent (CO_2e) for 20 year and 100 year global warming potentials (GWPs), 80.8 (20 year) and 27.2 (100 year) values were applied to total country-level CH_4 emissions for each year. For total country-level N_2O emissions, a 273 value was applied for each 20 and 100 year GWPs. The manure management sub-sector summed each CH_4 and N_2O 20 and 100 year GWPs into total 20 and 100 year GWPs. More information on specific data fields and values are described in the Supplementary section.

The following countries had their N_2O emissions replaced with the emissions generated from "Agriculture sector- Enteric fermentation and Manure Management Emissions from Cattle Individual Feedlots and Dairies": ARG, AUS, BRA, BWA, MEX, USA, and ZAF. These countries had their N_2O values replaced since the aggregation of individual feedlots and dairies generated higher N_2O emissions values than what the country-level approach estimated here using the IPCC approach. This was due to the individual feedlots and dairies having more detailed manure management systems with some having more than one type.

Of the 250 countries and administrative regions reported for this sector, 192 had emissions estimated generated for years 2015 to 2022, with 2022 emissions forward filled from 2021 emissions estimates. The remaining 58 countries and administrative regions (i.e, Bermuda, Palau, and Tuvalu) do not report or do not have cattle information in FAOSTAT, and their emissions estimates were set to zero for all years.

3. Discussion and Conclusion

By using FAOSTAT cattle information from the "Crops and livestock products" domain and generating emissions from the cattle stocks' items- "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" and "Milk animals, Raw milk of cattle", Climate TRACE produced more recent cattle emissions that is more representative of cattle at feedlots and dairies. Additionally, the mapping exercise performed in section 2.1.1 identified that FAOSTAT data is not always updated to reflect changes in reported country cattle numbers. This can create discrepancies in emissions reported depending on the data domain used.

Future work includes identifying the cattle slaughtered for meat production in countries that produced negative differences (section 2.2.1). This can include import/export data to help identify domestically cattle bred and slaughtered. Additionally, updated EFs will be considered to reflect changes in cattle practices in meat and dairy production in different countries. Lastly, countries that had temperature values from Arctic regions included in their annual average temperatures will have their values restricted to regions where feedlot and dairy production occurs. For example, in the U.S., this will exclude Alaska and focus on the continental U.S. For Canada, this will include restricting temperature values to southern areas away from the arctic. For Russia, the focused regions will be temperature values in southern and western regions. This will generate an IPCC EF from Table 10.14, "Manure management methane emission factors by temperature", that better reflects temperature influences on CH_4 manure management emissions.

4. Supplementary metadata section

Table S1 Countries values where the "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" populations are larger than "Cattle, non-dairy" population. The "+" sign indicates years where the "Cattle, non-dairy" population was larger than "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled", meaning these years had had feedlot cattle estimated. Negative values indicate years where all "Producing Animals/Slaughtered, Meat of cattle with the bone, fresh or chilled" populations were assumed to be on pasture.

Country \ Year	2015	2016	2017	2018	2019	2020	2021	2022
Albania	-184928	-189751	-202417	-133150	-211613	-217165	-181343	-199254
Armenia	-231319	-243917	-218974	-214788	-215263	-224289	-218468	-221378
Azerbaijan	+	+	-11264	-15137	-28442	-53655	-81707	-67681
Bahamas	-43	-41	-39	-39	-38	-36	-36	-36
Bahrain	-4942	-4384	-3888	-3653	-4040	-3623	-4038	-3831
Brunei Darussalam	-1553	-3875	-4739	-4375	-4244	-7169	-13244	-10207
Hong Kong	-21388	-20441	-20534	-19640	-20588	-20636	-20674	-20655
Egypt	+	+	+	+	-235564	-251666	-24192	-137929
Israel	-21866	-13939	-14484	-13164	-12877	+	+	+
Jordan	-88750	-91915	-86221	-84253	-91662	-94254	-98342	-96298

Lebanon	-189062	-170254	-187708	-180723	-197209	-180913	-177817	-179365
Mauritius	-6556	-6892	-6536	-6458	-6819	-5831	-5906	-5869
Montenegro	+	+	+	+	-1469	-4778	+	+
Netherlands	+	+	+	-104750	+	+	+	+
Palestine	-17472	-24519	-28437	-41090	-24509	-25934	-60787	-43361
Republic of Moldova	-3879	-5640	+	+	+	-4265	+	+
Sao Tome and Principe	-175	-92	-84	-84	-88	-85	-92	-89
Saudi Arabia	-100199	-101238	-102042	+	+	+	+	+
Syrian Arab Republic	+	+	-80590	-115178	-97916	-200074	-200432	-200253
Tunisia	-51896	-51791	-47559	-55415	-58604	-60928	-58568	-59748
Ukraine	-659600	-651500	-588500	-610900	-692900	-661200	-415700	-538450
United Arab Emirates	-3575	-6680	-9414	-10932	-13103	-16611	-18363	-17487

The Agriculture sector: Country-level Enteric fermentation and Manure Management Emissions Estimates from Cattle Feedlots and Dairies sector reports the following data on the Climate TRACE website:

- Country-level enteric fermentation CH_4, and 20 and 100 year GWPs emissions from feedlots and dairies
- Country-level manure management CH_4 and N_2O emissions, and 20 and 100 year from feedlots and dairies

Emissions estimates were reported for years 2015 to 2022, with 2022 emissions data forward filled with 2021 emissions data. The country-level cattle emissions described here encompasses the asset-level emissions estimates from the Climate TRACE agriculture sector: "*Facility-level Enteric fermentation and Manure Management Emissions from Cattle Feedlots and Dairies"*. Meaning, the facility-level emissions represent a subset of emissions contained in country-level emissions estimates. This sector does not include cattle on pasture emissions. All data is freely available on the Climate TRACE website (https://climatetrace.org/). A detailed description of what is available is described in Table S2.

Table S2 Metadata for Country-level Enteric fermentation and Manure Management Emissions Estimates from Cattle Feedlots and Dairies**.**

General Description	**Definition**
Sector definition	*Country-level feedlot and dairy emissions*
UNFCCC sector equivalent	*3.A.1 Cattle*
Temporal Coverage	*2015 – 2022*
Temporal Resolution	*Annual*
Data format	*CSV*
Coordinate Reference System	*None. ISO3 country code provided*
Number of countries available for download	*250 countries*
Total emissions for 2022	*Total Enteric Fermentation CH_4 emissions = 36,961,349.3 metric tons* *Total Manure Management CH_4 emissions = 3,273,954.7 metric tons* *Total Manure Management N_2O emissions = 871.24 metric tons*
Ownership	*Country*
What emission factors were used?	*IPCC CH. 10 and 11 EFs*

What is the difference between a "0" versus "NULL/none/nan" data field?	*"0" values are for true non-existent emissions. If we know that the sector has emissions for that specific gas, but the gas was not modeled, this is represented by "NULL/none/nan"*
total_CO2e_100yrGWP and total_CO2e_20yrGWP conversions	*Climate TRACE uses IPCC AR6 CO_2e GWPs. CO_2e conversion guidelines are here: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport_small.pdf*

Permissions and Use: All Climate TRACE data is freely available under the Creative Commons Attribution 4.0 International Public License, unless otherwise noted below.

Citation format: Davitt, A., Volpato, G., Lewis, C. (2023). *Country-level Enteric fermentation and Manure Management Emissions Estimates from Cattle Feedlots and Dairies.* WattTime, USA, Climate TRACE Emissions Inventory. https://climatetrace.org [Accessed date]

Geographic boundaries and names (iso3_country data attribute): The depiction and use of boundaries, geographic names and related data shown on maps and included in lists, tables, documents, and databases on Climate TRACE are generated from the Global Administrative Areas (GADM) project (Version 4.1 released on 16 July 2022) along with their corresponding ISO3 codes, and with the following adaptations:

- HKG (China, Hong Kong Special Administrative Region) and MAC (China, Macao Special Administrative Region) are reported at GADM level 0 (country/national);
- Kosovo has been assigned the ISO3 code 'XKX';
- XCA (Caspian Sea) has been removed from GADM level 0 and the area assigned to countries based on the extent of their territorial waters;
- XAD (Akrotiri and Dhekelia), XCL (Clipperton Island), XPI (Paracel Islands) and XSP (Spratly Islands) are not included in the Climate TRACE dataset;
- ZNC name changed to 'Turkish Republic of Northern Cyprus' at GADM level 0;
- The borders between India, Pakistan and China have been assigned to these countries based on GADM codes Z01 to Z09.

The above usage is not warranted to be error free and does not imply the expression of any opinion whatsoever on the part of Climate TRACE Coalition and its partners concerning the legal status of any country, area or territory or of its authorities, or concerning the delimitation of its borders.

Disclaimer: The emissions provided for this sector are our current best estimates of emissions, and we are committed to continually increasing the accuracy of the models on all levels. Please review our terms of use and the sector-specific methodology documentation before using the data. If you identify an error or would like to participate in our data validation process, please contact us.

References

1. Aubuchon, Adriene (2021). Stocker cattle could add value to your operation without breaking the bank Available at:

https://extension.missouri.edu/news/stocker-cattle-could-add-value-to-your-operation-without-breaking-the-bank-5192 (Accessed: 9 October 2023).
2. Chapter, I.P.C.C., 2006a. 10: Emissions from livestock and manure management. *Agriculture, Forestry and Other Land Use.* Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_10_Ch10_Livestock.pdf
3. Chapter, I.P.C.C., 2006b. 11: N2O Emissions from Managed Soils, and CO2 Emissions from Lime and Urea Application. *Agriculture, Forestry and Other Land Use.* Available at: https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf
4. Endres, M. I., & Schwartzkopf-Genswein, K. (2018). Overview of cattle production systems. Advances in Cattle Welfare, 1–26. doi:10.1016/b978-0-08-100938-3.00001-2
5. Hayek, M.N. and Garrett, R.D., 2018. Nationwide shift to grass-fed beef requires larger cattle population. *Environmental Research Letters*, *13*(8), p.084005.
6. McKinley, Blair, Parish, Jane, Watson, Richard, Anderson, John, Engelken, Terry, and WHite, Brad (2004). Stocker Production in Mississippi. Available at; https://extension.msstate.edu/sites/default/files/topic-files/cattle-business-mississippi-articles/cattle-business-mississippi-articles-landing-page/stocker_aug2004.pdf (Accessed: 9 October 2023).
7. United States. U.S. National Agricultural Statistics Service (2018). NASS - County Data FAQs. United States. Web Archive. https://www.nass.usda.gov/Data_and_Statistics/County_Data_Files/Frequently_Asked_Questions/index.php# (Accessed: 1 July 2023).