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Answers to Common Questions about Greenhouse Gases

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Introduction

WITH CONCERNS ABOUT CLIMATE CHANGE ON THE RISE, any meaningful public discourse about it requires a basic understanding of the types of greenhouse gases (GHGs) involved, where they come from, and projections about their impact. In this bulletin we have compiled this information, inspired by questions received from farmers and the public during producers' workshops and field days regarding GHG emissions. After discussing common terms, we respond to the six questions most often posed about US-based emissions that agriculture generates. We emphasize this sector not because of the amount or impact of emissions it creates, but rather because the industry highly influences public debate about emission reduction strategies in general.

What Are GHGs?

GHGs are gases that trap heat by absorbing and redirecting radiant energy in the thermal infrared range back toward the Earth, causing a **greenhouse effect** (the process during which GHGs trap heat from the sun that warms the Earth). GHGs further warm the Earth by redirecting energy in the form of invisible infrared light, which is emitted from heated Earth surfaces, back toward the Earth. GHGs not only trap the sun's heat but also prevent and/or slow the trapped heat from escaping into space. GHGs essentially act like a blanket insulating the Earth.

What Are the Main GHGs and How Are They Emitted?

The main GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapor (water in the gas phase), and fluorinated gases.

Carbon Dioxide

Carbon dioxide (CO_2) is the most commonly produced GHG and it comes from two primary sources—natural and anthropogenic (human-caused). Natural CO_2 emissions come from the decomposition of organic materials (carbon-based compounds originally derived from living organisms such as woods, plant residues, feather) and ocean release and respirations of biological activities (human, animal, microbes). Anthropogenic CO_2 emissions mainly come from

1. burning fossil fuels (coal, oil, and natural gas) and organic materials (wood, crop residues);
2. deforestation and land-use changes, such as the conversion of the forest into agricultural land, settlements, and commercial uses; and
3. industrial processes, such as the manufacture of fertilizer and goods.

Burning fossil fuels and organic materials contribute to about 87% of all human-produced CO_2, while deforestation and land-use changes and industrial processes emit about 9% and 4% of all human-produced CO_2, respectively (CO_2 Human Emissions 2017).

Methane

Methane (CH_4) is emitted during the production and transport of coal, natural gas, and oil. CH_4 emissions also result from livestock and other agricultural practices (rice and other crops cultivation) and by the decay of organic wastes (food processing, manure, municipal solid waste, etc.).

Nitrous Oxide

Nitrous oxide (N_2O) is emitted during agricultural and industrial activities, combustion of fossil fuels and solid waste, and during wastewater treatments. The major cause of increased atmospheric N_2O is anthropogenic activity, especially food production (Reay et al. 2012). Indeed, environmental scholars agree that agriculture is the largest human source of N_2O, about 60% of the total emissions caused by human activity (Ivens et al. 2011). The widespread use of nitrogenous fertilizers and the increase in animal production in particular account for most N_2O emissions in the agricultural sector (Reay et al. 2012; Bouwman et al. 2013).

Water Vapor

Water vapor is the most abundant GHG in the atmosphere, by both weight (about 80% of all GHGs) and volume (about 90%) (Gavin 2005). It affects climate change by absorbing longwave radiation and redirecting it back to the Earth's surface; however, it stays in the atmosphere for a much shorter period (about ten days before being precipitated out) compared to other GHGs. Human activity has only a small direct influence on its atmospheric concentration, primarily through irrigation and deforestation practices. Indeed, increased water vapor content in the atmosphere is mainly due to increased temperatures. Warm air can hold more moisture, so as temperatures rise, more evaporation from water sources and land occurs, thus increasing the atmospheric moisture content. Due to different temperatures around the world, atmospheric moisture contents vary by region.

Fluorinated Gases

Fluorinated gases (hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, nitrogen trifluoride, etc.) are emitted from a variety of industrial processes and are typically released in small quantities, but they are much more effective at trapping heat, resulting in greater warming of the Earth, compared to CO_2 (for example, sulfur hexafluoride is 23,500 times more potent than CO_2 in warming the Earth).

Why Do GHG Emissions Matter?

As GHG emissions increase, they form higher concentrations or a thicker blanket of heat, trapping GHGs in the atmosphere which alter the climate globally. Their prevalence impacts almost everything on Earth, such as people, animals, plants, society, and the environment—via more forest fires and extreme weather conditions and rising sea levels. Even more troubling, many of the major GHGs stay in the atmosphere for tens to hundreds of years after being released. Their effects on the climate thus persist over a long period of time, affecting both present and future generations.

Do GHGs Equally Affect Climate Change?

Greenhouse gases differ in their ability to trap heat, thus affecting climate changes differently. Each GHG's effect on climate change depends on three main factors:

1: How much (concentration or abundance) is in the atmosphere?

Larger emissions of GHGs lead to higher concentrations in the atmosphere. Higher concentrations have increased greenhouse effects. Figures 1–4 show global atmospheric concentrations of CO_2, CH_4, N_2O, and selected manufactured GHGs since 1950, which have all risen significantly over the last few hundred years: CO_2 concentrations increased 46% from an annual average of 280 ppm (parts per million) in the late 1700s to 410 ppm in 2019. Almost all of the increase is due to human activity. The atmospheric concentrations of CH_4 have more than doubled since preindustrial times, reaching approximately 1,800 ppb (parts per billion). Concentrations of N_2O in the atmosphere rarely exceeded 280 ppb before the 1920s. Levels have risen since the 1920s, reaching 331 ppb in 2019 (United States Environmental Protection Agency [US EPA] 2020a).

2: How long does each GHG stay in the atmosphere?

Each of these gases can remain in the atmosphere for different amounts of time, ranging from a few years to thousands of years. All GHGs (except water vapor) remain in the atmosphere long enough to become thoroughly mixed and dispersed. This means that the amount that is measured in the atmosphere is roughly the same all over the world, regardless of the source of the emission (US EPA 2022).

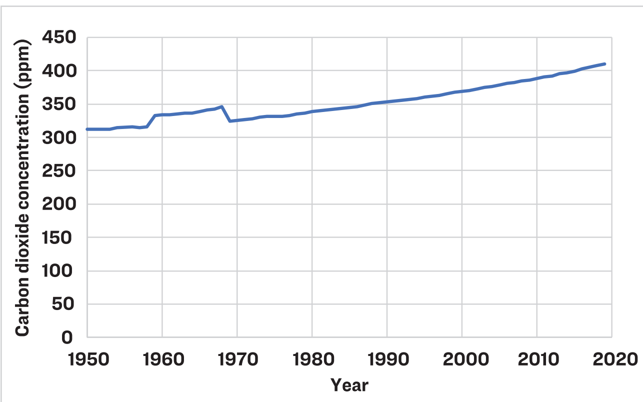

Figure 1. Global atmosphere concentrations of **CO_2** from 1950 to 2019. *Note: Data were measured from Antarctic ice cores before 1959 and then at another six locations (Mauna Loa, Hawaii; Barrow, Alaska; Cape Matatula, American Samoa; South Pole, Antarctica; Cape Grim, Australia; Lampedusa Island, Italy; the average concentration of the measured concentrations at the above locations is shown here). (Data adapted from US EPA 2020a.)*

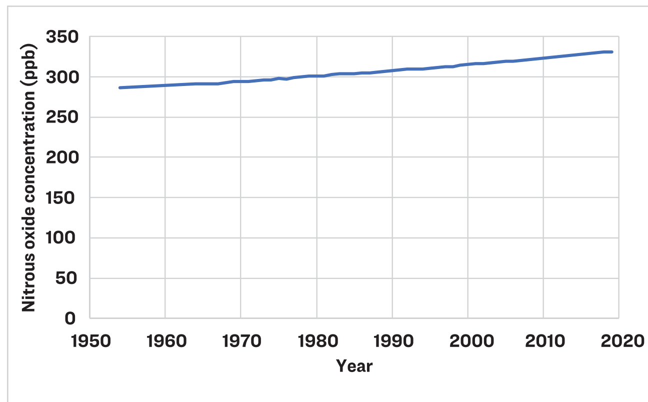

Figure 3. Global atmospheric concentration of **N_2O** from 1950 to 2019. *Note: Data measured from Antarctic ice cores before 1978 and then measured at another four locations (Cape Grim, Australia; South Pole, Antarctica; Barrow, Alaska; Mauna Loa, Hawaii; the average concentration of the measured concentrations at the above locations is shown here). (Data adapted from US EPA 2020a.)*

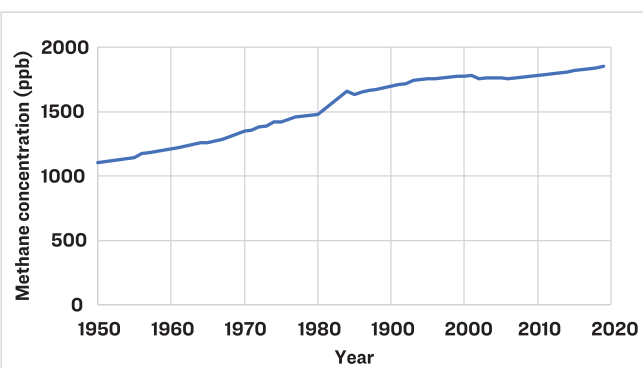

Figure 2. Global atmospheric concentration of **CH_2** from 1950 to 2019. *Note: Data measured from Antarctic ice cores before 1983 and then measured at another three locations (Cape Grim, Australia; Mauna Loa, Hawaii; Shetland Islands, Scotland. The average concentration of the measured concentrations at the above locations is shown here). (Data adapted from US EPA 2020a.)*

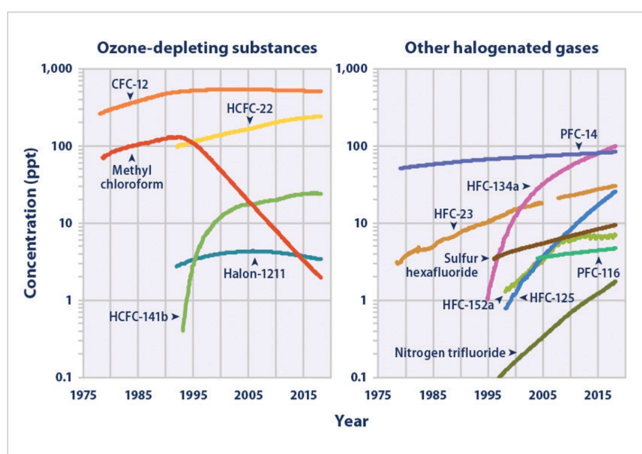

Figure 4. Global atmospheric concentrations of **selected halogenated gases**, 1978–2018. *(Adapted from US EPA 2020a.).*

3: How strongly does each GHG impact the atmosphere?

Some GHGs are more effective than others in terms of making the Earth warmer and thickening the Earth's blanket. Similar to normal blankets, the Earth's blanket materials (CO_2, CH_4, N_2O, etc.) have different warming effects. Global Warming Potential (GWP) reflects how long a GHG remains in the atmosphere, on average, and how strongly it absorbs energy. GHGs with a higher GWP absorb more energy, per pound, than gases with a lower GWP, and thus contribute more to warming the Earth. The GWP is a measure of how much heat one unit of a GHG will trap over a given period of time (20 and/or 100 years is usually used) relative to the same one unit of CO_2. GWPs thus allow us to answer the question: How much CO_2 would have the same warming effect as a certain amount of a particular GHG over a given period of time? For example, the 100-year GWP of N_2O is 275. Therefore, if one ton of N2O is released into the atmosphere, its effect on warming the Earth is the same as 275 tons of CO_2 emitted into the atmosphere. Table 1 shows major, long-lived GHGs, their average lifetime in the atmosphere, and their respective GWP. Water vapor is a GHG but is not considered to be a cause of man-made global warming since it does not persist in the atmosphere for a long time (about less than ten days). Relating to GWP, Carbon Dioxide Equivalent (CO_2e), as a standard unit, signifies the number of metric tons of CO_2 emissions with the equivalent global-warming impact as one metric ton of another GHG. A quantity of any GHG can be expressed as CO_2e by multiplying the amount of the GHG by its GWP. For an example, 10 million tons of methane is 280 million tons of CO_2e, based on methane's 100-year GWP of 28.

Table 1. Major long-lived greenhouse gases, their average lifetime in the atmosphere and their global-warming potential (US EPA 2020b).

Greenhouse gas	Average lifetime in the atmosphere	100-year global warming potential (GWP)
Carbon dioxide	See note[1]	1
Methane	12.4 year[2]	28-36
Nitrous oxide	121 year[2]	265-298
Fluorinated gases[3]	A few weeks to thousands of years	Varies (the highest is sulfur hexafluoride at 23,500)

1. No single value because CO_2 is not destroyed over time, but instead moves among different parts of the ocean-atmosphere-land system. Some of the excess CO_2 is absorbed quickly (for example, by the ocean surface), but some will remain in the atmosphere for thousands of years, due in part to the very slow process by which carbon is transferred to ocean sediments.
2. The lifetimes shown for CH_2 and N_2O are pertubation lifetimes, which are used to determine how a one-time pulse may decay as a function of time as needed for the calculation of global-warming potentials.
3. A group of gases that contain fluorine, including hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride, among other chemicals.

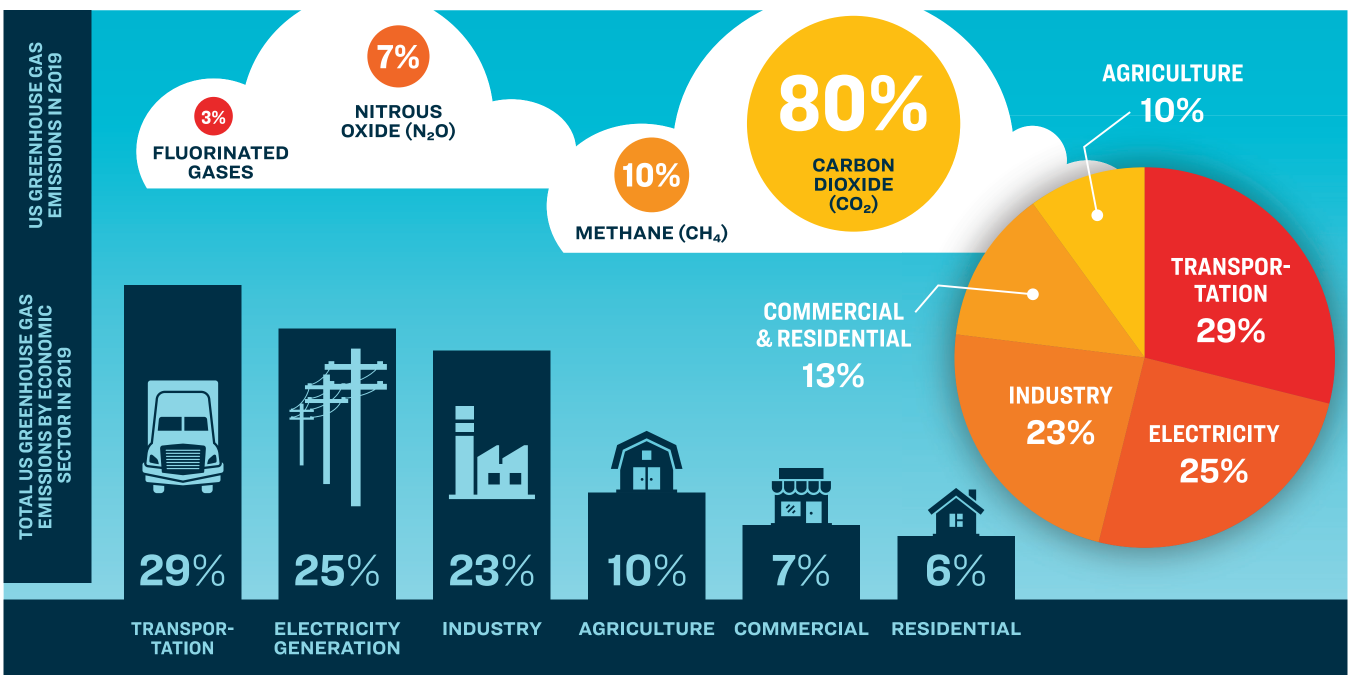

Figure 5. Overview of the main US GHG emissions, with a pie chart showing percent emissions from each sector in 2019. *(Adapted from US EPA 2020c.)*

What Are the Major GHG Emissions from US Agriculture?

GHGs emissions from the United States are often grouped into different sectors to help explain the role of a particular industry. The US EPA categorizes emissions based on six groups: agriculture, transportation, electricity generation, industry, commercial, and residential (Figure 5). The top emitters are the transportation and electricity generation sectors, which contribute 29% and 25%, respectively, of total US emissions. Agriculture, at 10%, could play a notable role in efforts to address climate change if farmers and ranchers undertake activities that reduce their operations' GHG emissions and/or remove GHGs from the atmosphere. Knowing the GHG emissions from agriculture is an essential step towards taking the right actions to reduce agriculture-based GHG emissions. Major GHG emissions from the US agriculture sector are shown in Table 2.

Based on the latest US EPA report (2019), 628.6 million metric tons of CO_2 equivalents were emitted by the agricultural sector, most of which came from N_2O and CH_4 emissions (Table 2).

Where Do the Bulk of Livestock GHG Emissions Originate?

A growing world population demands more livestock products. The United States is the world's largest beef producer, producing about 21% of global beef supplies (USDA Foreign Agricultural Service 2022). The livestock industry contributes about 4% of total US GHG emissions, with beef cattle accounting for the majority of that—about 243 MMT CO_2e (Rotz et al. 2019). The most important GHGs generated by the livestock industry are CH_4 and N_2O. The majority of these emissions originate from four main categories of the industry's activity:

1. enteric fermentation,
2. manure management,
3. feed production, processing, and transport, and
4. energy consumption.

Enteric Fermentation

Ruminant animals (cattle, buffalo, sheep, goats, etc.) produce methane as part of their digestive process. Ruminants acquire nutrients from plant-based food by fermenting food in a specialized,

Table 2. Emissions from Agriculture (MMT CO_2e.) *(Adapted from US-GHG-inventory-2021-Chapter 5-Agriculture)*

Gas/Source	1990	2005	2015	2016	2017	2018	2019
CO_2	**7.1**	**7.9**	**8.5**	**8.0**	**8.1**	**7.4**	**7.8**
Urea Fertilization	2.4	3.5	4.7	4.9	5.1	5.2	5.3
Liming	4.7	4.3	3.7	3.1	3.1	2.2	2.4
CH_4	**218.2**	**239.3**	**241.4**	**248.1**	**251.0**	**255.7**	**256.4**
Enteric Fermentation	164.7	169.3	166.9	172.2	175.8	178.0	178.6
Manure Management	37.1	51.6	57.9	59.6	59.9	61.7	62.4
Rice Cultivation	16.0	18.0	16.2	15.8	14.9	15.6	15.1
Field Burning of Agricultural Residues	0.4	0.4	0.4	0.4	0.4	0.4	0.4
N_2O	**330.1**	**329.9**	**366.2**	**348.4**	**346.4**	**357.9**	**364.4**
Agricultural Soil Management	315.9	313.4	348.5	330.1	327.6	338.2	344.6
Manure Management	14.0	16.4	17.5	18.1	18.7	19.4	19.6
Field Burning of Agricultural Residues	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Total	**555.3**	**577.1**	**616.1**	**604.4**	**605.5**	**621.0**	**628.6**

Note: Totals may not sum due to independent rounding.

four-compartment stomach before digestion. The main compartment where this fermentation occurs is called the rumen. Inside the rumen, microbial fermentation breaks down carbohydrates into simpler molecules so that they can be digested by the animals. CH_4 is a by-product of this process. Nonruminant species, such as pigs and chickens, also produce CH_4 but amounts are much lower by comparison (for example, CH_4 emissions factors for mature cows and swine are 114.3 Kg CH_4/head/year and 1.5 Kg CH_4/head/year, respectively (Crutzen et al. 1986; US EPA, Hogan 1993). In addition to the type of digestive system, an animal's feed quality and feed intake also affect CH_4 emissions. In general, lower feed quality and/or higher feed intake leads to higher CH_4 emissions. Feed intake is positively correlated to animal size, growth rate, activity level, and production stage (e.g., milk production, wool growth, pregnancy, or work). Therefore, feed intake varies among animal types and different management practices for those types (e.g., animals in feedlots or grazing on pasture).

Manure Management

CH_4 and N_2O are two main GHGs that are released during manure storage and processing. CH_4 is released from the anaerobic decomposition of organic material in manure. This occurs mostly when manure is managed in liquid form, such as in deep lagoons or holding tanks. Most of the CH_4 emissions from manure come from dairy and feedlot operations. Beef cattle raised on pasture or rangelands is not a significant source of CH_4 because the manure is applied in an aerobic condition. As reported in Inventory of US Greenhouse Gas Emissions and Sinks (US EPA 2021), CH_4 emissions from manure management were 32 million metric ton (MMT) CO_2e and 3.4 MMT CO_2e by dairy cattle and beef cattle, respectively. There are direct and indirect emissions of N_2O from manure. The direct emissions of N_2O from manure involve nitrification and denitrification processes. During the nitrification process, manure organic N is mineralized to ammonium which is then nitrified to nitrate (NO_3) under aerobic conditions. The denitrification processes occur under anaerobic conditions, during which NO_3 is denitrified to N_2O and nitrogen gas. During the storage and processing of manure, nitrogen is released in the atmosphere as ammonia that can be later transformed to N_2O, which are indirect emissions.

Feed Production, Processing, and Transport

CO_2 emissions originate from the growth of feed crops and pasture into natural habitats, which causes the oxidation of carbon in soil and vegetation. They also originate from the use of fossil fuel to manufacture fertilizer and process and transport feed. The emissions of N_2O come from the use of fertilizers (organic or synthetic) for feed production and from the direct deposition of manure on pasture or during the management and application of manure on crop fields. Direct or indirect N_2O emissions can vary greatly according to temperature and humidity at the time of application and the type of soil; their quantification is thus subject to high uncertainty.

Energy consumption: Energy consumption occurs along the entire livestock supply chains producing CO_2 emissions. At the feed-production level, energy consumption mostly relates to the production of fertilizers and to the use of machinery for crop management, harvesting, processing, and transportation. Energy is also consumed on the animal production site, either directly through mechanized operations or indirectly for the construction of buildings and of equipment. Finally, processing and transportation of animal commodities involve further energy use.

Summary

Addressing climate change is one of the most urgent issues of our time and addressing it requires understanding the gases that contribute to it and their origins. The gases contributing to climate change are numerous, but the most common ones produced by human activities are CO_2, CH_4, and N_2O. These gases stay in the atmosphere different amounts of time, from roughly 12 years for CH_4 to over 120 years for N_2O. The effectiveness of these gases on trapping heat varies as well, leading to the use of GWP numbers that allow for the comparison of different gases in units of CO2e. The sectors that emit the most emissions are transportation and electricity production. Agriculture, at 10% of total US GHG emissions, is the fourth-largest sector, with most of those emissions coming from N_2O and CH_4. These emissions are associated with enteric fermentation, manure management, feed production, and on-farm energy consumption.

References

Bouwman, L., K. K. Goldewijk, K. W. Van Der Hoek, A. H. Beusen, D. P. Van Vuuren, J. Willems, M. C. Rufino, and E. Stehfest. 2013. Exploring Global Changes in Nitrogen and Phosphorus Cycles in Agriculture Induced by Livestock Production over the 1900–2050 Period. *Proceedings of the National Academy of Sciences of the United States of America* 110(52): 20882–87.

CO2 Human Emissions. 2017. “Main Sources of Carbon Dioxide Emissions.” https://www.che-project.eu/news/main-sources-carbon-dioxide-emissions, accessed 30 September 2021.

Crutzen, P. J., I. Aselmann, and W. Seiler. 1986. Methane Production by Domestic Animals, Wild Ruminants, Other Herbivorous Fauna, and Humans. *Tellus B: Chemical and Physical Meteorology* 38(3-4): 271–84. DOI: 10.3402/tellusb.v38i3-4.15135.

Gavin. 2005. *RealClimate*. “Water Vapour: Feedback or Forcing?” http://www.realclimate.org/index.php/archives/2005/04/water-vapour-feedback-or-forcing/, accessed 17 January 17 2022.

Hogan, K. (ed). 1993. *Anthropogenic Methane Emissions in the United States: Estimates for 1990. Report to Congress*. EPA 430-R-93-003. US Environmental Protection Agency/Office of Air and Radiation: Washington DC.

Ivens, W. P. M. F., D. J. J. Tysmans, C. Kroeze, A. J. Lohr, and J. van Wijnen. 2011. Modeling Global N2O Emissions from Aquatic Systems. *Current Opinion in Environmental Sustainability* 3(5): 350–58.

Reay, D. S., E. A. Davidson, K. A. Smith, P. Smith, J. M. Melillo, F. Dentener, and P. J. Crutzen. 2012. Global Agriculture and Nitrous Oxide Emissions. *Nature Climate Change* 2: 410–16.

Rotz, C. A., S. Asem-Hiablie, S. Place, and G. Thoma. 2019. Environmental Footprints of Beef Cattle Production in the United States. *Agricultural Systems* 169: 1–13. http://doi.org/10.1016/j.agsy.2018.11.005.

United States Department of Agriculture Foreign Agricultural Service. 2022. “Livestock and Poultry: World Markets and Trade.” https://apps.fas.usda.gov/psdonline/circulars/livestock_poultry.pdf, accessed 18 March 2022.

United States Environmental Protection Agency. 2020a. “Climate Change Indicators: Atmospheric Concentrations of Greenhouse Gases.” https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases, accessed 30 September 2021.

United States Environmental Protection Agency. 2020b. Climate Change Indicators: Greenhouse Gases. https://www.epa.gov/climate-indicators/greenhouse-gases, accessed 1 October 2021.

United States Environmental Protection Agency. 2020c. Greenhouse Gas Inventory Data Explorer. https://cfpub.epa.gov/ghgdata/inventoryexplorer/, accessed 1 October 2021.

United States Environmental Protection Agency. 2021. Greenhouse Gas Emissions: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2019. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019, accessed 2 October 2021.

United States Environmental Protection Agency. 2022. Greenhouse Gas Emissions: Overview of Greenhouse Gases. https://www.epa.gov/ghgemissions/overview-greenhouse-gases, accessed 17 January 2022.

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