Global Warming Potentials (GWPs)/CO_2-equivalent (CO_2e) and the importance of time horizons

There are many different pollutants that contribute to global climate change, and they have varying lifetimes and potencies that define their climate impacts beyond pure "mass" emitted into the atmosphere. Climate metrics (e.g. GWP and CO_2e) help to compare or combine the emissions of pollutants according to their impact on the global climate.

GWP and the related CO_2e are the most common climate metrics used for climate analysis and policy.

A climate pollutant's global warming potential is its relative potency as an agent of climate change compared to CO_2 over a specified time interval. It is calculated via the cumulative radiative forcing over a specified time horizon caused by a unit emission of a pollutant relative to an equal mass of CO_2.

Emissions of either non-CO_2 climate pollutants or a sum of multiple climate pollutant emissions are often expressed in carbon dioxide equivalents (CO_2e), which is calculated by multiplying the mass of a non-CO_2 climate pollutant by its GWP. CO_2e denotes the amount of carbon dioxide that would have the same climate impact over a specified time horizon. Note that if a time horizon is not specified, it is usually 100 years.

GWP values depend on the time horizon of interest, and the more a greenhouse gas's lifetime differs from CO_2's, the more the time horizon affects the GWP value. GWP values for the same time horizon also change slightly with advancements of the underlying science (such as how potent a gas is or how long it lasts in the atmosphere). GWP values are reported in the IPCC assessment reports.

Most commonly used GWPs for methane (CH_4) and nitrous oxide (N_2O).

IPCC Report	Time Horizon	Methane (CH_4)	Nitrous oxide (N_2O)
AR4 2007	GWP20	72	289
	GWP100	25	298
AR5 2013	GWP20 *(fossil methane)*[i]	84 *(85)*	264
	GWP100 *(fossil methane)*	28 *(30)*	265
AR6 2021	GWP20 *(fossil methane)*	81 (83)	273
	GWP100 *(fossil methane)*	27 (30)	273

Here we report CO_2e using both 20- and 100-year time horizons based on the most recent IPCC sixth assessment report (2021), because this conveys climate impacts of emissions over all timescales (Ocko et al. 2017).

Equivalent activities

We follow emissions referenced in EPA calculations with modifications and additions listed below. Note that the EPA equivalency calculations are based on 100-year climate impact only.

Passenger vehicles

We include CH_4 and N_2O emissions from passenger vehicles explicitly. An average vehicle emits 4.26 metric tons of CO_2, 0.1 kg of CH_4, and 0.086 kg of N_2O every year. This yields an emission factor of 4.286 tCO_2e per vehicle for the 100-year time horizon and 4.291 tCO_2e per vehicle for the 20-year time horizon.

Pounds of beef produced

According to Poore & Nemecek 2018, on average, the life cycle of 1 kg of beef emits 4.5 kg of CO_2, 1.3 kg of CH_4, and 0.02 kg of N_2O.[ii]

Home Energy

We follow EPA's methodology to estimate the CO_2 emission factor of home energy use. In addition, we consider unburned CH_4 emissions from the natural gas portion of home energy use according to Merrin and Francisco 2019.

Natural gas CO_2 emission factor is calculated as follows:

$$39{,}319 \text{ ft}^3 \text{ per home} \times 0.0550 \text{ kg } CO_2/\text{ft}^3 \times 1/1{,}000 \text{ kg/metric ton} = 2.16 \text{ metric tons } CO_2/\text{home}$$

The amount of CH_4 emissions at 0.038% emission rate is 0.316 kg CO_2e/home.

Adding this CH_4 emission to the total emission factor 7.45 tCO_2/home yields 7.48 tCO_2e/home for the 20-year time horizon and 7.46 tCO_2e/home for the 100-year time horizon.

Home Electricity

We follow EPA's methodology to estimate the CO_2 emission factor of home electricity use. In addition, we consider CH_4 and N_2O emissions from the same data source – eGRID – where CO_2 emissions are based on. The emission factor is calculated as follows:

$$12{,}194 \text{ kWh per home} \times 823.1 \text{ lbs } CO_2 \text{ per MWh generated} \times 1/(1-0.051) \text{ MWh delivered/MWh generated} \times 1 \text{ MWh}/1{,}000 \text{ kWh} \times 1 \text{ metric ton}/2{,}204.6 \text{ lb} = 4.798 \; tCO_2/\text{home}$$

$$12{,}194 \text{ kWh per home} \times 0.066 \text{ lbs } CH_4 \text{ per MWh generated} \times 1/(1-0.051) \text{ MWh delivered/MWh generated} \times 1 \text{ MWh}/1{,}000 \text{ kWh} \times 1 \text{ metric ton}/2{,}204.6 \text{ lb} = 0.385 \text{ kg } CH_4/\text{home}$$

$$12{,}194 \text{ kWh per home} \times 0.009 \text{ lbs } N_2O \text{ per MWh generated} \times 1/(1-0.051) \text{ MWh delivered/MWh generated} \times 1 \text{ MWh}/1{,}000 \text{ kWh} \times 1 \text{ metric ton}/2{,}204.6 \text{ lb} = 0.052 \text{ kg } N_2O/\text{home}$$

This yields the emission factor of 4.84 tCO_2e/home for the 20-year time horizon and 4.82 tCO_2e/home for the 100-year time horizon.

Individual GHG emissions

		CO_2	CH_4	N_2O
Home Energy (lb gas)				
		6500	0.3	
Waste (lb gas)				
	MSW		28	
	Wastewater		3	0.6
Food (lb gas)				
		3500	52	5
Transportation (lb gas)				
	Car	9400	0.2	0.2
	Bus	50	0.02	0.001
	Rail	40	0.005	0.001
	Air	1100		
Total				
	lb/year	20590	84	6
	ton/year	10	0.04	0.003

Individual items and sources are listed below. Note that hydrofluorocarbon (HFC) emissions are not included in individual GHG emission estimates. Data has been rounded due to various uncertainties.

Home Energy

See above. Emissions are divided by the average US household size – 2.51 persons.

Waste

The EPA estimates that the average individual in the U.S. produced 4.4 lb of MSW per person per day as of 2011. EPA's GHG-calculator then estimates that 692 lb CO_2e is generated per person per year from waste. According to EPA's annual Inventory of U.S. GHG Emissions and Sinks (1990-2019), all emissions from municipal solid waste are CH_4 emissions – so this translates to ~28 lb CH_4 per person per year.

Per capita wastewater emissions were estimated by dividing the total methane and nitrous oxide wastewater emissions (the sum of domestic treatment emissions and domestic effluent emissions, from the EPA annual GHG inventory) by the U.S. population according to the census bureau. Data was used from the most recent EPA GHG inventory report for 2019 emissions.

Mt	CH_4	N_2O
Domestic treatment	0.412	0.069
Domestic effluent	0.072	0.0178

U.S. 2019 population: 334 million

Food

Emissions estimates from food were derived from the Jones & Kammen 2011 methodology, using the aggregated emissions factors for major food groups in their report and applying a percentage breakdown by gas for each food group as derived from the EIO-LCA model. Average household size is 2.5 people.

Estimates of average calories eaten per individual adult per day:

- 543 cal/day from meat, fish and eggs
- 286 cal/day from dairy
- 669 cal/day from grains and baked goods
- 271 cal/day from fruits and vegetables
- 736 cal/day from other (snacks, drinks, etc.)

	tCO_2e/yr /household	tCO_2/yr /household	tCH_4/yr /household	tN_2O/yr /household
Other (snacks and drinks)	2.507	1.86	0.01	0.001
Fruits and vegetables	0.748	0.52	0.002	0.0006
Grains and baked goods	0.896	0.42	0.003	0.001
Dairy	1.217	0.54	0.02	0.0006
Beef, pork, lamb	1.084	0.21	0.021	0.001
Poultry and eggs	0.617	0.32	0.004	0.0007
Fish and seafood	0.148	0.14	0.0004	0.000002

Transportation

Emissions from personal car use follows the method above for passenger vehicles.

Estimates of emissions from public transit were derived from the Jones & Kammen 2011 estimates of average miles traveled per mode of public transit, and average emissions factors for each mode, then separated by gas using the EPA annual GHG inventory.

	Miles traveled/year/person	**g CO_2e/mile**
Bus	73	300
Rail	106	172
Air (all CO_2)	2566	200

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[i] CO_2 produced from methane oxidation in the atmosphere is additional to the climate if methane emitted is from fossil sources.

[ii] The breakdown of GHGs follows the average percentage breakdown from multiple studies (Alemu et al. 2016, Basarab et al. 2012, Cardoso et al. 2016, Cederberg et al. 2009, Mazzetto et al. 2015, Phetteplace et al. 2001, Ridoutt et al. 2011, Verge et al. 2008, Veysset et al. 2011, White et al. 2014, White et al. 2015, Zhu et al. 2015)