Greenhouse Gases Equivalencies Calculator - Calculations and References

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This page describes the calculations used to convert greenhouse gas emission numbers into different types of equivalent units. Go to the equivalencies calculator page for more information.

A note on global warming potentials (GWPs): Some of the equivalencies in the calculator are reported as CO_2 equivalents (CO_2E). These are calculated using GWPs from the Intergovernmental Panel on Climate Change's Fourth Assessment Report.

Electricity Reductions (kilowatt-hours)

The Greenhouse Gas Equivalencies Calculator uses the AVoided Emissions and geneRation Tool (AVERT) U.S. national weighted average CO_2 marginal emission rate to convert reductions of kilowatt-hours into avoided units of carbon dioxide emissions.

Most users of the Equivalencies Calculator who seek equivalencies for electricity-related emissions want to know equivalencies for emissions reductions from energy efficiency (EE) or renewable energy (RE) programs. Calculating the emission impacts of EE and RE on the electricity grid requires estimating the amount of fossil-fired generation and emissions being displaced by EE and RE. A marginal emission factor is the best representation to estimate which fossil-fired units EE/RE are displacing across the fossil fleet. EE and RE programs are not generally assumed to affect baseload power plants that run all the time, but rather marginal power plants that are brought online as necessary to meet demand. Therefore, AVERT provides a national marginal emission factor for the Equivalencies Calculator.

Emission Factor

1,562.4 lbs CO_2/MWh × (4.536 × 10^{-4} metric tons/lb) × 0.001 MWh/kWh = 7.09 × 10^{-4} metric tons CO_2/kWh
(AVERT, U.S. national weighted average CO_2 marginal emission rate, year 2019 data)

Notes:

- This calculation does not include any greenhouse gases other than CO_2.
- This calculation includes line losses.
- Regional marginal emission rates are also available on the AVERT web page.

Sources

- EPA (2020) AVERT, U.S. national weighted average CO_2 marginal emission rate, year 2019 data. U.S. Environmental Protection Agency, Washington, DC.

Gallons of gasoline consumed

In the preamble to the joint EPA/Department of Transportation rulemaking on May 7, 2010 that established the initial National Program fuel economy standards for model years 2012-2016, the agencies stated that they had agreed to use a common conversion factor of 8,887 grams of CO_2 emissions per gallon of gasoline consumed (Federal Register 2010). For reference, to obtain the number of grams of CO_2 emitted per gallon of gasoline combusted, the heat content of the fuel per gallon can be multiplied by the kg CO_2 per heat content of the fuel.

This value assumes that all the carbon in the gasoline is converted to CO_2 (IPCC 2006).

Calculation

8,887 grams of CO_2/gallon of gasoline = 8.887×10^{-3} metric tons CO_2/gallon of gasoline

Sources

- Federal Register (2010). Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, page 25,330 (PDF) (407 pp, 5.7MB, About PDF).
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Gallons of diesel consumed

In the preamble to the joint EPA/Department of Transportation rulemaking on May 7, 2010 that established the initial National Program fuel economy standards for model years 2012-2016, the agencies stated that they had agreed to use a common conversion factor of 10,180 grams of CO_2 emissions per gallon of diesel consumed (Federal Register 2010). For reference, to obtain the number of grams of CO_2 emitted per gallon of diesel combusted, the heat content of the fuel per gallon can be multiplied by the kg CO_2 per heat content of the fuel.

This value assumes that all the carbon in the diesel is converted to CO_2 (IPCC 2006).

Calculation

10,180 grams of CO_2/gallon of diesel = 10.180 × 10^{-3} metric tons CO_2/gallon of diesel

Sources

- Federal Register (2010). Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, page 25,330 (PDF) (407 pp, 5.7MB, About PDF).
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Passenger vehicles per year

Passenger vehicles are defined as 2-axle 4-tire vehicles, including passenger cars, vans, pickup trucks, and sport/utility vehicles.

In 2018, the weighted average combined fuel economy of cars and light trucks was 22.5 miles per gallon (FHWA 2020). The average vehicle miles traveled (VMT) in 2018 was 11,556 miles per year (FHWA 2020).

In 2018, the ratio of carbon dioxide emissions to total greenhouse gas emissions (including carbon dioxide, methane, and nitrous oxide, all expressed as carbon dioxide equivalents) for passenger vehicles was 0.993 (EPA 2020).

The amount of carbon dioxide emitted per gallon of motor gasoline burned is 8.89 × 10^{-3} metric tons, as calculated in the “Gallons of gasoline consumed” section above.

To determine annual greenhouse gas emissions per passenger vehicle, the following methodology was used: VMT was divided by average gas mileage to determine gallons of gasoline consumed per vehicle per year. Gallons of gasoline consumed was multiplied by carbon dioxide per gallon of gasoline to determine carbon dioxide emitted per vehicle per year. Carbon dioxide emissions were then divided by the ratio of carbon dioxide emissions to total vehicle greenhouse gas emissions to account for vehicle methane and nitrous oxide emissions.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

8.89 × 10^{-3} metric tons CO_2/gallon gasoline × 11,556 VMT $_{\text{car/truck average}}$ × 1/22.5 miles per gallon $_{\text{car/truck average}}$ × 1 CO_2, CH_4, and N_2O/0.993 CO_2 = **4.60 metric tons CO_2E/vehicle /year**

Sources

- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Chapter 3 (Energy), Tables 3-13, 3-14, and 3-15. Environmental Protection Agency, Washington, D.C. EPA #430-R-20-002 (PDF) (116 pp, 3 MB About PDF)
- FHWA (2020). Highway Statistics 2018. Office of Highway Policy Information, Federal Highway Administration. Table VM-1. (1 pp, 193 KB About PDF)

Miles driven by the average passenger vehicle

Passenger vehicles are defined as 2-axle 4-tire vehicles, including passenger cars, vans, pickup trucks, and sport/utility vehicles.

In 2018, the weighted average combined fuel economy of cars and light trucks was 22.5 miles per gallon (FHWA 2020). In 2018, the ratio of carbon dioxide emissions to total greenhouse gas emissions (including carbon dioxide, methane, and nitrous oxide, all expressed as carbon dioxide equivalents) for passenger vehicles was 0.993 (EPA 2020).

The amount of carbon dioxide emitted per gallon of motor gasoline burned is 8.89×10^{-3} metric tons, as calculated in the "Gallons of gasoline consumed" section above.

To determine annual greenhouse gas emissions per mile, the following methodology was used: carbon dioxide emissions per gallon of gasoline were divided by the average fuel economy of vehicles to determine carbon dioxide emitted per mile traveled by a typical passenger vehicle. Carbon dioxide emissions were then divided by the ratio of carbon dioxide emissions to total vehicle greenhouse gas emissions to account for vehicle methane and nitrous oxide emissions.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

8.89×10^{-3} metric tons CO_2/gallon gasoline × 1/22.5 miles per gallon $_{\text{car/truck average}}$ × 1 CO_2, CH_4, and N_2O/0.993 CO_2 = 3.98 **x 10^{-4} metric tons CO_2E/mile**

Sources

- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Chapter 3 (Energy), Tables 3-13, 3-14, and 3-15. Environmental Protection Agency, Washington, D.C. EPA #430-R-20-002 (PDF) (116 pp, 3 MB About PDF)
- FHWA (2020). Highway Statistics 2018. Office of Highway Policy Information, Federal Highway Administration. Table VM-1. (1 pp, 193 KB About PDF)

Therms and Mcf of natural gas

Carbon dioxide emissions per therm are determined by converting million British thermal units (mmbtu) to therms, then multiplying the carbon coefficient times the fraction oxidized times the ratio of the molecular weight of carbon dioxide to carbon (44/12).

0.1 mmbtu equals one therm (EIA 2018). The average carbon coefficient of pipeline natural gas burned in 2018 is 14.43 kg carbon per mmbtu (EPA 2020). The fraction oxidized to CO_2 is assumed to be 100 percent (IPCC 2006).

Note: When using this equivalency, please keep in mind that it represents the CO_2 equivalency of CO_2 released for natural gas **burned** as a fuel, not natural gas released to the atmosphere. Direct methane emissions released to the atmosphere (without burning) are about 25 times more powerful than CO_2 in terms of their warming effect on the atmosphere.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

0.1 mmbtu/1 therm × 14.43 kg C/mmbtu × 44 kg CO_2/12 kg C × 1 metric ton/1,000 kg = **0.0053 metric tons CO_2/therm**

Carbon dioxide emissions per therm can be converted to carbon dioxide emissions per thousand cubic feet (Mcf) using the average heat content of natural gas in 2018, 10.36 therms/Mcf (EIA 2019).

0.0053 metric tons CO_2/therm x 10.36 therms/Mcf = **0.0548 metric tons CO_2/Mcf**

Sources

- EIA (2019). Monthly Energy Review March 2019, Table A4: Approximate Heat Content of Natural Gas for End-Use Sector Consumption. (PDF) (1 pp, 54 KB, About PDF)
- EIA (2018). Natural Gas Conversions – Frequently Asked Questions.
- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), Table A-43. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-20-002 (PDF) (108 pp, 2 MB, About PDF)
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Barrels of oil consumed

Carbon dioxide emissions per barrel of crude oil are determined by multiplying heat content times the carbon coefficient times the fraction oxidized times the ratio of the molecular weight of carbon dioxide to that of carbon (44/12).

The average heat content of crude oil is 5.80 mmbtu per barrel (EPA 2020). The average carbon coefficient of crude oil is 20.31 kg carbon per mmbtu (EPA 2020). The fraction oxidized is assumed to be 100 percent (IPCC 2006).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

5.80 mmbtu/barrel × 20.31 kg C/mmbtu × 44 kg CO_2/12 kg C × 1 metric ton/1,000 kg = **0.43 metric tons CO_2/barrel**

Sources

- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), Table A-43 for C coefficient and Table A-53 for heat content. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-20-002 (PDF) (108 pp, 2 MB, About PDF)
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Tanker trucks filled with gasoline

The amount of carbon dioxide emitted per gallon of motor gasoline burned is 8.89 × 10^{-3} metric tons, as calculated in the “Gallons of gasoline consumed” section above. A barrel equals 42 gallons. A typical gasoline tanker truck contains 8,500 gallons.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

8.89 × 10^{-3} metric tons CO_2/gallon × 8,500 gallons/tanker truck = **75.54 metric tons CO_2/tanker truck**

Sources

- Federal Register (2010). Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards; Final Rule, page 25,330 (PDF) (407 pp, 5.7MB, About PDF).
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Number of incandescent bulbs switched to light-emitting diode bulbs

A 9 watt light-emitting diode (LED) bulb produces the same light output as a 43 watt incandescent light bulb. Annual energy consumed by a light bulb is calculated by multiplying the power (43 watts) by the average daily use (3 hours/day) by the number of days per year (365). Assuming an average daily use of 3 hours per day, an incandescent bulb consumes 47.1 kWh per year, and an LED bulb consumes 9.9 kWh per year (EPA 2019). Annual energy savings from replacing an incandescent light bulb with an equivalent LED bulb are calculated by multiplying the 34-watt difference in power between the two bulbs (43 watts minus 9 watts) by 3 hours per day and by 365 days per year.

Carbon dioxide emissions reduced per light bulb switched from an incandescent bulb to a light-emitting diode bulb are calculated by multiplying annual energy savings by the national weighted average carbon dioxide marginal emission rate for delivered electricity. The national weighted average carbon dioxide marginal emission rate for delivered electricity in 2019 was 1,562.4 lbs CO_2 per megawatt-hour, which accounts for losses during transmission and distribution (EPA 2020).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

34 watts x 3 hours/day x 365 days/year x 1 kWh/1,000 Wh = **37.2 kWh/year/bulb replaced**

37.2 kWh/bulb/year x 1,562.4 pounds CO_2/MWh delivered electricity x 1 MWh/1,000 kWh x 1 metric ton/2,204.6 lbs = **2.64×10^{-2} metric tons CO_2/bulb replaced**

Sources

- EPA (2020). AVERT, U.S. national weighted average CO_2 marginal emission rate, year 2018 data. U.S. Environmental Protection Agency, Washington, DC.
- EPA (2019). Savings Calculator for ENERGY STAR Qualified Light Bulbs. U.S. Environmental Protection Agency, Washington, DC.

Home electricity use

In 2019, 120.9 million homes in the United States consumed 1,437 billion kilowatt-hours (kWh) of electricity (EIA 2020a). On average, each home consumed 11,880 kWh of delivered electricity (EIA 2020a). The national average carbon dioxide output rate for electricity generated in 2018 was 947.2 lbs CO_2 per megawatt-hour (EPA 2020), which translates to about 1,021.6 lbs CO_2 per megawatt-hour for delivered electricity, assuming transmission and distribution losses of 7.3% (EIA 2020b; EPA 2020).[1]

Annual home electricity consumption was multiplied by the carbon dioxide emission rate (per unit of electricity delivered) to determine annual carbon dioxide emissions per home.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

11,880 kWh per home × 947.2 lbs CO_2 per megawatt-hour generated × 1/(1-0.073) MWh delivered/MWh generated × 1 MWh/1,000 kWh × 1 metric ton/2,204.6 lb = **5.505 metric tons CO_2/home.**

Sources

- EIA (2020a). 2019 Annual Energy Outlook, Table A4: Residential Sector Key Indicators and Consumption.
- EIA (2020b). 2019 Annual Energy Outlook, Table A8: Electricity Supply, Disposition, Prices, and Emissions.
- EPA (2020). eGRID, U.S. annual national emission factor, year 2018 data. U.S. Environmental Protection Agency, Washington, DC.

Home energy use

In 2019, there were 120.9 million homes in the United States (EIA 2020a). On average, each home consumed 11,880 kWh of delivered electricity. Nationwide household consumption of natural gas, liquefied petroleum gas, and fuel oil totaled 5.22, 0.46, and 0.45 quadrillion Btu, respectively, in 2019 (EIA 2020a). Averaged across households in the United States, this amounts to 41,712 cubic feet of natural gas, 42 gallons of liquefied petroleum gas, and 27 gallons of fuel oil per home.

The national average carbon dioxide output rate for generated electricity in 2018 was 947.2 lbs CO_2 per megawatt-hour (EPA 2020), which translates to about 1,021.6 lbs CO_2 per megawatt-hour for delivered electricity (assuming transmission and distribution losses of 7.3%) (EPA 2020; EIA 2020b).[1]

The average carbon dioxide coefficient of natural gas is 0.0548 kg CO_2 per cubic foot (EIA 2019c). The fraction oxidized to CO_2 is 100 percent (IPCC 2006).

The average carbon dioxide coefficient of distillate fuel oil is 430.80 kg CO_2 per 42-gallon barrel (EPA 2020). The fraction oxidized to CO_2 is 100 percent (IPCC 2006).

The average carbon dioxide coefficient of liquefied petroleum gases is 235.7 kg CO_2 per 42-gallon barrel (EPA 2020). The fraction oxidized is 100 percent (IPCC 2006).

Total home electricity, natural gas, distillate fuel oil, and liquefied petroleum gas consumption figures were converted from their various units to metric tons of CO_2 and added together to obtain total CO_2 emissions per home.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

1. Electricity: 11,880 kWh per home × 947 lbs CO_2 per megawatt-hour generated × (1/(1-0.073)) MWh generated/MWh delivered × 1 MWh/1,000 kWh × 1 metric ton/2,204.6 lb = 5.505 metric tons CO_2/home.

2. Natural gas: 41,712 cubic feet per home × 0.0548 kg CO_2/cubic foot × 1/1,000 kg/metric ton = 2.29 metric tons CO_2/home

3. Liquid petroleum gas: 41.8 gallons per home × 1/42 barrels/gallon × 235.7 kg CO_2/barrel × 1/1,000 kg/metric ton = 0.23 metric tons CO_2/home

4. Fuel oil: 27.1 gallons per home × 1/42 barrels/gallon × 430.80 kg CO_2/barrel × 1/1,000 kg/metric ton = 0.28 metric tons CO_2/home

Total CO_2 emissions for energy use per home: 5.505 metric tons CO_2 for electricity + 2.29 metric tons CO_2 for natural gas + 0.23 metric tons CO_2 for liquid petroleum gas + 0.29 metric tons CO_2 for fuel oil = **8.30 metric tons CO_2 per home per year**.

Sources

- EIA (2020a). 2020 Annual Energy Outlook, Table A4: Residential Sector Key Indicators and Consumption.
- EIA (2020b). 2020 Annual Energy Outlook, Table A8: Electricity Supply, Disposition, Prices, and Emissions.
- EIA (2019). Monthly Energy Review November 2019, Table A4: Approximate Heat Content of Natural Gas for End-Use Sector Consumption. (PDF) (270 pp, 2.65 MB, About PDF)
- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Annex 2 (Methodology for Estimating CO_2 Emissions from Fossil Fuel Combustion), Table A-47 and Table A-53. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-20-002 (PDF) (108 pp, 2 MB, About PDF)
- EPA (2020). eGRID, U.S. annual national emission factor, year 2016 data. U.S. Environmental Protection Agency, Washington, DC.
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Number of urban tree seedlings grown for 10 years

A medium growth coniferous or deciduous tree, planted in an urban setting and allowed to grow for 10 years, sequesters 23.2 and 38.0 lbs of carbon, respectively. These estimates are based on the following assumptions:

- The medium growth coniferous and deciduous trees are raised in a nursery for one year until they become 1 inch in diameter at 4.5 feet above the ground (the size of tree purchased in a 15-gallon container).
- The nursery-grown trees are then planted in a suburban/urban setting; the trees are not densely planted.

- The calculation takes into account "survival factors" developed by U.S. DOE (1998). For example, after 5 years (one year in the nursery and 4 in the urban setting), the probability of survival is 68 percent; after 10 years, the probability declines to 59 percent. To estimate losses of growing trees, in lieu of a census conducted to accurately account for the total amount of seedlings planted versus surviving to a certain age, the sequestration rate (in lbs per tree) is multiplied by the survival factor to yield a probability-weighted sequestration rate. These values are summed for the 10-year period, beginning from the time of planting, to derive the estimate of 23.2 lbs of carbon per coniferous tree or 38.0 lbs of carbon per deciduous tree.

The estimates of carbon sequestered by coniferous and deciduous trees were then weighted by the percent share of coniferous versus deciduous trees in cities across the United States. Of a sample of approximately 11,000 coniferous and deciduous trees in seventeen major U.S. cities, approximately 11 percent and 89 percent of sampled trees were coniferous and deciduous, respectively (McPherson et al. 2016). Therefore, the weighted average carbon sequestered by a medium growth coniferous or deciduous tree, planted in an urban setting and allowed to grow for 10 years, is 36.4 lbs of carbon per tree.

Please note the following caveats to these assumptions:

- While most trees take 1 year in a nursery to reach the seedling stage, trees grown under different conditions and trees of certain species may take longer: up to 6 years.
- Average survival rates in urban areas are based on broad assumptions, and the rates will vary significantly depending upon site conditions.
- Carbon sequestration is dependent on growth rate, which varies by location and other conditions.
- This method estimates only direct sequestration of carbon, and does not include the energy savings that result from buildings being shaded by urban tree cover.
- This method is best used as an estimation for suburban/urban areas (i.e., parks, along sidewalks, yards) with highly dispersed tree plantings and is not appropriate for reforestation projects.

To convert to units of metric tons CO_2 per tree, multiply by the ratio of the molecular weight of carbon dioxide to that of carbon (44/12) and the ratio of metric tons per pound (1/2,204.6).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

(0.11 [percent of coniferous trees in sampled urban settings] × 23.2 lbs C/coniferous tree) + (0.89 [percent of deciduous trees in sampled urban settings] × 38.0 lbs C/deciduous tree) = 36.4 lbs C/tree

36.4 lbs C/tree × (44 units CO_2/12 units C) × 1 metric ton/2,204.6 lbs = **0.060 metric ton CO_2 per urban tree planted**

Sources

- McPherson, E. G.; van D. N. S.; Peper, P. J. (2016). Urban tree database and allometric equations. Gen. Tech. Rep. PSW-GTR-253. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 86 p.
- U.S. DOE (1998). Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings. Voluntary Reporting of Greenhouse Gases, U.S. Department of Energy, Energy Information Administration (16 pp, 111K, About PDF)

Acres of U.S. forests sequestering CO2 for one year

Forests are defined herein as managed forests that have been classified as forests for over 20 years (i.e., excluding forests converted to/from other land-use types). Please refer to the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* for a discussion of the definition of U.S. forests and methodology for estimating carbon stored in U.S. forests (EPA 2020).

Growing forests accumulate and store carbon. Through the process of photosynthesis, trees remove CO_2 from the atmosphere and store it as cellulose, lignin, and other compounds. The rate of accumulation of carbon in a forested landscape is equal to overall tree growth minus removals (i.e., harvest for the production of paper and wood and tree loss from natural disturbances) minus decomposition. In most U.S. forests, growth exceeds removals and decomposition, so the amount of carbon stored nationally in forested lands is increasing overall, though at a decreasing rate.

Calculation for U.S. Forests

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* (EPA 2020) provides data on the net change in forest carbon stocks and forest area.

Annual Net Change in Carbon Stocks per Area in Year t = (Carbon $\text{Stocks}_{(t+1)}$ - Carbon Stocks_{t})/Area of land remaining in the same land-use category

Step 1: Determine the carbon stock change between years by subtracting carbon stocks in year t from carbon stocks in year (t+1). This calculation, also found in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* (EPA 2020), uses the USDA Forest Service estimates of carbon stocks in 2019 minus carbon stocks in 2018. (This calculation includes carbon stocks in the aboveground biomass, belowground biomass, dead wood, litter, and soil organic and mineral carbon pools. C gains attributed to harvested wood products are not included in this calculation.)

Annual Net Change in Carbon Stocks in Year 2018 = 56,016 MMT C – 55,897 MMT C = **154 MMT C**

Step 2: Determine the annual net change in carbon stocks (i.e., sequestration) per area by dividing the carbon stock change in U.S. forests from Step 1 by the total area of U.S. forests remaining in forests in year t (i.e., the area of land that did not change land-use categories between the time periods).

Applying the Step 2 calculation to data developed by the USDA Forest Service for the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* yields a result of 200 metric tons of carbon per hectare (or 81 metric tons of carbon per acre) for the carbon stock density of U.S. forests in 2018, with an annual net change in carbon stock per area in 2018 of 0.55 metric tons of carbon sequestered per hectare per year (or 0.22 metric tons of carbon sequestered per acre per year).

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

Carbon Stock Density in Year 2018 = (55,897 MMT C × 10^6) / (279,787 thou. hectares × 10^3) = **200 metric tons of carbon stored per hectare**

Annual Net Change in Carbon Stock per Area in Year 2018 = (-154 MMT C × 10^6) / (279,787 thou. hectares × 10^3) = **-0.55 metric tons of carbon sequestered per hectare per year***

*Negative values indicate carbon sequestration.

From 2007 to 2018, the average annual sequestration of carbon per area was 0.55 metric tons C/hectare/year (or 0.22 metric tons C/acre/year) in the United States, with a minimum value of 0.52 metric tons C/hectare/year (or 0.22 metric tons C/acre/year) in 2014, and a maximum value of 0.57 metric tons C/hectare/year (or 0.23 metric tons C/acre/year) in 2011 and 2015.

These values include carbon in the five forest pools: aboveground biomass, belowground biomass, dead wood, litter, and soil organic and mineral carbon, and are based on state-level Forest Inventory and Analysis (FIA) data. Forest carbon stocks and carbon stock change are based on the stock difference methodology and algorithms described by Smith, Heath, and Nichols (2010).

Conversion Factor for Carbon Sequestered in One Year by 1 Acre of Average U.S. Forest

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

-0.22 metric ton C/acre/year* × (44 units CO_2/12 units C) = **-0.82 metric ton CO_2/acre/year sequestered annually by one acre of average U.S. forest.**

*Negative values indicate carbon sequestration.

Please note that this is an estimate for “average” U.S. forests from 2017 to 2018; i.e., the annual net change in carbon stock for U.S. forests as a whole between 2017 and 2018. Significant geographical variations underlie the national estimates, and the values calculated here might not be representative of individual regions, states, or changes in the species composition of additional acres of forest.

To estimate carbon sequestered (in metric tons of CO_2) by additional "average" forestry acres in one year, multiply the number of additional acres by -0.82 metric ton CO_2 acre/year.

Sources

- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-20-002 (PDF) (733 pp, 14 MB, About PDF)
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 (Agriculture, Forestry and Other Land Use). Intergovernmental Panel on Climate Change, Geneva, Switzerland.
- Smith, J., Heath, L., & Nichols, M. (2010). *U.S. Forest Carbon Calculation Tool User's Guide: Forestland Carbon Stocks and Net Annual Stock Change*. *General Technical Report NRS-13 revised,* U.S. Department of Agriculture Forest Service, Northern Research Station.

Acres of U.S. forest preserved from conversion to cropland

Forests are defined herein as managed forests that have been classified as forests for over 20 years (i.e., excluding forests converted to/from other land-use types). Please refer to the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* for a discussion of the definition of U.S. forests and methodology for estimating carbon stored in U.S. forests (EPA 2020).

Based on data developed by the USDA Forest Service for the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018*, the carbon stock density of U.S. forests in 2018 was 200 metric tons of carbon per hectare (or 81 metric tons of carbon per acre) (EPA 2020). This estimate is composed of the five carbon pools: aboveground biomass (53 metric tons C/hectare), belowground biomass (11 metric tons C/hectare), dead wood (10 metric tons C/hectare), litter (13 metric tons C/hectare), and soil carbon, which includes mineral soils (92 metric tons C/hectare) and organic soils (21 metric tons C/hectare).

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* estimates soil carbon stock changes using U.S.-specific equations, IPCC guidelines, and data from the USDA Natural Resource Inventory and the DayCent biogeochemical model (EPA 2020). When calculating carbon stock changes in biomass due to conversion from forestland to cropland, the IPCC guidelines indicate that the average carbon stock change is equal to the carbon stock change due to removal of biomass from the outgoing land use (i.e., forestland) plus the carbon stocks from one year of growth in the incoming land use (i.e., cropland), or the carbon in biomass immediately after the conversion minus the carbon in biomass prior to the conversion plus the carbon stocks from one year of growth in the incoming land use (i.e., cropland) (IPCC 2006). The carbon stock in annual cropland biomass after one year is 5 metric tons C per hectare, and the carbon content of dry aboveground biomass is 45 percent (IPCC 2006). Therefore, the carbon stock in cropland after one year of growth is estimated to be 2.25 metric tons C per hectare (or 0.91 metric tons C per acre).

The averaged reference soil carbon stock (for high-activity clay, low-activity clay, sandy soils, and histosols for all climate regions in the United States) is 40.83 metric tons C/hectare (EPA 2020). Carbon stock change in soils is time-dependent, with a default time period for transition between equilibrium soil carbon values of 20 years for soils in cropland systems (IPCC 2006). Consequently, it is assumed that the change in equilibrium soil carbon will be annualized over 20 years to represent the annual flux in mineral and organic soils.

Organic soils also emit CO_2 when drained. Emissions from drained organic soils in forestland and drained organic soils in cropland vary based on the drainage depth and climate (IPCC 2006). The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* estimates emissions from drained organic soils using U.S.-specific emission factors for cropland and IPCC (2014) default emission factors for forestland (EPA 2020).

The annual change in emissions from one hectare of drained organic soils can be calculated as the difference between the emission factors for forest soils and cropland soils. The emission factors for drained organic soil on temperate forestland are 2.60 metric tons C/hectare/year and 0.31 metric tons C/hectare/year (EPA 2020, IPCC 2014), and the average emission factor for drained organic soil on cropland for all climate regions is 13.17 metric tons C/hectare/year (EPA 2020).

The IPCC (2006) guidelines indicate that there are insufficient data to provide a default approach or parameters to estimate carbon stock change from dead organic matter pools or belowground carbon stocks in perennial cropland (IPCC 2006).

Calculation for Converting U.S. Forests to U.S. Cropland

Annual Change in Biomass Carbon Stocks on Land Converted to Other Land-Use Category

$$\Delta CB = \Delta C_G + C_{Conversion} - \Delta C_L$$

Where:

ΔCB = annual change in carbon stocks in biomass on land converted to another land-use category (i.e., change in biomass on land converted from forest to cropland)

ΔC_G = annual increase in carbon stocks in biomass due to growth on land converted to another land-use category (i.e., 2.25 metric tons C/hectare on cropland one year after conversion from forestland)

$C_{Conversion}$ =initial change in carbon stocks in biomass on land converted to another land-use category. The sum of the carbon stocks in aboveground, belowground, dead wood, and litter biomass (-86.97 metric tons C/hectare). Immediately after conversion from forestland to cropland, the carbon stock of aboveground biomass is assumed to be zero, as the land is cleared of all vegetation before planting crops)

ΔC_L = annual decrease in biomass stocks due to losses from harvesting, fuel wood gathering, and disturbances on land converted to other land-use category (assumed to be zero)

Therefore: $\Delta CB = \Delta C_G + C_{Conversion} - \Delta C_L$ = -84.72 metric tons C/hectare/year of biomass carbon stocks are lost when forestland is converted to cropland in the year of conversion.

Annual Change in Organic Carbon Stocks in Mineral and Organic Soils

$$\Delta C_{Soil} = (SOC_0 - SOC_{(0-T)})/D$$

Where:

ΔC_{Soil} = annual change in carbon stocks in mineral and organic soils

SOC_0 = soil organic carbon stock in last year of inventory time period (i.e., 40.83 mt/hectare, the average reference soil carbon stock)

$SOC_{(0\text{-}T)}$ = soil organic carbon stock at beginning of inventory time period (i.e., 113 mt C/hectare, which includes 92 mt C/hectare in mineral soils plus 21 mt C/hectare in organic soils)

D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values (i.e., 20 years for cropland systems)

Therefore: $\Delta C_{Soil} = (SOC_0 - SOC_{(0\text{-}T)})/D = (40.83 - 113)/20 = -3.60$ metric tons C/hectare/year of soil C lost.

Source: **(IPCC 2006)**.

Annual Change in Emissions from Drained Organic Soils

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2018* uses default IPCC (2014) factors for drained organic soil on forestland and U.S.-specific factors for cropland. The change in emissions from drained organic soils per hectare is estimated as the difference between emission factors for drained organic forest soils and drained organic cropland soils.

$$\Delta L_{Organic} = EF_{cropland} - EF_{forestland}$$

Where:

$\Delta L_{Organic}$ = Annual change in emissions from drained organic soils per hectare

$EF_{cropland}$= 13.17 metric tons C/hectare/year (average of emission factors for drained organic cropland soils in sub-tropical, cold temperate, and warm temperate climates in the United States) (EPA 2020)

$EF_{forestland}$= 2.60 + 0.31 = 2.91 metric tons C/hectare/year (emission factors for temperate drained organic forest soils) (IPCC 2014)

$\Delta L_{organic}$ = 13.17 - 2.91 = 10.26 metric tons C/hectare/year emitted

Consequently, the change in carbon density from converting forestland to cropland would be -84.72 metric tons of C/hectare/year of biomass plus -3.60 metric tons C/hectare/year of soil C, minus 10.26 metric tons C/hectare/year from drained organic soils, equaling a total loss of 98.5 metric tons C/hectare/year (or -39.89 metric tons C/acre/year) in the year of conversion. To convert to carbon dioxide, multiply by the ratio of the molecular weight of carbon dioxide to that of carbon (44/12), to yield a value of -361.44 metric tons CO_2/hectare/year (or -147.27 metric tons CO_2/acre/year) in the year of conversion.

Conversion Factor for Carbon Sequestered by 1 Acre of Forest Preserved from Conversion to Cropland

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

-39.89 metric tons C/acre/year* x (44 units CO_2/12 units C) = **-146.27 metric tons CO_2/acre/year (in the year of conversion)**

*Negative values indicate CO_2 that is NOT emitted.

To estimate CO_2 not emitted when an acre of forest is preserved from conversion to cropland, simply multiply the number of acres of forest not converted by -146.27 mt CO_2/acre/year. Note that this represents CO_2 avoided in the year of conversion. Please also note that this calculation method assumes that all of the forest biomass is oxidized during clearing (i.e., none of the burned biomass remains as charcoal or ash) and does not include any carbon stored in harvested wood products post-harvest. Also note that this estimate includes both mineral soil and organic soil carbon stocks.

Sources

- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-20-002 (PDF) (733 pp, 14 MB, About PDF)
- IPCC (2014). 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Chapter 2: Drained Inland Organic Soils. Intergovernmental Panel on Climate Change, Geneva, Switzerland.
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 (Agriculture, Forestry and Other Land Use). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Propane cylinders used for home barbecues

Propane is 81.7 percent carbon (EPA 2020). The fraction oxidized is assumed to be 100 percent (IPCC 2006).

Carbon dioxide emissions per pound of propane were determined by multiplying the weight of propane in a cylinder times the carbon content percentage times the fraction oxidized times the ratio of the molecular weight of carbon dioxide to that of carbon (44/12). Propane cylinders vary with respect to size; for the purpose of this equivalency calculation, a typical cylinder for home use was assumed to contain 18 pounds of propane.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

18 pounds propane/1 cylinder × 0.817 pounds C/pound propane × 0.4536 kilograms/pound × 44 kg CO_2/12 kg C × 1 metric ton/1,000 kg = **0.024 metric tons CO_2/cylinder**

Sources

- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Annex 2 (Methodology for Estimating CO_2 Emissions from Fossil Fuel Combustion), Table A-56. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-20-002 (PDF) (108 pp, 2 MB, About PDF).
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Railcars of coal burned

The average heat content of coal consumed by the electric power sector in the U.S. in 2018 was 20.85 mmbtu per metric ton (EIA 2019). The average carbon coefficient of coal combusted for electricity generation in 2018 was 26.09 kilograms carbon per mmbtu (EPA 2020). The fraction oxidized is assumed to be 100 percent (IPCC 2006).

Carbon dioxide emissions per ton of coal were determined by multiplying heat content times the carbon coefficient times the fraction oxidized times the ratio of the molecular weight of carbon dioxide to that of carbon (44/12). The amount of coal in an average railcar was assumed to be 100.19 short tons, or 90.89 metric tons (Hancock 2001).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

20.85 mmbtu/metric ton coal × 26.09 kg C/mmbtu × 44 kg CO_2/12 kg C × 90.89 metric tons coal/railcar × 1 metric ton/1,000 kg = **181.29 metric tons CO_2/railcar**

Sources

- EIA (2019). Monthly Energy Review November 2019, Table A5: Approximate Heat Content of Coal and Coal Coke. (PDF) (1 pp, 56 KB, About PDF)
- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Annex 2 (Methodology for Estimating CO_2 Emissions from Fossil Fuel Combustion), Table A-43. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-20-002 (PDF) (108 pp, 3 MB, About PDF).
- Hancock (2001). Hancock, Kathleen and Sreekanth, Ande. *Conversion of Weight of Freight to Number of Railcars*. *Transportation Research Board*, Paper 01-2056, 2001.
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Pounds of coal burned

The average heat content of coal consumed by the electric power sector in the U.S. in 2018 was 20.85 mmbtu per metric ton (EIA 2019). The average carbon coefficient of coal combusted for electricity generation in 2018 was 26.09 kilograms carbon per mmbtu (EPA 2019). The fraction oxidized is 100 percent (IPCC 2006).

Carbon dioxide emissions per pound of coal were determined by multiplying heat content times the carbon coefficient times the fraction oxidized times the ratio of the molecular weight of carbon dioxide to that of carbon (44/12).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

20.85 mmbtu/metric ton coal × 26.09 kg C/mmbtu × 44 kg CO_2/12 kg C × 1 metric ton coal/2,204.6 pound of coal x 1 metric ton/1,000 kg = **9.05×10^{-4} metric tons CO_2/pound of coal**

Sources

- EIA (2019). Monthly Energy Review November 2019, Table A5: Approximate Heat Content of Coal and Coal Coke. (PDF) (1 pp, 56 KB, About PDF)
- EPA (2020). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018. Annex 2 (Methodology for Estimating CO_2 Emissions from Fossil Fuel Combustion), Table A-43. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-R-20-002 (PDF) (108 pp, 2 MB, About PDF).
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 (Energy). Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Tons of waste recycled instead of landfilled

To develop the conversion factor for recycling rather than landfilling waste, emission factors from EPA's Waste Reduction Model (WARM) were used (EPA 2019). These emission factors were developed following a life-cycle assessment methodology using estimation techniques developed for national inventories of greenhouse gas emissions. According to WARM, the net emission reduction from recycling mixed recyclables (e.g., paper, metals, plastics), compared with a baseline in which the materials are landfilled (i.e., accounting for the avoided emissions from landfilling), is 2.94 metric tons of carbon dioxide equivalent per short ton.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

2.94 metric tons CO_2 equivalent/ton of waste recycled instead of landfilled

Sources

- EPA (2019). Waste Reduction Model (WARM), Version 15. U.S. Environmental Protection Agency.

Number of garbage trucks of waste recycled instead of landfilled

The carbon dioxide equivalent emissions avoided from recycling instead of landfilling 1 ton of waste are 2.94 metric tons CO_2 equivalent per ton, as calculated in the "Tons of waste recycled instead of landfilled" section above.

Carbon dioxide emissions reduced per garbage truck full of waste were determined by multiplying emissions avoided from recycling instead of landfilling 1 ton of waste by the amount of waste in an average garbage truck. The amount of waste in an average garbage truck was assumed to be 7 tons (EPA 2002).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

2.94 metric tons CO_2 equivalent /ton of waste recycled instead of landfilled x 7 tons/garbage truck = **20.58 metric tons CO_2E/garbage truck of waste recycled instead of landfilled**

Sources

- EPA (2019). Waste Reduction Model (WARM), Version 15. U.S. Environmental Protection Agency.
- EPA (2002). Waste Transfer Stations: A Manual for Decision-Making. U.S. Environmental Protection Agency (PDF) (66 pp, 523 KB, About PDF).

Trash bags of waste recycled instead of landfilled

According to WARM, the net emission reduction from recycling mixed recyclables (e.g., paper, metals, plastics), compared with a baseline in which the materials are landfilled (i.e., accounting for the avoided emissions from landfilling), is 2.94 metric tons CO_2 equivalent per short ton, as calculated in the "Tons of waste recycled instead of landfilled" section above.

Carbon dioxide emissions reduced per trash bag full of waste were determined by multiplying emissions avoided from recycling instead of landfilling 1 ton of waste by the amount of waste in an average trash bag.

The amount of waste in an average trash bag was calculated by multiplying the average density of mixed recyclables by the average volume of a trash bag.

According to EPA's standard volume-to-weight conversion factors, the average density of mixed recyclables is 111 lbs per cubic yard (EPA 2016a). The volume of a standard-sized trash bag was assumed to be 25 gallons, based on a typical range of 20 to 30 gallons (EPA 2016b).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

2.94 metric tons CO_2 equivalent /short ton of waste recycled instead of landfilled × 1 short ton/2,000 lbs × 111 lbs of waste/cubic yard × 1 cubic yard/173.57 dry gallons × 25 gallons/trash bag = **2.35 x 10^{-2} metric tons CO_2 equivalent/trash bag of waste recycled instead of landfilled**

Sources

- EPA (2019). Waste Reduction Model (WARM), Version 15. U.S. Environmental Protection Agency.
- EPA (2016a). Volume-to-Weight Conversion Factors (PDF). Office of Resource Conservation and Recovery. April 2016. U.S. Environmental Protection Agency. (7 pp, 318 KB, About PDF)
- EPA (2016b). Waste Container Options. Last updated on February 21, 2016. U.S. Environmental Protection Agency.

Coal-fired power plant emissions for one year

In 2018, a total of 264 power plants used coal to generate at least 95% of their electricity (EPA 2020). These plants emitted 1,047,138,303.3 metric tons of CO_2 in 2018.

Carbon dioxide emissions per power plant were calculated by dividing the total emissions from power plants whose primary source of fuel was coal by the number of power plants.

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

1,047,138,303.3 metric tons of CO_2 × 1/264 power plants = **3,966,432.97 metric tons CO_2/power plant**

Sources

- EPA (2020). eGRID year 2018 data. U.S. Environmental Protection Agency, Washington, DC.

Number of wind turbines running for a year

In 2018, the average nameplate capacity of wind turbines installed in the U.S. was 2.42 MW (DOE 2019). The average wind capacity factor in the U.S. in 2018 was 35 percent (DOE 2019).

Electricity generation from an average wind turbine was determined by multiplying the average nameplate capacity of a wind turbine in the United States (2.42 MW) by the average U.S. wind capacity factor (0.35) and by the number of hours per year. It was assumed that the electricity generated from an installed wind turbine would replace marginal sources of grid electricity.

The U.S. annual wind national marginal emission rate to convert reductions of kilowatt-hours into avoided units of carbon dioxide emissions is 6.48×10^{-4} (EPA 2020).

Carbon dioxide emissions avoided per year per wind turbine installed were determined by multiplying the average electricity generated per wind turbine in a year by the annual wind national marginal emission rate (EPA 2020).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

2.42 $_{\text{MWaverage capacity}}$ x 0.35 x 8,760 hours/year x 1,000 kWh/MWh x 6.4818 x 10^{-4} metric tons CO_2/kWh reduced = **4,807 metric tons CO_2/year/wind turbine installed**

Sources

- DOE (2019). 2018 Wind Technologies Market Report (98 pp, 2.47 MB). U.S. Department of Energy, Energy Efficiency and Renewable Energy Division.
- EPA (2020) AVERT, U.S. annual wind national marginal emission rate, year 2019 data. U.S. Environmental Protection Agency, Washington, DC.

Number of smartphones charged

According to U.S. DOE, the 24-hour energy consumed by a common smartphone battery is 14.46 Watt-hours (DOE 2020). This includes the amount of energy needed to charge a fully depleted smartphone battery and maintain that full charge throughout the day. The average time required to completely recharge a smartphone battery is 2 hours (Ferreira et al. 2011). Maintenance mode power, also known as the power consumed when the phone is fully charged and the charger is still plugged in, is 0.13 Watts (DOE 2020). To obtain the amount of energy consumed to charge the smartphone, subtract the amount of energy consumed in “maintenance mode” (0.13 Watts times 22 hours) from the 24-hour energy consumed (14.46 Watt-hours).

Carbon dioxide emissions per smartphone charged were determined by multiplying the energy use per smartphone charged by the national weighted average carbon dioxide marginal emission rate for delivered electricity. The national weighted average carbon dioxide marginal emission rate for delivered electricity in 2019 was 1,562.4 lbs CO_2 per megawatt-hour, which accounts for losses during transmission and distribution (EPA 2020).

Calculation

Note: Due to rounding, performing the calculations given in the equations below may not return the exact results shown.

[14.46 Wh – (22 hours x 0.13 Watts)] x 1 kWh/1,000 Wh = 0.012 kWh/smartphone charged

0.012 kWh/charge x 1,562.4 pounds CO_2/MWh delivered electricity x 1 MWh/1,000 kWh x 1 metric ton/2,204.6 lbs = **8.22 x 10^{-6} metric tons CO_2/smartphone charged**

Sources

- DOE (2020). Compliance Certification Database. Energy Efficiency and Renewable Energy Appliance and Equipment Standards Program.
- EPA (2029). AVERT, U.S. national weighted average CO_2 marginal emission rate, year 2019 data. U.S. Environmental Protection Agency, Washington, DC.
- Federal Register (2016). Energy Conservation Program: Energy Conservation Standards for Battery Chargers; Final Rule, page 38,284 (PDF) (71 pp, 0.7 MB, About PDF).
- Ferreira, D., Dey, A. K., & Kostakos, V. (2011). Understanding Human-Smartphone Concerns: A Study of Battery Life. Pervasive Computing, pp.19-33. doi:10.1007/978-3-642-21726-5_2.

[1] The annual 2019 U.S. transmission and distribution losses were determined as ((Net Generation to the Grid + Net Imports – Total Electricity Sales)/Total Electricity Sales) (i.e., (3,988 + 48 –3,762)/3,762 = 7.28%). This percentage considers all transmission and distribution losses that occur between net generation and electricity sales. The data are from the Annual Energy Outlook 2020, Table A8: Electricity Supply, Disposition, Prices, and Emissions available at: https://www.eia.gov/outlooks/aeo/.

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