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EPA United States Environmental Protection Agency

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 emissions 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 emissions factor for the Equivalencies Calculator.

Emission Factor

1,640.7 lbs CO_2/MWh × (4.536 × 10^{-4} metric tons/lb) × 0.001 MWh/kWh = 7.44 × 10^{-4} metric tons CO_2/kWh
(AVERT, U.S. national weighted average CO_2 marginal emission rate, year 2016 data)

Notes:

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

Sources

- EPA (2017) AVERT, U.S. national weighted average CO_2 marginal emission rate, year 2016 data. U.S. Environmental Protection Agency, Washington, DC.

Gallons of gasoline consumed

To obtain the number of grams of CO_2 emitted per gallon of gasoline combusted, the heat content of the fuel per gallon is multiplied by the kg CO_2 per heat content of the fuel. 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).

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. 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 2015, the weighted average combined fuel economy of cars and light trucks combined was 22.0 miles per gallon (FHWA 2017). The average vehicle miles traveled in 2015 was 11,443 miles per year (FHWA 2017).

In 2015, 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 0.989 (EPA 2017).

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: vehicle miles traveled (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 × 11,443 VMT $_{\text{car/truck average}}$ × 1/22.0 miles per gallon $_{\text{car/truck average}}$ × 1 CO_2, CH_4, and N_2O/0.989 CO_2 = **4.67 metric tons CO_2E/vehicle /year**

Sources

- EPA (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Chapter 3 (Energy), Tables 3-12, 3-13, and 3-14. Environmental Protection Agency, Washington, D.C. EPA #430-P-17-001 (PDF) (633 pp, 15 MB About PDF)
- FHWA (2017). Highway Statistics 2015. Office of Highway Policy Information, Federal Highway Administration. Table VM-1. (1 pp, 37 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 2015, the weighted average fuel economy of cars and light trucks combined was 22.0 miles per gallon (FHWA 2017). In 2015, 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 0.989 (EPA 2017).

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 × 1/22.0 miles per gallon $_{\text{car/truck average}}$ × 1 CO_2, CH_4, and N_2O/0.989 CO_2 = **4.08×10^{-4} metric tons CO_2E/mile**

Sources

- EPA (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Chapter 3 (Energy), Tables 3-12, 3-13, and 3-14. Environmental Protection Agency, Washington, D.C. EPA #430-P-17-001 (PDF) (633 pp, 15 MB About PDF)
- FHWA (2017). Highway Statistics 2015. Office of Highway Policy Information, Federal Highway Administration. Table VM-1. (1 pp, 37 KB About PDF)

Therms and Mcf of natural gas

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

The average heat content of natural gas is 0.1 mmbtu per therm (EIA 2016). The average carbon coefficient of natural gas is 14.46 kg carbon per mmbtu (EPA 2017). The fraction oxidized to CO_2 is 100 percent (IPCC 2006).

Note: When using this equivalency, please keep in mind that it represents the CO_2 equivalency 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 × 14.46 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 2015, 10.37 therms/Mcf (EIA 2017).

0.0053 metric tons CO_2/therm x 10.37 therms/Mcf = **0.0550 metric tons CO_2/Mcf**

Sources

- EIA (2017). Monthly Energy Review April 2017: Approximate Heat Content of Natural Gas for End-Use Sector Consumption, Table A4. (PDF) (35.6 KB, About PDF)
- EIA (2016). Natural Gas Conversions – Frequently Asked Questions.
- EPA (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), Table A-40. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-P-17-001 (PDF) (100 pp, 2 MB, About PDF)
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. 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 2017). The average carbon coefficient of crude oil is 20.31 kg carbon per mmbtu (EPA 2017). The fraction oxidized is 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 (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), Table A-40 and Table A-49. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-P-17-001 (PDF) (100 pp, 2 MB, About PDF)
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. 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. 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 2015). Annual energy savings from replacing an incandescent light bulb with an equivalent LED bulb are calculated by subtracting the annual energy consumption of the LED bulb (9.9 kWh) from the annual energy consumption of the incandescent bulb (47.1 kWh).

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 generated electricity in 2016 was 1,641 lbs CO_2 per megawatt-hour (EPA 2017), which translates to about 1,769 lbs CO_2 per megawatt-hour for delivered electricity (assuming transmission and distribution losses at 7.3%) (EIA 2017; EPA 2017).[1]

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 1,769 pounds CO_2/MWh delivered electricity x 1 MWh/1,000 kWh x 1 metric ton/2,204.6 lbs = **2.99×10^{-2} metric tons CO_2/bulb replaced**

Sources

- EIA (2017). 2017 Annual Energy Outlook, Table A8.
- EPA (2017). AVERT, U.S. national weighted average CO_2 marginal emission rate, year 2016 data. U.S. Environmental Protection Agency, Washington, DC.
- EPA (2015). Savings Calculator for ENERGY STAR Qualified Light Bulbs. U.S. Environmental Protection Agency, Washington, DC.

Home electricity use

In 2016, 116.1 million homes in the United States consumed 1,410 billion kilowatt-hours (kWh) of electricity (EIA 2017a). On average, each home consumed 12,148 kWh of delivered electricity (EIA 2017a). The national average carbon dioxide output rate for electricity generated in 2016 was 1,122.9 lbs CO_2 per megawatt-hour (EPA 2017), which translates to about 1,210.8 lbs CO_2 per megawatt-hour for delivered electricity, assuming transmission and distribution losses at 7.3% (EIA 2017b; EPA 2017).[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.

12,148 kWh per home × 1,122.9 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 = **6.672 metric tons CO_2/home.**

Sources

- EIA (2017a). 2017 Annual Energy Outlook, Table A4.
- EIA (2017b). 2017 Annual Energy Outlook, Table A8.
- EPA (2017). eGRID, U.S. annual national emission factor, year 2014 data. U.S. Environmental Protection Agency, Washington, DC.

Home energy use

In 2016, there were 116.1 million homes in the United States (EIA 2017a). On average, each home consumed 12,148 kWh of delivered electricity. Nationwide household consumption of natural gas, liquefied petroleum gas, and fuel oil totaled 4.56, 0.43, and 0.43 quadrillion Btu, respectively, in 2016 (EIA 2017a). Averaged across households in the United States, this amounts to 37,922 cubic feet of natural gas, 41 gallons of liquefied petroleum gas, and 27 gallons of fuel oil per home.

The national average carbon dioxide output rate for generated electricity in 2016 was 1,122.9 lbs CO_2 per megawatt-hour (EPA 2017a), which translates to about 1,210.8 lbs CO_2 per megawatt-hour for delivered electricity (assuming transmission and distribution losses at 7.3%) (EPA 2017a; EIA 2017b).[1]

The average carbon dioxide coefficient of natural gas is 0.0550 kg CO_2 per cubic foot (EPA 2017b). The fraction oxidized to CO_2 is 100 percent (IPCC 2006).

The average carbon dioxide coefficient of distillate fuel oil is 429.61 kg CO_2 per 42-gallon barrel (EPA 2017b). 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 2017b). 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: 12,148 kWh per home × 1,123 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 = 6.672 metric tons CO_2/home.

2. Natural gas: 37,922 cubic feet per home × 0.0550 kg CO_2/cubic foot × 1/1,000 kg/metric ton = 2.09 metric tons CO_2/home

3. Liquid petroleum gas: 40.7 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: 26.9 gallons per home × 1/42 barrels/gallon × 429.61 kg CO_2/barrel × 1/1,000 kg/metric ton = 0.27 metric tons CO_2/home

Total CO_2 emissions for energy use per home: 6.672 metric tons CO_2 for electricity + 2.09 metric tons CO_2 for natural gas + 0.23 metric tons CO_2 for liquid petroleum gas + 0.27 metric tons CO_2 for fuel oil = **9.26 metric tons CO_2 per home per year**.

Sources

- EIA (2017a). 2017 Annual Energy Outlook, Table A4.
- EIA (2017b). 2017 Annual Energy Outlook, Table A8.
- EPA (2017a). eGRID, U.S. annual national emission factor, year 2014 data. U.S. Environmental Protection Agency, Washington, DC.
- EPA (2017b). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), Table A-61. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-P-17-001 (PDF) (100 pp, 2 MB, About PDF)
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Number of tree seedlings grown for 10 years

A medium growth coniferous tree, planted in an urban setting and allowed to grow for 10 years, sequesters 23.2 lbs of carbon. This estimate is based on the following assumptions:

- The medium growth coniferous 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. For each year, 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 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.

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.

23.2 lbs C/tree × (44 units CO_2/12 units C) × 1 metric ton/2,204.6 lbs = **0.039 metric ton CO_2 per urban tree planted**

Sources

- 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 storing carbon 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: 1990–2015* for a discussion of the definition of U.S. forests and methodology for estimating carbon stored in U.S. forests (EPA 2017).

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 is equal to growth minus removals (i.e., harvest for the production of paper and wood) minus decomposition. In most U.S. forests, growth exceeds removals and decomposition, so the amount of carbon stored nationally is increasing overall.

Calculation for U.S. Forests

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015* (EPA 2017) provides data on the net change in forest carbon stocks and forest area. Net changes in carbon attributed to harvested wood products are not included in the calculation.

Annual Net Change in Carbon Stocks per Area in Year n = (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 includes carbon stocks in the above-ground biomass, below-ground biomass, dead wood, litter, and soil organic carbon pools.)

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 n+1 (i.e., the area of land that did not change land-use categories between the time periods).

Applying these calculations to data developed by the USDA Forest Service for the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015* yields a result of 187 metric tons of carbon per hectare (or 76 metric tons of carbon per acre) for the carbon stock density of U.S. forests in 2015, with an annual net change in carbon stock per area in 2015 of 0.57 metric tons of carbon sequestered per hectare per year (or 0.23 metric tons of carbon sequestered per acre per year). These values include carbon in the five forest pools: above-ground biomass, below-ground biomass, deadwood, litter, and soil organic 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.

-0.23 metric ton C/acre/year* x (44 units CO_2/12 units C) = **-0.85 metric ton CO_2 sequestered annually by one acre of average U.S. forest.[1]**

*Negative values indicate carbon sequestration.

Please note that this is an estimate for "average" U.S. forests in 2015; i.e., for U.S. forests as a whole in 2015. 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 forestry acres in one year, simply multiply the number of acres by 0.85 mt CO_2 acre/year. From 2005–2015 the average annual sequestration of carbon per area was 0.59 metric tons C hectare/year (or 0.24 metric tons C acre/year) in the United States, with a minimum value of 0.57 metric tons C hectare/year (or 0.23 metric tons C acre/year) in 2005, and a maximum value of 0.61 metric tons C hectare/year (or 0.25 metric tons C acre/year) in 2011.

Sources

- EPA (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-P-17-001 (PDF) (633 pp, 15 MB, About PDF)
- IPCC (2006). *Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use.* Task Force on National Greenhouse Gas Inventories.

- 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: 1990–2015* for a discussion of the definition of U.S. forests and methodology for estimating carbon stored in U.S. forests (EPA 2017).

Based on data developed by the USDA Forest Service for the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015*, the carbon stock density of U.S. forests in 2015 was 187 metric tons of carbon per hectare (or 76 metric tons of carbon per acre) (EPA 2017). This estimate is composed of the five carbon pools: aboveground biomass (52 metric tons C/hectare), belowground biomass (11 metric tons C /hectare), dead wood (9 metric tons C/hectare), litter (10 metric tons/C hectare), and soil organic carbon, which includes mineral soils (104 metric tons C/hectare).

The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015* estimates soil carbon stock changes using U.S.-specific equations and data from the USDA Natural Resource Inventory and the Century biogeochemical model (EPA 2017). 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, and sandy soils for all climate regions in the United States) is 40.83 metric tons C/hectare (EPA 2017). Carbon stock change in soils is time-dependent, with a default time period for transition between equilibrium soil organic carbon values of 20 years for mineral soils in cropland systems (IPCC 2006). Consequently, it is assumed that the change in equilibrium mineral soil organic carbon will be annualized over 20 years to represent the annual flux. 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 below-ground 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

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)

$C_{Conversion}$ = initial change in carbon stocks in biomass on land converted to another land-use category. The sum of the carbon stocks in aboveground, belowground, deadwood, and litter biomass (-81.68 metric tons C/hectare). Immediately after conversion from forestland to cropland, 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: $\Delta CB = \Delta C_G + C_{Conversion} - \Delta C_L$ = -79.43 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 Soils

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

Where:

$\Delta C_{Mineral}$ = annual change in carbon stocks in mineral soils

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

$SOC_{(0-T)}$ = soil organic carbon stock at beginning of inventory time period (i.e., 104 mt C/hectare)

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: $\Delta C_{Mineral} = (SOC_0 - SOC_{(0-T)})/D = (40.83 - 104)/20 = -3.17$ metric tons C/hectare/year of soil organic C lost.

Source: **(IPCC 2006)**.

Consequently, the change in carbon density from converting forestland to cropland would be -79.43 metric tons of C/hectare/year of biomass plus -3.17 metric tons C/hectare/year of soil organic C, equaling a total loss of 82.60 metric tons C/hectare/ year (or -33.43 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 -302.85 metric tons CO_2 hectare/year (or -122.56 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.

-33.43 metric tons C/acre/year* x (44 units CO_2/12 units C) = **-122.56 metric tons CO_2/acre/year (in the year of conversion)[2]**

*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 -122.56 mt CO_2e/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). Also note that this estimate only includes mineral soil carbon stocks, as most forests in the contiguous United States are growing on mineral soils. In the case of mineral soil forests, soil carbon stocks could be replenished or even increased, depending on the starting stocks, how the agricultural lands are managed, and the time frame over which lands are managed.

Sources

- EPA (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-P-17-001 (PDF) (633 pp, 15 MB, About PDF)
- IPCC (2006). *Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Use.* Task Force on National Greenhouse Gas Inventories.

Propane cylinders used for home barbecues

Propane is 81.7 percent carbon (EPA 2017). The fraction oxidized is 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 (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), Table A-52, U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-P-17-001 (PDF) (100 pp, 2 MB, About PDF).
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Railcars of coal burned

The average heat content of coal consumed for electricity generation in the U.S. in 2015 was 21.10 mmbtu per metric ton (EIA 2017). The average carbon coefficient of coal combusted for electricity generation in 2015 was 26.05 kilograms carbon per mmbtu (EPA 2017). The fraction oxidized is 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.

21.10 mmbtu/metric ton coal × 26.05 kg C/mmbtu × 44 kg CO_2/12 kg C × 90.89 metric tons coal/railcar × 1 metric ton/1,000 kg = **183.22 metric tons CO_2/railcar**

Sources

- EIA (2017) Monthly Energy Review April 2017: Approximate Heat Content of Coal and Coal Coke. Table A5. (1 pp, 78 KB, About PDF).
- EPA (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), Table A-40, U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-P-17-001 (PDF) (100 pp, 2 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. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Pounds of coal burned

The average heat content of coal consumed for electricity generation in the U.S. in 2015 was 21.10 mmbtu per metric ton (EIA 2017). The average carbon coefficient of coal combusted for electricity generation in 2015 was 26.05 kilograms carbon per mmbtu (EPA 2017). 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.

21.10 mmbtu/metric ton coal × 26.05 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 = **9.14×10^{-4} metric tons CO_2/pound of coal**

Sources

- EIA (2017) Monthly Energy Review April 2017: Approximate Heat Content of Coal and Coal Coke, Table A5. (1 pp, 78 KB, About PDF).
- EPA (2017). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. Annex 2 (Methodology for estimating CO_2 emissions from fossil fuel combustion), Table A-40. U.S. Environmental Protection Agency, Washington, DC. U.S. EPA #430-P-17-001 (PDF) (100 pp, 2 MB, About PDF)
- IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. 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 2016). 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 0.78 metric tons of carbon equivalent per short ton. This factor was then converted to metric tons of carbon dioxide equivalent by multiplying by 44/12, the molecular weight ratio of carbon dioxide to carbon.

Calculation

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

0.78 metric tons of carbon equivalent/ton × 44 kg CO_2/12 kg C = **2.87 metric tons CO_2 equivalent/ton of waste recycled instead of landfilled**

Sources

- EPA (2016). Waste Reduction Model (WARM), Version 14. 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 2.87 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.

2.87 metric tons CO_2 equivalent /ton of waste recycled instead of landfilled x 7 tons/garbage truck = **20.07 metric tons CO_2E/garbage truck of waste recycled instead of landfilled**

Sources

- EPA (2016). Waste Reduction Model (WARM), Version 14. 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).

Coal-fired power plant emissions for one year

In 2014, a total of 369 power plants used coal to generate at least 95% of their electricity (EPA 2017). These plants emitted 1,490,275,587 metric tons of CO_2 in 2014.

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.

1,490,275,587 metric tons of CO_2 × 1/369 power plants = **4,038,687.23 metric tons CO_2/power plant**

Sources

- EPA (2017). eGRID year 2014 data. U.S. Environmental Protection Agency, Washington, DC.

Number of wind turbines running for a year

In 2015, the average nameplate capacity of wind turbines installed in the U.S. was 2.00 MW (DOE 2016). The average wind capacity factor in the U.S. in 2015 was 32 percent (DOE 2016).

Electricity generation from an average wind turbine was determined by multiplying the average nameplate capacity of a wind turbine in the U.S. (2.00 MW) by the average U.S. wind capacity factor (0.32) 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 7.06×10^{-4} (EPA 2017).

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 2017).

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

2.00 $_{\text{MWaverage capacity}}$ x 0.32 x 8,760 hours/year x 1,000 kWh/MWh x 7.0619 x 10^{-4} metric tons CO_2/kWh reduced = **3,948 metric tons CO_2/year/wind turbine installed**

Sources

- DOE (2016). 2015 Wind Technologies Market Report (102 pp, 2.55 MB). U.S. Department of Energy, Energy Efficiency and Renewable Energy Division.
- EPA (2017) AVERT, U.S. annual wind national marginal emission rate, year 2016 data. U.S. Environmental Protection Agency, Washington, DC.

[1] The annual 2016 U.S. transmission and distribution losses were determined as ((Net Generation to the Grid + Net Imports – Total Electricity Sales)/Total Electricity Sales) (i.e., (3,940 + 57 – 3,727)/3,727 = 7.26%). This percentage considers all transmission and distribution losses that occur between net generation and electricity sales. The data are from the Annual Energy Outlook 2017, Table A8 available at: http://www.eia.gov/forecasts/aeo/.

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