Independent Statistics and Analysis
U.S. Energy Information Administration

U.S. Energy-Related Carbon Dioxide Emissions, 2021—Appendix and Methodology

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Sector Contributions to Changes in U.S. Energy-Related CO_2

Annual changes in U.S. energy-related CO_2 emissions in each sector are affected by changes in:

- Electricity consumption
- The fuel mix of electricity generation (which determines the carbon intensity of electricity consumed)
- Direct energy consumption (also known as primary energy)
- The fuel mix of direct consumption of primary energy (which determines the carbon intensity of primary energy consumed)

Table 1 shows each end-use sector's share of the total change in energy-related CO_2 emissions for the U.S. economy in 2021. The table includes CO_2 emissions related to changes in:

- Each sector's electricity consumption, measured in British thermal units (Btu), 2020–21
- The electricity generation fuel mix for electricity consumption and the carbon intensity (CO_2/Btu) of electricity sales to end-use sectors
- Primary energy consumption (Btu) by sector
- Carbon intensity (CO_2/Btu) by sector
- The total of all end-use sectors based on the sum total of the changes for electricity and direct primary energy consumption

Table 1 also includes the sum of these changes.

Table 1. Sector contributions by electricity and primary energy changes to the total energy-related carbon dioxide (CO_2) emissions change

million metric tons of CO_2

	Residential	Commercial	Industrial	Transportation	Total all sectors
Change in electricity-related CO_2 emissions, 2020–21	33	40	30	0	102
Change related to the carbon intensity of electricity-related CO_2 emissions, 2020–21	22	20	15	0	56
Change in electricity-related CO_2 with no change in carbon intensity, 2020–21	11	20	15	0	46
Change in primary energy-related CO_2 emissions, 2020–21	3	10	24	185	222
Change related to the carbon intensity of primary energy-related CO_2 emissions, 2020–21	-3	0	-7	3	-7
Change in primary energy-related CO_2 emissions with no change in carbon intensity, 2020–21	6	10	31	182	229
Sum of the change in electricity and primary energy CO_2 emissions, 2020–21	36	50	54	185	325

Data source: U.S. Energy Information Administration, *Monthly Energy Review*, October 2022, Tables 11.2−5, Carbon Dioxide Emissions from Energy Consumption by Sectors

Methodology for Table 1

We divide total energy-related CO_2 emissions for each U.S. end-use sector into two components: primary (or direct) emissions and indirect emissions. Primary emissions are CO_2 emissions resulting from fossil fuel combustion in each sector (for example, natural gas used for home heating). Indirect emissions refers to emissions created by electricity generation, which we attribute to each end-use sector based on its share of total electricity consumption. Row 7 shows changes in total energy-related emissions for each end-use sector, row 4 shows changes in primary emissions, and row 1 shows changes in indirect emissions.

The first row in Table 1 represents the total change in electricity-related CO_2 emissions by end-use sector between 2020 and 2021. The change in electricity-related CO_2 emissions are driven by two components: the change in the carbon content of consumed electricity and the change in the total electricity demand. In other words, we express the total change in electricity-related CO_2 emissions as

$$\Delta\, CO_2\ electricity_{s,y} = \Delta\, CO_2\ electricity\ mix_{s,y} + \Delta\, CO_2\ electricity\ demand_{s,y} \quad (1)$$

where
s = an end-use sector; and
y = the year.

We calculate the second term, the change in electricity-related emissions associated with changes in electricity demand, by multiplying the previous year's electricity-related emissions in that sector by that sector's change in electricity consumption

$$\Delta\, CO_2\ electricity\ demand_{s,y} = CO_2\ electricity_{s,y-1} \cdot \%\Delta\ electricity\ consumption_{s,y} \quad (2)$$

This value represents the change in total electricity-related CO_2 emissions in the sector, assuming that the electricity generation mix and carbon content are held constant. If this assumption is true, then the change in demand-related electricity CO_2 emissions will be equal to the total change in electricity CO_2 emissions. However, the electricity mix is usually dynamic over time. To account for this potential discrepancy, we define the change in emissions associated with the carbon content of electricity by reordering Equation 1 as

$$\Delta\, CO_2\ electricity\ mix_{s,y} = \Delta\, CO_2\ electricity_{s,y} - \Delta\, CO_2\ electricity\ demand_{s,y} \quad (3)$$

We calculate primary emissions for each end-use sector by subtracting indirect emissions from total emissions, or

$$CO_2\ primary_{s,y} = CO_2\ total_{s,y} - CO_2\ electricity_{s,y} \quad (4)$$

Total emissions are taken directly from the EIA *Monthly Energy Review* (MER), with the methodology defined in the MER Section 11 Notes. We then break down these primary emissions into carbon content and demand components in much the same way as electricity-related emissions. The demand component of changes in primary emissions is expressed as

$$\Delta\, CO_2\ demand\ primary\ energy_{s,y} = CO_2\ primary_{s,y-1} \cdot \%\ \Delta\ primary\ consumption_{s,y} \quad (5)$$

and the change in emissions associated with the change in carbon content of primary energy is calculated as

$$\Delta\, CO_2\ primary\ energy\ content_{s,y} = \Delta\, CO_2\ primary_{s,y} - \Delta\, CO_2\ demand\ primary\ energy_{s,y} \quad (6)$$

CO_2 Emissions from Electricity Generated Outside of the Electric Power Sector

Not all electricity used in the United States is generated by the electric power sector. In particular, in the commercial and industrial sectors, coal, natural gas, petroleum, and biomass are also used to generate power for onsite use (accounting for 4% of total generation). Table 2 presents our analysis of CO_2 emissions originating from electricity generation outside of the electric power sector.

Table 2. Carbon dioxide (CO_2) emissions from electricity generated outside of the electric power sector

million metric tons of CO_2

	CO_2 emissions from generation within the commercial sector (excludes CO_2 emissions from the electric power sector)				CO_2 emissions from generation within the industrial sector (excludes CO_2 emissions from the electric power sector)				Total commercial and industrial CO_2 emissions from generation (excludes CO_2 emissions from the electric power sector)
	Coal	Natural gas	Petroleum	Total	Coal	Natural gas	Petroleum	Total	Total
2005	0.81	1.84	0.23	2.88	15.94	28.16	2.45	46.56	49.44
2006	0.74	1.88	0.13	2.75	15.65	29.14	1.92	46.71	49.46
2007	0.77	1.85	0.10	2.72	10.91	30.08	1.89	42.88	45.60
2008	0.82	1.82	0.06	2.69	10.84	28.26	1.36	40.47	43.17
2009	0.70	1.86	0.07	2.63	9.77	28.19	1.22	39.18	41.81
2010	0.68	2.14	0.07	2.88	17.01	30.06	0.88	47.94	50.83
2011	0.74	2.55	0.05	3.34	11.85	30.90	0.78	43.53	46.87
2012	0.63	3.42	0.11	4.16	9.59	34.35	1.70	45.64	49.80
2013	1.05	3.62	0.13	4.79	9.66	34.93	1.38	45.97	50.77
2014	0.41	3.93	0.17	4.52	9.55	34.07	0.92	44.54	49.06
2015	0.32	3.85	0.10	4.27	8.14	34.30	0.67	43.12	47.39
2016	0.21	2.55	0.04	2.80	6.09	29.33	0.60	36.03	38.83
2017	0.18	2.75	0.08	3.00	5.55	29.69	0.54	35.78	38.78
2018	0.16	2.89	0.10	3.16	5.03	31.05	0.49	36.57	39.72
2019	0.14	3.06	0.09	3.29	4.29	34.00	0.46	38.74	42.04
2020	0.13	2.85	0.09	3.06	3.53	34.00	0.40	37.93	41.00
2021	0.16	2.73	0.10	2.99	3.74	32.51	0.38	36.63	39.62

Data source: U.S. Energy Information Administration, *Monthly Energy Review*, October 2022, Table 7.3c, Consumption of Selected Combustible Fuels for Electricity Generation: Commercial and Industrial Sectors (Subset of Table 7.3a) and Carbon dioxide Emissions Coefficients by Fuel

Methodology for Table 2

We based the estimates in Table 2 on our *Monthly Energy Review* (MER), Table 7.3c, Consumption of Selected Combustible Fuels for Electricity Generation: Commercial and Industrial Sectors (Subset of Table 7.3a). To perform this calculation, we used the following CO_2 emissions factors:

- Coal
  - 96.10 million metric tons per quadrillion Btu for the commercial sector
  - 95.81 million metric tons per quadrillion Btu for the industrial sector
- Natural gas
  - 52.91 million metric tons per quadrillion Btu for both the commercial sector and the industrial sector
- Petroleum
  - 74.15 million metric tons per quadrillion Btu for the commercial sector
  - 73.93 million metric tons per quadrillion Btu for the industrial sector

Emissions factors for coal and natural gas consumed in the United States are from the detailed factors spreadsheet available on our Environment page. We constructed petroleum factors manually by using each end-use sector's consumption and emissions of distillate fuel oil and residual fuel oil.

We applied these factors to the amount of each fuel combusted (in Btu) to produce electricity in the commercial and industrial sectors. These calculations account for the changes in the carbon intensity (CO_2 per kilowatthour) of electricity generated from all sources. Biomass is excluded from these emissions calculations because we assume biomass to be carbon neutral.

Methodology Used in This Analysis

With the exception of Figures 2 and 3, whose methodologies are described below, we publish the data in this report either as values in our MER or the result of calculations based on published values (for example, CO_2 emissions per unit of energy consumed [MMmt CO_2 per Btu]).

Methodology for Figure 2

Figure 2 shows how several key factors of energy-related CO_2 emissions, as determined by the Kaya identity, change over time and how these changes influence total energy-related CO_2 emissions. These key factors are:

- Population
- GDP per capita
- Energy intensity
- Carbon intensity

Each of these factors is either directly published in the MER (for example, population) or is the result of taking the ratio of two published series (for example, GDP per capita). To put the factors' growth or decline into context, we index them to 1990. In Figure 2, we divide the yearly value of each factor by its value in 1990 and multiply it by 100 to put it into percentage terms. Each point in the series represents the magnitude of each factor relative to 1990, expressed as a percentage.

Methodology for Figure 3

Figure 3 shows the change in total energy-related CO_2 between 2020 and 2021 for the key emissions factors that make up the Kaya identity:

- Population
- GDP per capita
- Energy intensity
- Carbon intensity

The product of each component in the Kaya identity results in total energy-related CO_2 emissions. We calculate the changes in total CO_2 emissions from each factor by taking the difference between total energy-related CO_2 emissions in 2021 (that is, the product of each factor's 2021 value) and a hypothetical total emissions value (that is, the product of each factor's 2021 value except for the factor of interest, which uses its 2020 value). For example, the total change in energy-related CO_2 emissions between 2021 and 2020 resulting from changes in GDP per capita is given by:

$$(Pop_{2021} \cdot GDPPC_{2021} \cdot EI_{2021} \cdot CI_{2021}) - (Pop_{2021} \cdot GDPPC_{2020} \cdot EI_{2021} \cdot CI_{2021})$$

where

GDPPC = GDP per capita;
Pop = population;
EI = energy intensity; and
CI = carbon intensity.

These values do not sum to the total change in emissions because of interactions among the changes in each component.

Table 3. Rates of change in Kaya identity components, 2020–2021
percentage

Parameter	2020–2021 percentage change
Population	+ 0.1%
GDP per capita (GDP/population)	+ 5.5%
Energy intensity (Btu/GDP)	- 0.4%
Carbon intensity (CO_2/Btu)	+ 1.7%

Data source: Table created by the U.S. Energy Information Administration (EIA), based on data from EIA's Energy Intensity and Carbon intensity; GDP per capita, U.S. Bureau of Economic Analysis and U.S. Census Bureau; and Population, U.S. Census Bureau

Terms Used in This Analysis

British thermal units (Btu): The quantity of heat required to raise the temperature of one pound of liquid water by 1°F at the temperature at which water has its greatest density (approximately 39°F).

Carbon intensity (economy): The amount of carbon by weight emitted per unit of economic activity—most commonly gross domestic product (GDP) (CO_2 emissions/GDP). The carbon intensity of the economy is the product of the energy intensity of the economy and the carbon intensity of the energy supply. We currently express this value as the full weight of the CO_2 emitted, rather than the weight of just carbon.

Carbon intensity (energy supply): The amount of carbon by weight emitted per unit of energy consumed (CO_2 emissions/energy). A common measure of carbon intensity is the weight of CO_2 per Btu of energy. When considering only one fossil fuel, the carbon intensity and the emissions coefficient are identical. When considering several fuels, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels. We currently measure this value as the full weight of the CO_2 emitted, rather than the weight of just carbon.

Cooling degree days (CDD): A measure of how warm a location is during a period of time relative to a base temperature of 65°F. CDD are used in energy analysis as an indicator of air-conditioning energy requirements or use. The measure is computed for each day by subtracting the base temperature (65°F) from the average of the day's high and low temperatures, and negative values are set equal to zero. Each day's CDD are added to create a CDD measure for a specific time period.

Energy intensity: A measure relating the output of an activity to its energy input. Energy intensity is most commonly applied to the economy as a whole, where we measure output as GDP and primary energy in Btu to allow for the addition of all energy forms (energy/GDP). On an economy-wide level, energy intensity reflects both energy efficiency and the structure of the economy. Economies in the process of industrializing tend to have higher energy intensities than economies in their post-industrial phase. On a smaller scale, for example, energy intensity can relate the amount of energy consumed in buildings to the amount of residential or commercial floorspace.

Gross domestic product (GDP): The total value of goods and services produced by labor and property located in the United States. As long as the labor and property are located in the United States, the supplier (that is, the workers, or for property, the owners) may be either U.S. residents or residents of foreign countries.

Heating degree days (HDD): A measure of how cold a location is during a period of time relative to a base temperature, most commonly 65°F. HDD are used in energy analysis as an indicator of space heating energy requirements or use. We compute this measure for each day by subtracting the average of the day's high and low temperatures from the base temperature (65°F), and negative values are set equal to zero. We sum each day's HDD to create an HDD measure for a specific time period.

You can find more definitions in our Glossary.