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U.S. Energy-Related Carbon Dioxide Emissions, 2016

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U.S. energy-related carbon dioxide emissions decreased 1.7% in 2016

Energy-related carbon dioxide (CO_2) emissions decreased by 89 million metric tons (MMmt), from 5,259 MMmt in 2015 to 5,170 MMmt in 2016. Although real gross domestic product (GDP) increased 1.5% over that period, other factors contributing to energy-related CO_2 emissions more than offset the growth in GDP, leading to a 1.7% decline in energy-related CO_2.

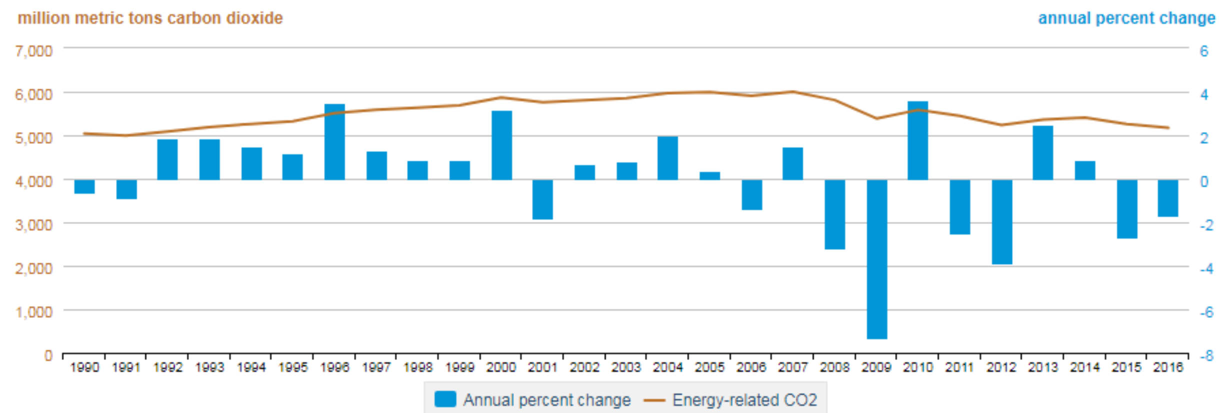
These factors include the following:

- A decline in the carbon intensity of the energy supply (CO_2/British thermal units [Btu]) of 1.7%
- A 1.4% decline in energy intensity (Btu/GDP)

Combining these two factors, the overall carbon intensity of the economy (CO_2/GDP) declined by 3.1%.

Emissions have declined in 6 out of the past 10 years, and energy-related CO_2 emissions in 2016 were 823 MMmt (14%) below 2005 levels.

Figure 1. Energy-related CO2 emissions, 1990–2016



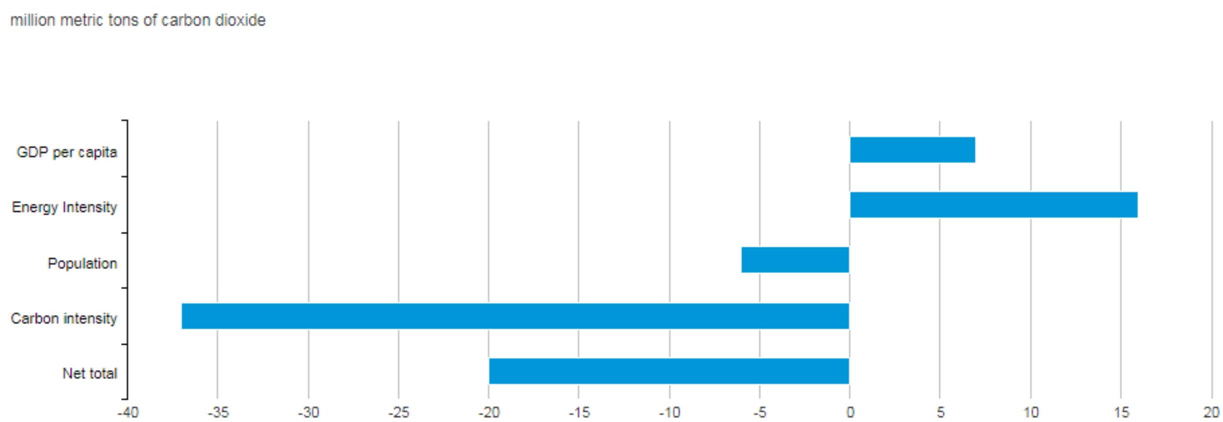
Source: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*.

Note: Unless otherwise indicated, all data in this analysis refer to the U.S. Energy Information Administration's (EIA) August 2017 *Monthly Energy Review*.

The decrease in energy-related CO2 emissions in 2016 mainly reflected a decline in carbon intensity of the energy consumed

- In 2016, the carbon intensity of U.S. energy consumption declined by 1.7%. From 2005 to 2015, the average annual decline was 1.0%. As a result, energy-related CO2 emissions were 37 MMmt lower than where they would have been had the prior trend continued.
- Population growth of 0.7% —slightly lower than the 2005–15 annual average of 0.8%—put downward pressure on CO2 emissions growth, resulting in a 6 MMmt decline in CO2 emissions compared with the 2005–15 trend.
- Energy intensity added 16 MMmt of CO2 emissions, falling at a rate of 1.4%, compared with the higher 2005–15 annual average decline of 1.7% per year.
- Growth in GDP per capita also put upward pressure on CO2 emissions, adding about 7 MMmt compared with the 2005–15 trend.
- The net effect for 2016 was CO2 emissions that were about 20 MMmt lower than they would have been had components of the Kaya energy/carbon decomposition (shown in Figure 2) matched their 2005–15 trend rates.

Figure 2. Changes in CO2 emissions attributed to Kaya Identity factors from 2015 to 2016 compared with the trend from the prior decade

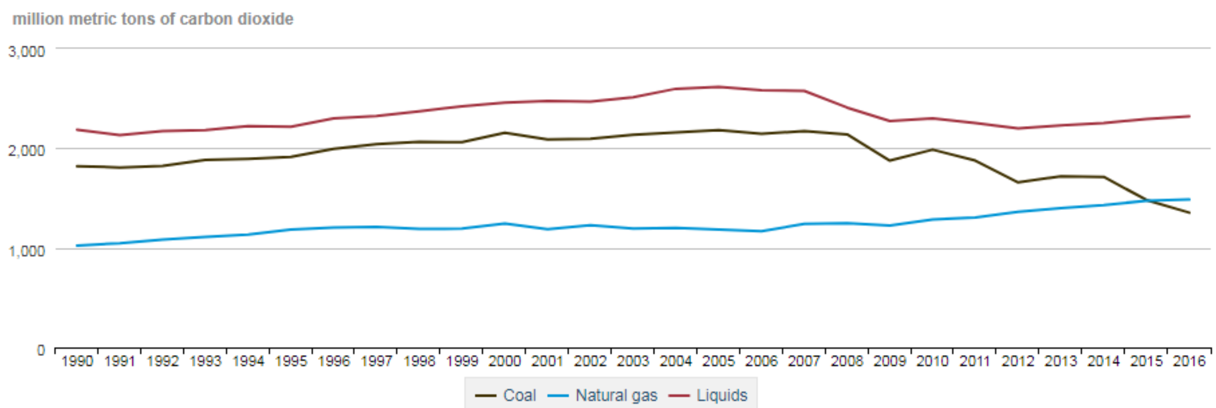


Sources: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 12.1 Carbon dioxide emissions from energy consumption by source. Bureau of Economic Analysis, *Current-Dollar and "real" Gross Domestic Product*. Bureau of Census, *U.S. Population 2016*.

Natural gas CO2 emissions surpassed those from coal in 2016

- CO2 emissions from petroleum and other liquids, which have been the largest source of energy-related CO2 in recent decades, have been increasing since 2012 after remaining relatively constant from 2004 to 2007 and then generally decreasing through 2012.
- Since the beginning of the 2007–09 recession, coal CO2 emissions have also generally declined. Although total coal CO2 emissions in 2016 were lower than those from petroleum and other liquids, coal is comparatively more carbon intensive, with more CO2 released per Btu of energy. The decline in coal CO2 emissions has contributed to a lower overall carbon intensity of U.S. energy consumption and kept emissions below pre-recession levels.
- Natural gas CO2 emissions have increased every year since 2009. The natural gas share of electricity generation has grown as the coal share declined, partially offsetting the decline in energy-related CO2 emissions from coal. Natural gas CO2 emissions surpassed those from coal in 2016. However, because natural gas produces more energy for the same amount of emissions as coal, growth in natural gas consumption contributed to the overall 2016 decline in total emissions.

Figure 3. Energy-related CO2 emissions by fuel, 1990–2016

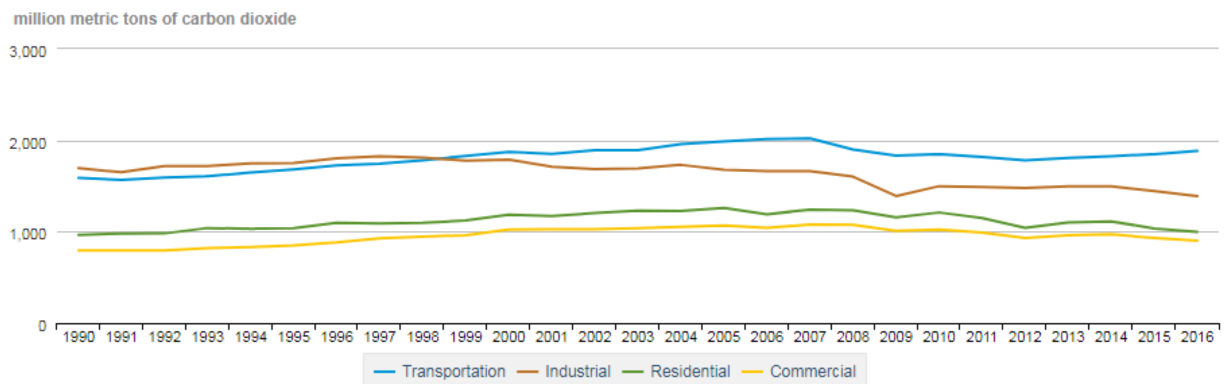


Source: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 12.1 Carbon dioxide emissions from energy consumption by source.

Of the four end-use sectors, only transportation CO_2 emissions increased in 2016

- Since the late 1990s, the transportation sector has produced the most CO_2 emissions. These emissions were highest in 2007, prior to the recession, and have not returned to those levels, despite increasing every year since 2012.
- The industrial sector, which was the largest source of CO_2 emissions throughout most of the 1990s, has experienced declining emissions, with further declines occurring in 2016.
- Emissions from the residential and commercial sectors, known collectively as the building sector, are mainly indirect emissions from consumption of electricity purchased from the electric power sector. These indirect emissions declined by about 3.5% in 2016. Direct building sector CO_2 emissions—primarily from heating—decreased by 3.2% in 2016.

Figure 4. Energy-related CO_2 by end-use sectors, 1990–2016



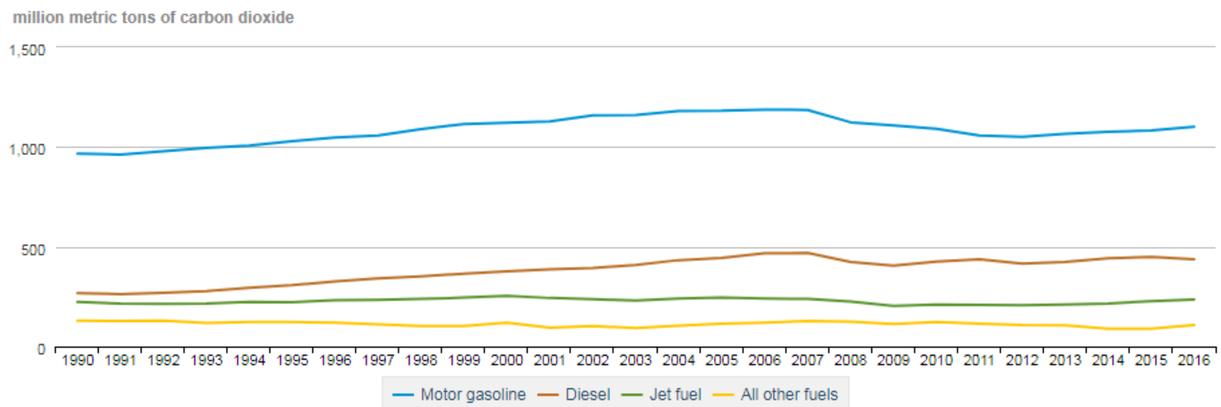
Source: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 12.2 Carbon dioxide emissions from energy consumption: residential sector; Table 12.3 Carbon dioxide emissions from energy consumption: commercial sector; Table 12.4 Carbon dioxide emissions from energy consumption: industrial sector; Table 12.5 Carbon dioxide emissions from energy consumption: transportation sector.

The 2016 increase in energy-related CO_2 emissions from the transportation sector was led by motor gasoline consumption

Since 2012, declines and the subsequent stability in the price of motor gasoline and other fuels, along with the continued economic recovery, have led to higher fuel consumption and increases in energy-related CO_2 emissions in the transportation sector. Transportation-related CO_2 emissions increased by 34 million metric tons (MMmt) (1.9%) in 2016.

- Motor gasoline accounted for 56.0% of the 34 MMmt net increase in transportation-sector CO_2 emissions in 2016— totaling 19 MMmt—an increase of 1.8% from the 2015 level.
- Emissions from jet fuel increased by about 4.0% (9 MMmt) between 2015 and 2016.
- Diesel fuel emissions, on the other hand, declined by 2.7% between 2015 and 2016.

Figure 5. Transportation-related CO_2 emissions by fuel, 1990–2016



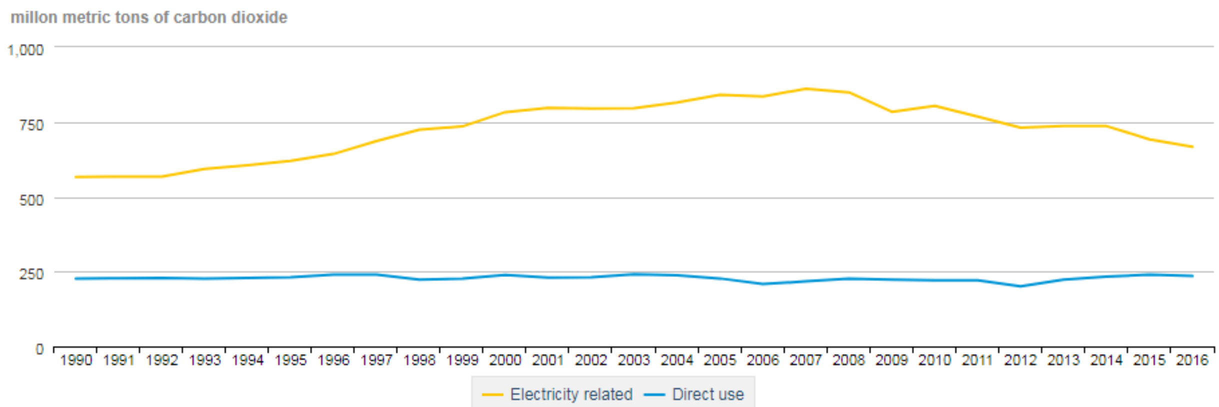
Source: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 12.5 Carbon dioxide emissions from energy consumption: transportation sector.

Commercial sector energy-related CO2 emissions declined in 2016

Commercial sector CO2 emissions declined by 30 MMmt (3.2%) in 2016.

- Indirect commercial-sector CO2 emissions from the use of electricity purchased from the electric power sector decreased by 3.7% (25 MMmt) in 2016, which was nearly 84% of the sector's total decrease.
- Direct CO2 emissions in the commercial sector decreased 2.0% (5 MMmt) in 2016, accounting for the remaining 16% of the total commercial sector decrease.

Figure 6. Commercial sector energy-related CO2 emissions, 1990–2016



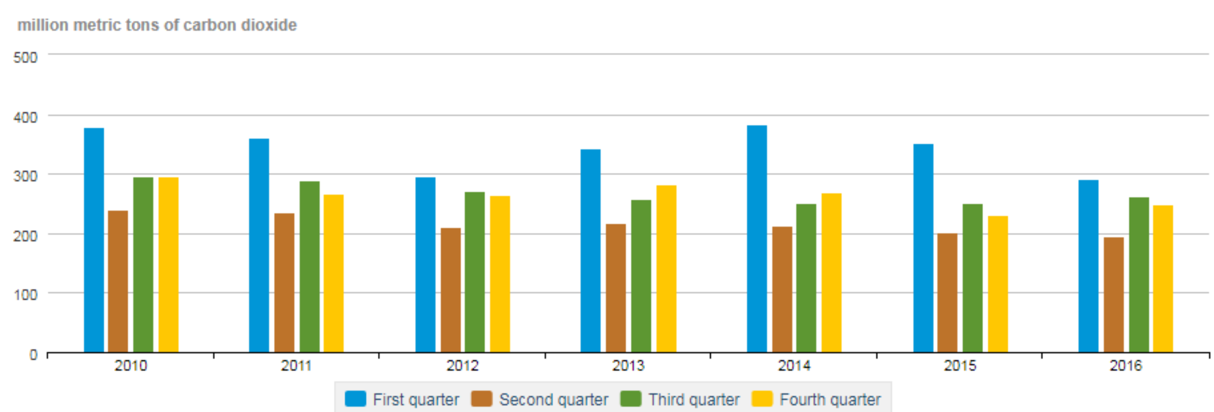
Sources: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 12.3 Carbon dioxide emissions from energy consumption: commercial sector.

On a quarterly basis, residential energy-related CO2 emissions in 2016 were very similar to 2012 levels

Residential sector CO2 emissions declined by 37 MMmt (3.6%) in 2016. Both 2012 and 2016 were warmer than average, and they had similar emissions patterns.

- First-quarter emissions in both 2016 and 2012 were below those of recent years because the heating requirements were relatively low compared with recent years.
- Emissions are typically lowest in the second quarter because residential heating and cooling requirements are low; residential CO2 emissions in 2016 were the lowest second-quarter level since 1988 and 15 MMmt below 2012.
- The third quarter is the warmest time of year. Third-quarter CO2 emissions have generally declined since 2010—helped by the decline in the carbon intensity of fuels used to generate electricity. However, third-quarter cooling degree days in 2016 were 14% higher than the 10-year average, leading to relatively higher emissions than in the three previous years, but slightly below the 2012 level.
- In the fourth quarter of 2016, emissions were higher than the 2015 level, but they were still lower than in other recent years. In total, residential CO2 emissions in 2016 were the lowest since 1992.

Figure 7. Residential energy-related CO2 emissions by quarter, 2010–16



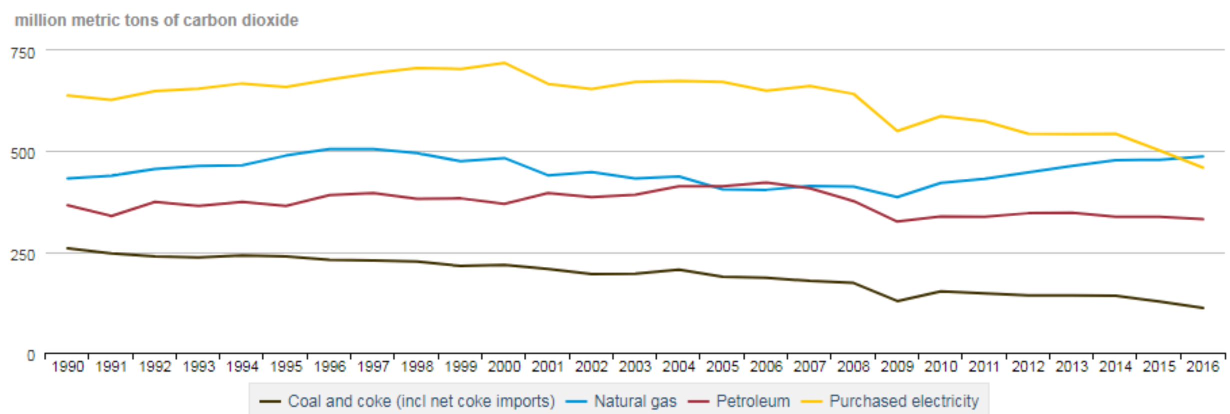
Source: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 12.2 Carbon dioxide emissions from energy consumption: residential sector.

Industrial sector energy-related CO2 emissions declined from 2015 to 2016

The industrial sector's CO2 emissions, which fell by 3.9% (56 MMmt) in 2016, have remained essentially flat in recent years despite increasing industrial output. Continuing growth in less energy-intensive industrial output helped to stabilize emissions in this sector.

- In 2010, unlike other recent years, CO2 emissions from all industrial fuel sources increased by 7.8% as the economy recovered from the recession that led to the large emissions declines of 2009.
- Industrial CO2 emissions from purchased electricity and coal declined most years from 2011 to 2016.
- Petroleum CO2 emissions in the industrial sector were relatively flat in recent years.
- Natural gas CO2 emissions have risen every year since 2009, although in 2015, the rise was very slight. Because it is the least carbon-intensive fossil fuel, natural gas use has helped to reduce overall CO2 emissions growth. In 2016, CO2 emissions from natural gas exceeded those of purchased electricity.

Figure 8. CO2 emissions from industrial fuels, 1990–2016



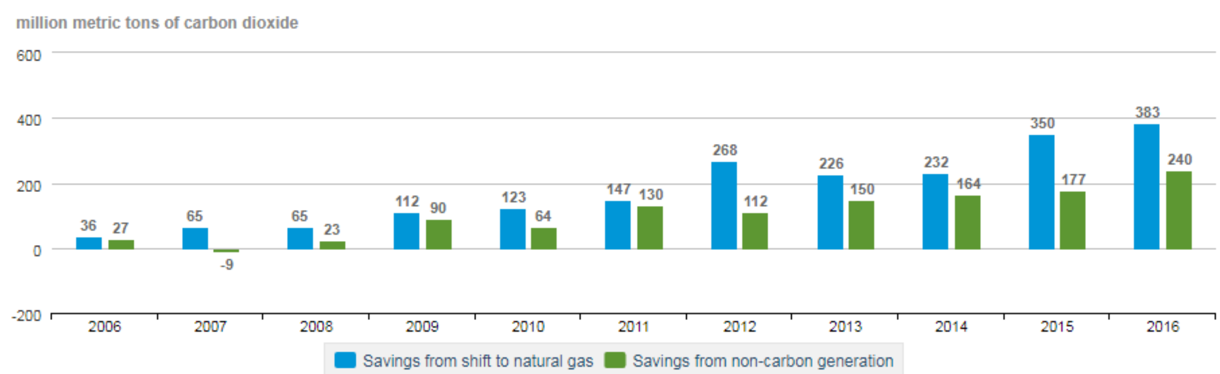
Source: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 12.4 Carbon dioxide emissions from energy consumption: industrial sector.

Increased use of natural gas and the growth in non-carbon generation has contributed to the decline in the carbon intensity of electricity generation since 2005

Two basic factors contributed to lower electricity generation carbon intensity (CO_2/kilowatthour) since 2005: substitution of coal-fired generation with the less-carbon-intensive and more efficient combined-cycle natural gas-fired generation, and growth in non-carbon electricity generation, especially wind and solar. This analysis includes estimated CO_2 emissions from electricity generated in all sectors. Non-carbon electricity generation includes distributed solar.

- Between 2005 and 2016, CO_2 emissions declined by a cumulative 3,176 MMmt as a result of these two factors. Of this total, 2,007 MMmt can be attributed to the shift in fossil fuels to natural gas, and 1,169 MMmt can be attributed to the increase in non-fossil generation sources.
- Although total electricity generation use grew by about 1% from 2005 to 2016, related CO_2 emissions fell by 24% over that period.
- From 2005 to 2016, fossil-fuel electricity generation declined by about 9%, while non-fossil (non-carbon) electricity generation rose by 25%.

Figure 9. Electricity generation carbon dioxide savings from changes in the fuel mix since 2005



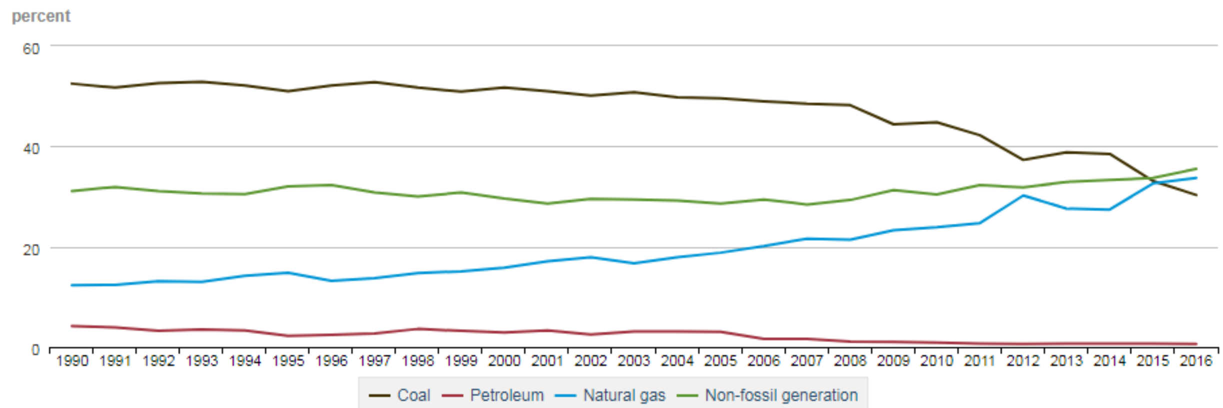
Sources: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 12.6 Carbon Dioxide Emissions From Energy Consumption: Electric Power Sector and calculations made for this analysis based on Table 7.3c Consumption of Selected Combustible Fuels for Electricity Generation: Commercial and Industrial Sectors (Subset of Table 7.3a). Distributed solar generation from Table 10.6 Solar Electricity Net Generation is added to generation values from Table 7.2a Electricity Net Generation: Total (All Sectors).

The increasing share of non-fossil fuel electricity generation has helped lower the carbon intensity of electricity supply

The trend of declining coal-fired electricity generation and increasing non-fossil fuel and natural gas-fired generation continued in 2016.

- Coal's share of total electricity generation fell from 53% in 1990 to 30% in 2016.
- The natural gas share of electricity generation grew from approximately 12% in 1990 to 30% in 2012 and to 34% in 2016.
- The non-fossil fuel electricity generation share (35%), including both nuclear and renewables, exceeded that of both coal and natural gas in 2016.

Figure 10. Electricity generation share of three fossil fuels and of non-fossil generation, 1990–2016



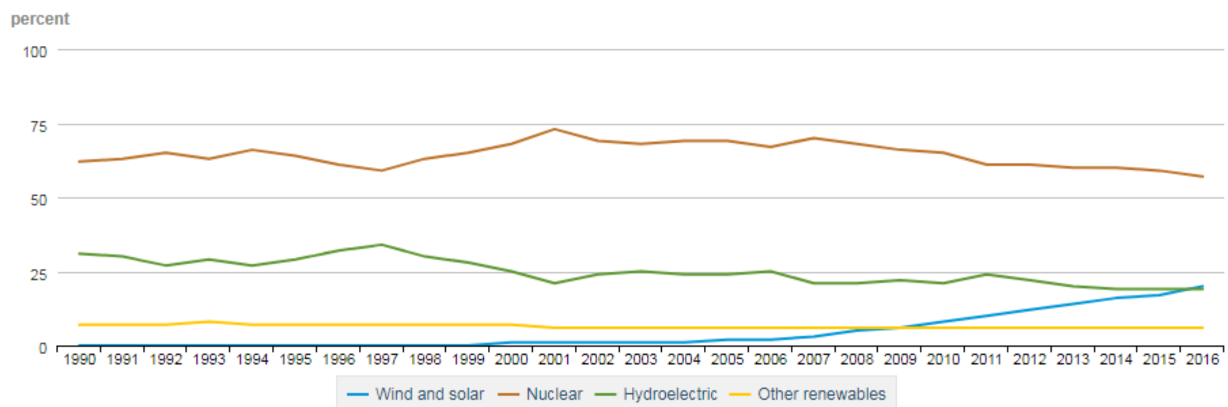
Source: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 7.2a Electricity net generation: Total (All Sectors); Table 10.6 Solar Electricity Net Generation.

Growth in wind and solar electricity generation has helped lower the carbon intensity of electricity supply

Although nuclear power remains the dominant source of non-fossil electricity generation, growth in wind and solar generation since 2008 has also contributed to a decline in the carbon intensity of electricity generation.

- Althought nuclear generation increased in 2016, the nuclear share of non-fossil electricity generation has generally declined since reaching 73% in 2001.
- Hydropower, which historically has been the largest source of renewable electricity generation, has also lost share, falling from 34% of non-fossil fuel generation in 1997 to 19% in 2016.
- Wind and solar (combined) accounted for about 20% of non-fossil electricity generation in 2016 and slightly exceeded hydropower after rising from less than 1% in 2000 to 2% in 2006.
- Other renewables, such as biomass, have remained flat at about a 6% share of non-fossil electricity generation since 2001.

Figure 11. Share of non-fossil electricity generation by source, 1990–2016



Source: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*, Table 7.2a Electricity net generation: Total (All Sectors); Table 10.6 Solar Electricity Net Generation.

Table 1. Weighted factors for electricity and primary energy by sector for the energy-related CO2 emissions, percent change from 2015 to 2016

	Electricity change 2015–16	Change in carbon intensity of electricity 2015–16	Electricity share of sector CO2 2016	Change in electricity-weighted CO2 2015–16
Residential	1.3%	-4.5%	69.2%	-2.3%
Commercial	0.9%	-4.5%	74.0%	-2.7%
Industrial	-4.1%	-4.5%	33.1%	-2.9%
Transportation	-0.8%	-4.5%	0.2%	0.0%

	Primary energy change 2015–16	Change in carbon intensity of primary energy 2015–16	Primary energy share of sector CO2 2016	Change in primary energy-weighted CO2 2015–16
Residential	-4.3%	0.3%	30.8%	-1.3%
Commercial	-1.5%	-0.5%	26.0%	-0.5%
Industrial	-0.4%	-1.1%	66.9%	-0.9%
Transportation	2.1%	-0.2%	99.8%	1.9%

	Sector CO2 change MER tables 2015–16	Electricity and primary energy CO2 change times sector share 2015–16	Sector share of total CO2 2016	Sum of change in electricity and primary energy-weighted CO2 2015–16
Residential	-3.6%	-0.7%	19.3%	-3.5%
Commercial	-3.2%	-0.6%	17.4%	-3.2%
Industrial	-3.9%	-1.0%	26.8%	-3.8%
Transportation	1.9%	0.7%	36.4%	1.9%
Total all sectors	-1.7%	-1.6%		

Sources: U.S. Energy Information Administration, August 2017 *Monthly Energy Review*,
Table 12.1 Carbon Dioxide Emissions From Energy Consumption by Source
Table 12.2 Carbon Dioxide Emissions From Energy Consumption: Residential Sector
Table 12.3 Carbon Dioxide Emissions From Energy Consumption: Commercial Sector
Table 12.4 Carbon Dioxide Emissions From Energy Consumption: Industrial Sector
Table 12.5 Carbon Dioxide Emissions From Energy Consumption: Transportation Sector
Differences in percent changes are calculated using unrounded numbers.
Electricity is purchased electricity. Emissions from fuels consumed to generate electricity within the commercial and industrial sectors are counted as CO2 from primary energy.

Table 1 decomposes the rates of change by sector for electricity (indirect) and primary (direct) energy consumption and separates those rates of change in electricity and primary energy consumption from the changes in the respective carbon intensities. The sums of those changes multiplied by the share of CO2 emissions from each energy type approximate the CO2 changes in each sector.

Using the residential sector as an example—the 1.3% increase in electricity consumed between 2015 and 2016 was offset by a decline in carbon intensity of the electricity supply (-4.5%)—yields a total of 3.2% (not shown in the table). When -3.2% is multiplied by the 2016 electricity CO2 emissions share of 69.2%, the resulting electricity-weighted change is -2.3%. Adding that value to the residential sector's weighted change of primary energy (-1.3%), results in a total sector change of -3.5%. Finally, when weighted by the residential share of total CO2 emissions (19.3%), the weighted-sector share is -0.7%. The sectors are summed to get total energy-related CO2 emission changes. Rounding errors account for slight differences in totals.

Future implications of the 2016 decline in CO2 emissions

The conditions that occurred in 2016 that put downward pressure on emissions do not necessarily reflect future trends.

For EIA's forecasts and projections on emissions and their key drivers, see the Short-Term Energy Outlook (STEO), with monthly forecasts through 2018, and the Annual Energy Outlook (AEO), with annual projections through 2050. EIA's International Energy Outlook (IEO) contains projections of international energy consumption and emissions through 2040. Full-length versions of the AEO and IEO are on a biennial schedule. Summary versions of these publications appear in alternating years.

The analysis of energy-related CO2 emissions presented here is based on data in the Monthly Energy Review (MER). Chapter 12 of the MER reports monthly U.S. energy-related CO2 emissions derived from EIA's monthly energy data. For the full range of EIA's emissions products, see the Environment webpage.

Terms used in this analysis

British thermal unit(s) (Btu): The quantity of heat required to raise the temperature of 1 pound of liquid water by 1 degree Fahrenheit at the temperature at which water has its greatest density (approximately 39 degrees Fahrenheit).

Carbon intensity (economy): The amount of carbon by weight emitted per unit of economic activity. Carbon intensity most commonly applied to the economy as a whole, where output is measured as the gross domestic product (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. Note: this value is currently expressed as the full weight of the carbon dioxide emitted (CO2/GDP).

Carbon intensity (energy supply): The amount of carbon by weight emitted per unit of energy consumed. A common measure of carbon intensity is weight of carbon per Btu of energy. When only one fossil fuel is under consideration, the carbon intensity and the emissions coefficient are identical. When several fuels are under consideration, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels. Note: this value is currently measured as the full weight of the carbon dioxide emitted (CO2/energy or CO2/Btu).

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

Energy intensity: A measure relating the output of an activity to the energy input to that activity. Energy intensity is most commonly applied to the economy as a whole, where output is measured as the gross domestic product (GDP), and energy is measured in Btu to allow for the summing of all energy forms. On an economy-wide level, energy intensity is reflective of 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. The term *energy intensity* can also be used on a smaller scale to relate, for example, the amount of energy consumed in buildings to the amount of residential or commercial floor space.

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 over a period of time relative to a base temperature, most commonly specified as 65 degrees Fahrenheit. The measure is computed for each day by subtracting the average of the day's high and low temperatures from the base temperature (65 degrees), with negative values set equal to zero. Each day's heating degree days are summed to create a heating-degree-day measure for a specified reference period. Heating degree days are used in energy analysis as an indicator of space heating energy requirements or use.

See the EIA glossary for other definitions.

Methodology used in this analysis

With the exception of Figures 2 and 9, the data in this report are directly from the published values in the EIA's Monthly Energy Review (MER) or based on relatively simple calculations such as CO2/Btu of energy. The methodology of figures 2 and 9 is as follows:

Figure 2. Changes in CO2 emissions attributed to Kaya Identity factors from 2015 to 2016 compared with the trend from the prior decade: This figure gives context to the most recent year-to-year change by comparing it to the average change for key parameters over the previous decade. The key parameters are population, per capita GDP (GDP/population), energy intensity, and carbon intensity of the energy supply—also know as the factors in the Kaya Identity. The changes in these key parameters determine changes in energy-related CO2. By comparing the rate of change for each parameter from 2015 to 2016 to the average rate of change for that parameter for the previous decade, the contribution of each parameter to the overall deviation from trend can be calculated. The

table below summarizes the rates of change that drive the results. The larger the positive value, the greater the increase in emissions. The larger the negative value, the lesser the increase in emissions.

Parameter	Previous decade annual % change	2015–16 % change
Population	+0.8	+0.7
Carbon intensity (CO2/Btu)	-1.0	-1.7
Per capita output (GDP/pop.)	+0.7	+0.8
Energy intensity (Btu/GDP)	-1.7	-1.4
Change in energy CO2	-1.3	-1.7

Figure 9. Electricity generation CO2 savings from changes in the fuel mix since 2005: This figure shows the emissions savings from two factors that have allowed emissions to decrease from 2005 to 2016, while generation has risen slightly. The first factor is the shift within fossil fuel generation from coal to natural gas. The second factor is the increase in non-carbon electricity generation.

To capture this CO2 savings from the shift to natural gas, the fossil fuel carbon factor (fossil fuel CO2/fossil fuel generation) is frozen at the 2005 level. This factor is then multiplied by the actual fossil fuel generation for subsequent years. The difference between that value and the actual value for fossil fuel-generated CO2 emissions is the savings in that year. For example, the carbon factor in 2005 for fossil fuel generation was 0.851 metric tons per megawatthour (mt/MWh). By 2016, the carbon intensity had declined to 0.706 mt/MWh. Multiplying the 2005 value times the 2016 level of generation would yield 2,251 million metric tons (MMmt) of CO2, versus the actual value of 1,868 MMmt. Therefore, the savings from the shift to natural gas was 383 MMmt of CO2 in 2016.

Because non-carbon generation (the second factor) has a zero-carbon factor for direct emissions, the overall reduction in total carbon intensity was applied to total generation, i.e., multiplying total generation by the 2005 value of 0.608 mt/MWh. The savings in fossil fuel generation was subtracted from the total and the difference was credited to non-carbon electricity generation. For example, the total savings in 2016 was 623 MMmt, so the amount allocated to non-carbon generation is 623 MMmt minus 383 MMmt and equals 240 MMmt of CO2.