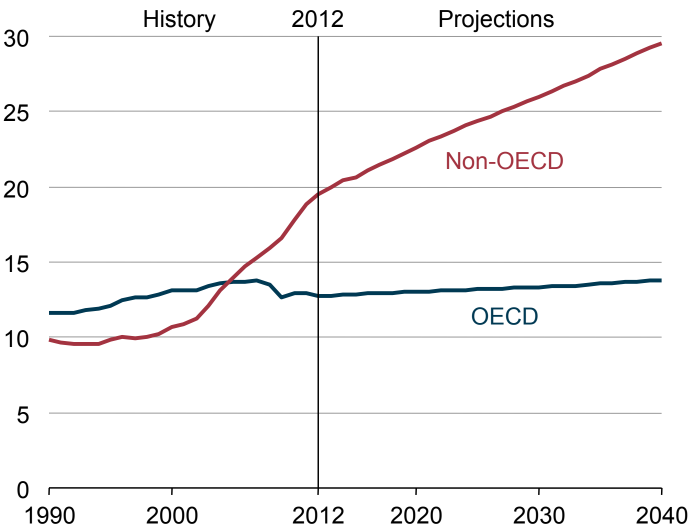
Chapter 9

Energy-related CO2 emissions

Overview

Because anthropogenic emissions of carbon dioxide (CO2) result primarily from the combustion of fossil fuels, energy consumption is at the center of the climate change debate. In the *International Energy Outlook 2016* (IEO2016) Reference case, world energy-related CO2 emissions[331] increase from 32.3 billion metric tons in 2012 to 35.6 billion metric tons in 2020 and to 43.2 billion metric tons in 2040. The Reference case estimates do not include effects of the recently finalized Clean Power Plan (CPP) regulations in the United States, which reduce projected U.S. emissions in 2040 by 0.5 billion metric tons. Much of the growth in emissions is attributed to developing nations outside the Organization for Economic Cooperation and Development (OECD), many of which continue to rely heavily on fossil fuels to meet the fast-paced growth of energy demand. In the IEO2016 Reference case, non-OECD emissions in 2040 total 29.4 billion metric tons, or about 51% higher than the 2012 level. In comparison, OECD emissions total 13.8 billion metric tons in 2040, or about 8% higher than the 2012 level (Table 9-1 and Figure 9-1).

Figure 9-1. OECD and non-OECD energy-related carbon dioxide emissions, 1990–2040 (billion metric tons)



In conjunction with the 21st Conference of Parties in Paris (COP21, November 30 through December 12, 2015), many countries have submitted emissions reduction goals, or Intended Nationally Determined Contributions (INDCs), under the United Nations Framework Convention on Climate Change (UNFCC) *(see "Policies to limit CO2 emissions in the United States and China," below)*. EIA has tried to incorporate

Table 9-1. World energy-related carbon dioxide emissions by fuel type, 1990–2040 (billion metric tons)

Region/Country	1990	2012	2020	2030	2040	Average annual percent change, 2012–40	Total change, 2012–40 (billion metric tons)	Percent change, 2012–40
OECD	**11.6**	**12.8**	**13.0**	**13.3**	**13.8**	**0.3**	**1.0**	**8**
Liquid fuels	5.5	5.7	5.6	5.5	5.6	-0.1	-0.2	-3
Natural gas	2.0	3.1	3.3	3.8	4.2	1.1	1.1	35
Coal	4.1	3.9	4.1	4.1	4.0	0.1	0.1	2
OECD with CPP	**11.6**	**12.8**	**12.7**	**12.7**	**13.3**	**0.1**	**0.5**	**4**
Liquid fuels	5.5	5.7	5.6	5.5	5.5	-0.1	-0.2	-3
Natural gas	2.0	3.1	3.4	3.8	4.2	1.0	1.1	34
Coal	4.1	3.9	3.7	3.5	3.5	-0.4	-0.4	-10
Non-OECD	**9.9**	**19.5**	**22.6**	**25.8**	**29.4**	**1.5**	**9.9**	**51**
Liquid fuels	3.6	6.0	7.3	8.5	10.0	1.9	4.0	67
Natural gas	2.0	3.4	4.0	5.4	6.9	2.5	3.5	102
Coal	4.2	10.1	11.3	11.9	12.5	0.8	2.4	24
World	**21.4**	**32.3**	**35.6**	**39.1**	**43.2**	**1.0**	**10.9**	**34**
Liquid fuels	9.1	11.7	12.9	14.0	15.5	1.0	3.8	33
Natural gas	4.0	6.6	7.3	9.2	11.2	1.9	4.6	70
Coal	8.4	14.0	15.4	15.9	16.5	0.6	2.5	18
World with CPP	**21.4**	**32.3**	**35.3**	**38.5**	**42.7**	**1.0**	**10.4**	**32**
Liquid fuels	9.1	11.7	12.9	14.0	15.5	1.0	3.8	33
Natural gas	4.0	6.6	7.4	9.2	11.1	1.9	4.6	70
Coal	8.4	14.0	15.0	15.3	16.0	0.5	2.0	14

[331] In IEO2016, energy-related CO2 emissions are defined as emissions related to the combustion of fossil fuels (liquid fuels, natural gas, and coal) and emissions associated with petroleum feedstocks. Emissions from the flaring of natural gas are not included.

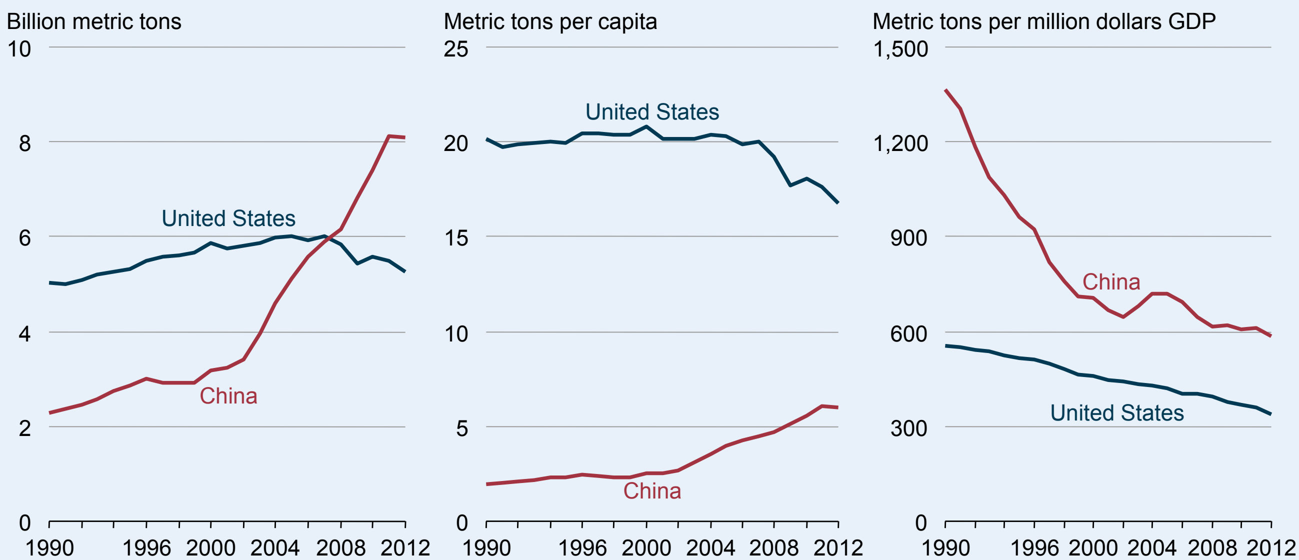
some of the specific details, such as renewable energy goals, in the IEO2016 Reference case; however, a great deal of uncertainty remains with regard to the implementation of policies to meet stated goals. In addition, beyond energy-related CO2, other gases (e.g., methane) and sources (e.g., deforestation) that contribute to greenhouse gas (GHG) emissions but are not considered in IEO2016 could have significant effects on national or regional shares of total global GHG emissions and the achievement of INDCs. EIA's projections for CO2 emissions may change significantly as laws and policies aimed at reducing GHG emissions are implemented and enforced, or if existing laws are enhanced.

Policies to limit CO2 emissions in the United States and China

The United States and China are the countries with the most energy-related CO2 emissions. Together they accounted for about 40% of global CO2 emissions in 2012. In 2014, both countries announced their Intended Nationally Determined Contributions (INDCs) to the mitigation of their respective GHG emissions. It remains unclear, however, whether either country will meet or exceed its announced target. Further efforts to reduce GHG emissions were discussed at the Conference of the Parties to the United Nations Framework on Climate Change (COP21), held in Paris November 30 through December 12, 2015.[332] EIA will continue to assess the targets resulting from COP21 for inclusion in future analyses.

The United States, which in 2009 set a goal of reducing GHG emissions by 17% from 2005 levels by 2020, has now announced an INDC of 26% to 28% below its 2005 level by 2025. China's INDC states the objective of peaking its CO2 emissions by about 2030 while making best efforts to achieve an earlier peak. China's INDC also proposes a goal of 20% nonfossil energy use in 2030. In addition, in September 2015, China announced its intent to expand the country's seven current regional emissions trading programs in to a national cap-and-trade program beginning in 2017, although specific emissions caps and other policy details have not yet been announced. China surpassed the United States as the world's largest CO2 emitter in 2008 (Figure 9-2). In 2012 its CO2 emissions per capita were about one-third of the U.S. level, and its emissions per unit of economic output were about 70% higher than the U.S. level.

Figure 9-2. Carbon dioxide emissions from energy consumption in the United States and China, 1990–2012



In the United States, about 80% of all CO2 emissions in 2012 were related to energy, with the remainder attributed to sources such as cement production, agricultural activities, land use changes, and forestry. Two of the largest sources of U.S. energy-related CO2 emissions are the transportation sector and the electric power sector. For transportation, the main mechanism to reduce emissions is increasing the stringency of fuel economy and GHG emissions standards for both light-duty vehicles and heavy trucks. For electric power, the U.S. Environmental Protection Agency (EPA) has finalized a Clean Power Plan (CPP) aimed at significantly reducing CO2 emissions from existing fossil-fueled generators.

In China, the ultimate achievement of emissions targets will depend on its need to balance environmental goals with economic growth and development. In the past, China's energy demand growth has been driven by development plans as part of the government's five-year planning cycles that have centered mainly on industrial expansion. China is still industrializing, and its energy needs will grow despite slowing economic growth and a shift to less energy-intensive industries. China's energy mix is dominated by coal, the most carbon-intensive fossil fuel, and it is likely to remain so for the foreseeable future. If its total CO2 emissions are to peak near 2030, coal consumption will have to stop growing, and perhaps decline substantially, between 2015 and 2035 unless carbon capture and storage (CCS) technology, which is a relatively new technology, is rapidly adopted.

(continued on page 141)

[332]United Nations Framework Convention on Climate Change, "United Nations Climate Change Conference, Paris, France," http://unfccc.int/files/meetings/paris_nov_2015/application/pdf/overview-schedule_cop21cmp11.pdf.

China's growing middle class is expected to increase its demand for energy services as income per capita increases, and its sectoral shares of energy consumption are expected to continue shifting from industry to the building and transportation sectors. In both sectors, the energy efficiencies of China's technologies have improved in recent years, which should help China curb the rate of growth in its energy use.

CO2 emissions by fuel

Energy-related CO2 emissions from the use of liquid fuels, natural gas, and coal all increase in the IEO2016 Reference case, with the relative contributions of the individual fuels shifting over time (Figure 9-3). In 1990, CO2 emissions associated with the consumption of liquid fuels accounted for the largest portion (43%) of global emissions. In 2012, they had fallen to 36% of total emissions, and they remain at that level through 2040 in the IEO2016 Reference case. Coal, which is the most carbon-intensive fossil fuel, became the leading source of world energy-related CO2 emissions in 2006, and it remains the leading source through 2040 in the Reference case. However, although coal accounted for 39% of total emissions in 1990 and 43% in 2012, its share is projected to decline to 38% in 2040, only slightly higher than the liquid fuels share. The natural gas share of CO2 emissions, which was relatively small at 19% of total GHG emissions in 1990 and 20% in 2012, increases in the IEO2016 Reference case to 26% of total fossil fuel emissions in 2040.

Worldwide consumption of energy derived from fossil fuels grows by about 177 quadrillion Btu from 2012 to 2040 in the IEO2016 Reference case. In 2012, fossil fuels accounted for 84% of worldwide energy consumption. If fossil fuels had kept the same share in the Reference case, they would have increased from 461 quadrillion Btu in 2012 to 684 quadrillion Btu by 2040. However, with the increase in renewable and nuclear energy, the share of fossil fuels in total decreases to 78%, and the mix of those fossil fuels changes. The coal share of total energy use falls from 28% in 2012 to 22% in 2040. Over the same period, the liquids share falls from 33% to 30%, while the natural gas share rises from 23% to 26%.

The net result of both the reduced share of fossil-fuel energy and the shift in the fossil-fuel mix is that projected energy-related CO2 emissions in 2040 are 10% lower in 2040 than they would have been without the changes. Natural gas is the largest contributor to CO2 emissions growth in both the OECD and non-OECD economies, accounting for 100% and 35%, respectively, of the projected CO2 emissions increases in the two regions (Figure 9-4).

Growth in CO2 emissions from the consumption of liquids worldwide is projected to average 1.0% annually in the IEO2016 Reference case, resulting in an absolute increase of 3.8 billion metric tons of liquids-related CO2 emissions from 2012 to 2040. In the OECD countries, liquids-related CO2 emissions decline by an average of 0.1%/year. In the non-OECD countries, rising demand for transportation and industrial uses of liquid fuels contributes to a growth rate of 1.9%/year for total CO2 emissions from the combustion of liquid fuels.

In the IEO2016 Reference case, world coal-related CO2 emissions show slower growth over the 28-year projection period than in projections in past IEOs, averaging 0.6%/year and resulting in an 18% increase in coal-related emissions and a 14% increase if the U.S. CPP is included. Coal-related emissions in the OECD and non-OECD regions increase by 0.1% and 0.8%/year from 2012 to 2040, respectively. Under the U.S. CPP, OECD coal-related CO2 emissions would decrease by 0.4%/year. The world's top three national sources of coal-related emissions are China, India, and the United States, which remain at the top throughout the projection period and in combination account for 70% of world coal-related CO2 emissions in 2040.

Figure 9-3. World energy-related carbon dioxide emissions by fuel type, 1990–2040 (billion metric tons)

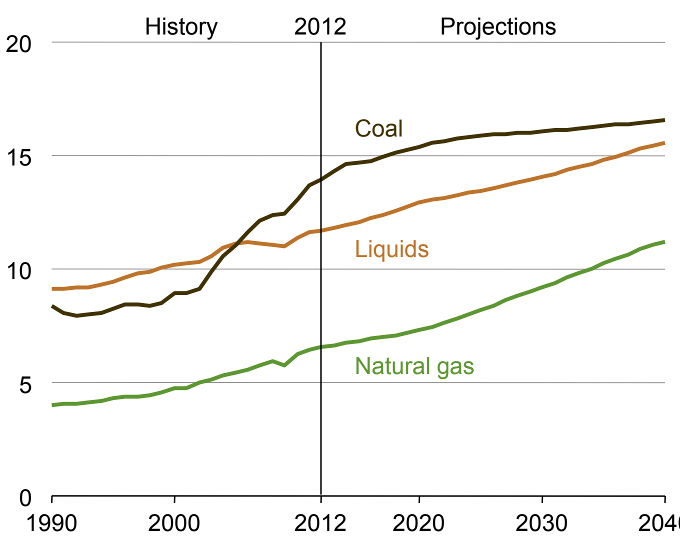
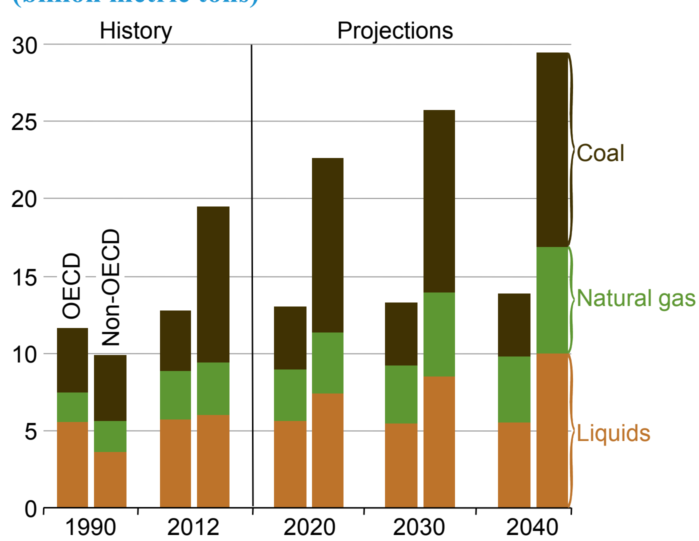


Figure 9-4. OECD and non-OECD energy-related carbon dioxide emissions by fuel type, 1990–2040 (billion metric tons)



Uncertainties in projecting European Union emissions reductions

The European Union (EU) has pledged a goal of a 40% reduction in total GHG emissions from 1990 levels by 2030.[333] However, at this time only parts of the programs to implement the pledge are in place, and for the IEO2016 Reference case EIA has not assumed anything beyond what EU countries now have in place. Considering programs currently in place, OECD Europe's energy-related carbon dioxide emissions rise slightly through 2040; however, Turkey and Norway (which are included in OECD Europe) are not part of the EU.[334]

Much of the difference between the emissions level projected in the Reference case and the EU goal would likely be covered by emission allowance credits. The cornerstone of the EU's efforts to reduce GHG emissions is the EU Emissions Trading System (ETS). The EU ETS is a cap-and-trade system that covers approximately 45% of the GHG emissions in the EU's 28 member states, plus Iceland, Liechtenstein, and Norway. The ETS was introduced in 2005 in a first-phase trial period that lasted through 2007. The second phase began in 2008 and ended in 2012. A large surplus of allowances that were accumulated during the first two phases will be available for use in the third phase, from 2013 to 2020.[335]The ETS credit surplus is one of many uncertainties surrounding the prospects for EU reductions. Other uncertainties include:

- Negotiations under way to reform the post-2020 ETS are expected to continue for another two years.[336] Without a better understanding of the rules after 2020, it is difficult to project emissions to 2040.
- With economic growth in the EU lower than projected when the ETS was designed, there are substantial banked (unused) credits. Also, covered industries continue to receive some free allowances. The surplus credits are estimated to reach 2.6 billion metric tons in 2020 with nearly 2.0 billion metric tons remaining in 2030 unless the post-2020 reforms are stringent and enforceable.[337] Further, the current reduction factor of 1.74% (the rate at which the annual cap is reduced) probably is inadequate to achieve the stated EU goals.[338]
- In terms of energy-related carbon dioxide emissions, renewable electricity generation is the primary marginal source of noncarbon energy. In the IEO2016 Reference case, OECD Europe's renewable energy goals are evaluated on a country-by-country basis.
- Nuclear power, the largest existing source of noncarbon energy, faces an uncertain future in OECD Europe. For example, France has been phasing in renewables to replace nuclear capacity. In addition, several EU nations, including Germany and Switzerland, have announced plans to phase out or shut down their operating nuclear reactors in the aftermath of the March 2011 disaster at Japan's Fukushima Daiichi nuclear power plant.
- On the energy-demand side, OECD Europe already has achieved relatively low energy intensity, and the region's energy intensity is projected to fall from 4.4 thousand Btu per dollar of GDP in 2012 (measured in purchasing power parity terms) to 3.2 thousand Btu per dollar in 2040 in the IEO2016 Reference case.
- The price of EU ETS credits has remained around 8 Euros over the past few years, well below the level of 40 to 50 Euros that many analysts believe would be required to initiate a larger shift from fossil fuels to noncarbon energy sources.[339]
- Another important uncertainty is whether land use, land use change, and forestry (LULUCF) will be included in the EU goal. As of April 2016, specific rules for their inclusion had not been published[340] and LULUCF is not included in the IEO2016 projections. However, the rules could greatly influence levels of energy-related carbon dioxide emissions.

[333]European Commission, "Climate Action: 2030 climate & energy framework" (September 24, 2015), http://ec.europa.eu/clima/policies/strategies/2030/index_en.htm.

[334]The EU membership intersects with the countries included in the IEO2016 OECD Europe region, as follows: Norway and Turkey are included in OECD Europe but are not EU member countries; Bulgaria, Cyprus, Latvia, Lithuania, Malta, and Romania are EU member countries but are not included in OECD Europe; Israel is reported in OECD Europe for statistical purposes.

[335]Carbon Market Watch, "Policy Briefing: What's needed to fix the EU's carbon market: Recommendations for the Market Stability Reserve and future ETS reform proposals" (July 9, 2014), http://carbonmarketwatch.org/whats-needed-to-fix-the-eus-carbon-market-recommendations-for-the-market-stability-reserve-and-future-ets-reform-proposals/.

[336]Bloomberg New Energy Finance, "EU Carbon Allowances Rise as More Bidders Participate in Sales" (September 8, 2015), www.bnef.com (subscription site).

[337]Carbon Market Watch, "Policy Briefing: What's needed to fix the EU's carbon market: Recommendations for the Market Stability Reserve and future ETS reform proposals" (July 9, 2014), http://carbonmarketwatch.org/whats-needed-to-fix-the-eus-carbon-market-recommendations-for-the-market-stability-reserve-and-future-ets-reform-proposals/.

[338]Carbon Market Watch, "Policy Briefing: What's needed to fix the EU's carbon market: Recommendations for the Market Stability Reserve and future ETS reform proposals" (July 9, 2014), http://carbonmarketwatch.org/whats-needed-to-fix-the-eus-carbon-market-recommendations-for-the-market-stability-reserve-and-future-ets-reform-proposals/.

[339]businessGreen, "EU carbon price tops €8 for first time since 2012" (July 21, 2015), http://www.businessgreen.com/bg/news/2418553/eu-carbon-price-tops-eur8-for-first-time-since-2012 (subscription site).

[340]Climate Action Tracker, "European Union" (April 7, 2016), http://climateactiontracker.org/countries/eu.html.

CO2 emissions by region

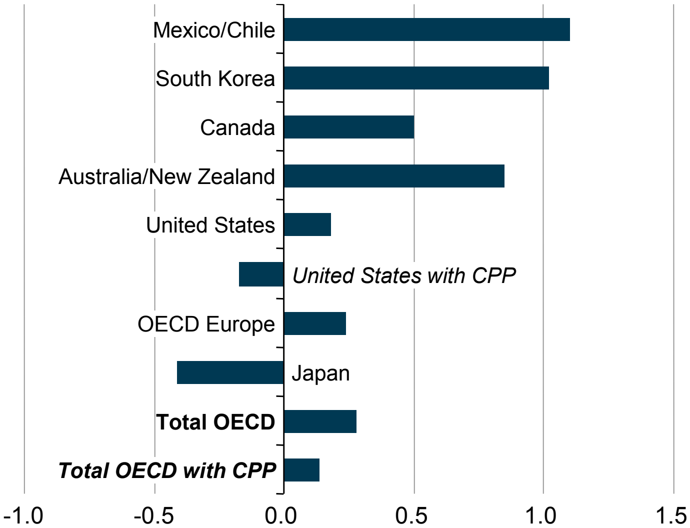
World energy-related CO2 emissions increase at an average annual rate of 1.0% from 2012 to 2040 in the IEO2016 Reference case (Table 9-2). On average, OECD emissions increase by 0.3%/year and non-OECD emissions increase by 1.5%/year. Among the OECD countries, energy-related CO2 emissions from the combined region of Mexico and Chile grow by an average of 1.1%/year, and emissions from South Korea increase by an average of 1.0%/year (Figure 9-6). The two regions also have among the highest projected rates of economic growth in the OECD over the period, with Mexico/Chile's GDP increasing by 3.1%/year in the IEO2016 Reference case and South Korea's GDP increasing by 2.1%/year. For all the other OECD countries and regions, CO2 emissions increase by an average of less than 1%/year. Japan's CO2 emissions decline by an average of 0.4%/year from 2012 to 2040. In OECD Europe, CO2 emissions increase by 0.2%/year; and in the OECD Americas, CO2 emissions increase by 0.3%/year over the projection period, with the growth rate dropping to 0%/year after implementation of the CPP. In 2040, OECD Europe accounts for about 10% of world emissions, as compared with about 13% in 2012, and the OECD Americas region accounts for 16% (or 15%, if the CPP is taken into account), down from 20% in 2012. For the OECD region as a whole, GDP growth averages 2.0%/year.

Non-OECD Asia accounts for about 59% of the growth in world CO2 emissions from 2012 to 2040. China's emissions grow by an average of only 1.0%/year (Figure 9-7), but they still account for 41% of the total increase in non-OECD Asia's emissions.

Table 9-2. World energy-related carbon dioxide emissions by region and country in the Reference case with and without the U.S. Clean Power Plan (CPP), 1990–2040 (billion metric tons)

Region/Country	1990	2012	2020	2030	2040	Average annual percent change, 1990–2012	Average annual percent change, 2012–40	Total change, 2012–40 (billion metric tons)	Percent change, 2012–40
OECD	**11.6**	**12.8**	**13.0**	**13.3**	**13.8**	**0.4**	**0.3**	**1.0**	**8.0**
OECD with CPP	**11.6**	**12.8**	**12.7**	**12.7**	**13.3**	**0.4**	**0.1**	**0.5**	**3.9**
OECD Americas	5.8	6.3	6.6	6.7	6.9	0.3	0.3	0.5	8.6
OECD Americas with CPP	5.8	6.3	6.3	6.1	6.4	0.3	0.0	1.0	0.3
United States	5.0	5.3	5.5	5.5	5.5	0.1	0.2	0.4	6.9
United States with CPP	5.0	5.3	5.2	4.9	5.0	0.1	-0.2	-0.2	-4.6
Canada	0.5	0.6	0.6	0.6	0.6	0.9	0.5	0.1	14.9
Mexico/Chile	0.3	0.5	0.5	0.6	0.7	1.9	1.1	0.2	35.7
OECD Europe	4.2	4.1	4.1	4.3	4.4	-0.1	0.2	0.3	7.1
OECD Asia	1.6	2.3	2.4	2.4	2.5	1.8	0.3	0.2	8.2
Japan	1.0	1.2	1.2	1.2	1.1	0.8	-0.4	-0.1	-10.9
South Korea	0.2	0.6	0.7	0.8	0.8	4.5	1.0	0.2	32.9
Australia/ New Zealand	0.3	0.4	0.5	0.5	0.6	1.8	0.8	0.1	26.7
Non-OECD	**9.9**	**19.5**	**22.6**	**25.8**	**29.4**	**3.1**	**1.5**	**9.9**	**50.9**
Non-OECD Europe and Eurasia	4.2	2.9	2.9	3.1	3.2	-1.6	0.3	0.2	7.9
Russia	2.4	1.8	1.8	1.9	1.9	-1.3	0.1	0.1	3.8
Other	1.8	1.1	1.1	1.2	1.3	-2.1	0.5	0.2	14.3
Non-OECD Asia	3.7	12.2	14.5	16.4	18.7	5.6	1.5	6.5	53.2
China	2.3	8.4	9.9	10.6	11.1	6.1	1.0	2.7	31.9
India	0.6	1.8	2.1	2.7	3.7	5.3	2.7	2.0	109.9
Other	0.8	2.0	2.5	3.1	3.9	4.3	2.3	1.9	91.2
Middle East	0.7	1.9	2.4	2.9	3.4	4.8	2.2	1.6	82.0
Africa	0.7	1.2	1.4	1.8	2.2	2.7	2.3	1.1	89.2
Non-OECD Americas	0.7	1.3	1.4	1.6	1.9	3.0	1.4	0.6	46.8
Brazil	0.2	0.5	0.5	0.7	0.8	3.5	1.5	0.3	52.4
Other	0.4	0.8	0.8	1.0	1.1	2.7	1.3	0.3	43.1
Total World	**21.4**	**32.3**	**35.6**	**39.1**	**43.2**	**1.9**	**1.0**	**10.9**	**33.9**
Total World with CPP	**21.4**	**32.3**	**35.3**	**38.5**	**42.7**	**1.9**	**1.0**	**10.4**	**32.3**

Figure 9-5. Average annual growth of energy-related carbon dioxide emissions in OECD economies with and without the U.S. Clean Power Plan (CPP), 2012–40 (percent per year)



India's CO2 emissions increase by 2.7%/year, and emissions in the rest of non-OECD Asia increase by an average of 2.3%/year, accounting for 30% and 29%, respectively, of the total non-OECD Asia increase in CO2 emissions. From 2012 to 2040, emissions from coal combustion in non-OECD Asia increase by 2.2 billion metric tons, and emissions from liquid fuels increase by 2.3 billion metric tons, while emissions from natural gas combustion increase by 2.0 billion metric tons (Figure 9-7).

Among the non-OECD regions, the slowest growth in CO2 emissions, at 0.3%/year, is projected for non-OECD Europe and Eurasia in the IEO2016 Reference case. Total CO2 emissions in non-OECD Europe and Eurasia increase only slightly, from 2.9 billion metric tons in 2012 to 3.2 billion metric tons in 2040, in part because of Russia's projected population decline and increasing reliance on nuclear power to meet electricity demand in the future. Natural gas continues to be the region's leading source of energy-related CO2 emissions throughout the projection, accounting for 69% of regional energy-related CO2 emissions growth from 2012 to 2040.

Figure 9-6. Average annual growth of energy-related carbon dioxide emissions in non-OECD economies, 2012–40 (percent per year)

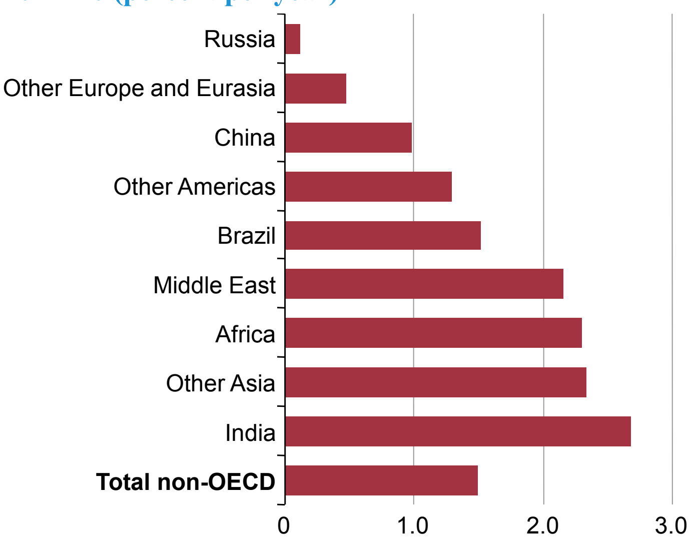
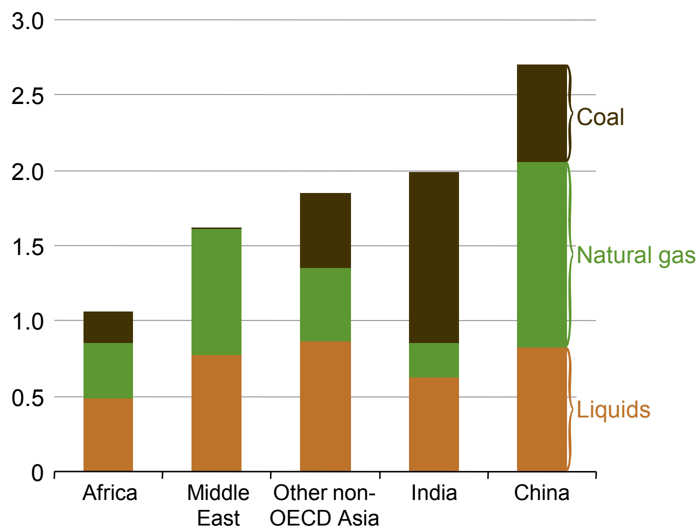


Figure 9-7. Increases in carbon dioxide emissions by fuel type in non-OECD regions with the highest absolute emissions growth, 2012–40 (billion metric tons)



U.S. Clean Power Plan Rule

In March 2015, the United States submitted its Intended Nationally Determined Contribution (INDC) for GHG emissions reduction to the United Nations Framework Convention on Climate Change (UNFCCC). The U.S. INDC pledges an emissions reduction of 26% to 28% below 2005 levels by 2025.[341] The U.S. Environmental Protection Agency (EPA) published the final version of the U.S. Clean Power Plan rule (CPP) in August 2015.[342] The effect of that rule was not included in the baseline for U.S. projections in IEO2016 because of the timing of its release. However, estimates of the effect based on the proposed rule have been included in this chapter.

(continued on page 145)

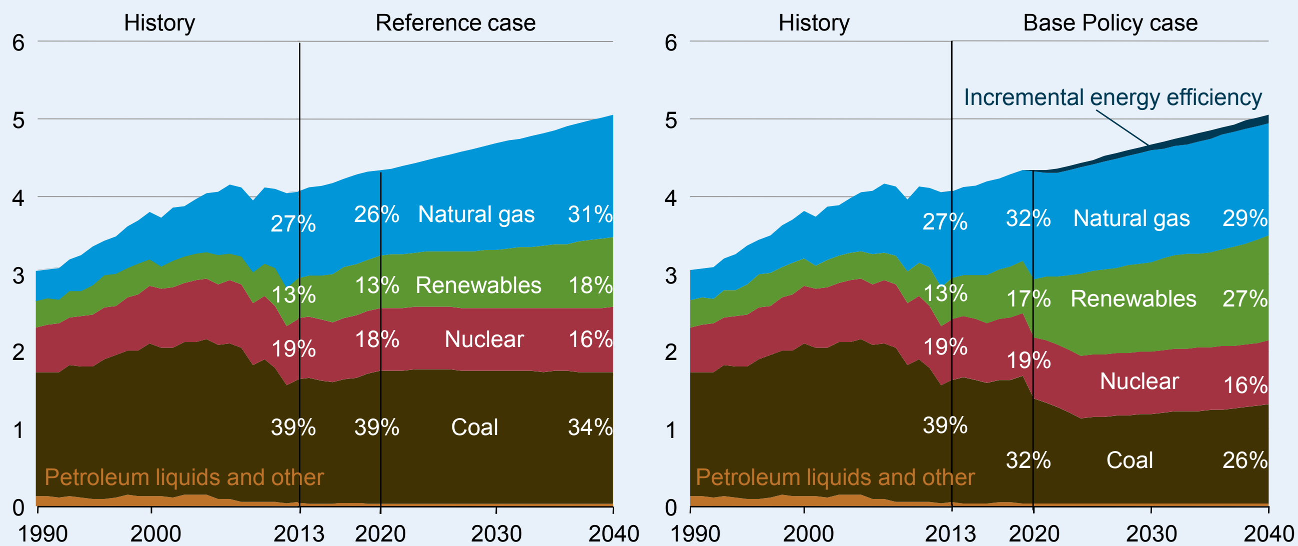
[341]The White House, Office of the Press Secretary, "FACT SHEET: U.S. Reports its 2025 Emissions Target to the UNFCCC" (Washington, DC: March 31, 2015), https://www.whitehouse.gov/the-press-office/2015/03/31/fact-sheet-us-reports-its-2025-emissions-target-unfccc.

[342]United States Environmental Protection Agency, "Clean Power Plan for Existing Power Plants" (Washington, DC: November 16, 2015), http://www2.epa.gov/cleanpowerplan/clean-power-plan-existing-power-plants.

The final CPP reflects substantive changes from the proposed rule, but the overall expected level of CO2 emissions reduction is similar to the level expected under the proposed rule. To the extent that the requirements are similar, a reasonable indicator of potential changes resulting from the final CPP is provided in EIA's analysis of the proposed rule.[343]

In EIA's analysis, the key impact of the proposed CPP rule was a projected reduction in U.S. coal-fired generation, by 560 billion kilowatthours (kWh) in 2030, to approximately 33% less than the projected 1,713 billion kWh without the CPP rule (Figure 9-8). Thus, under the proposed rule, the projected reduction in output from U.S. coal-fired power plants would yield CO2 emissions of roughly 613 million metric tons (25% below 2005 levels) in 2020 and roughly 830 million metric tons (34% below 2005 levels) in 2030.

Figure 9-8. U.S. electricity generation by primary fuel in the AEO2015 Reference case, 1990–2040, and incremental energy savings in the AEO2015 Base Policy case, 1990–2040 (trillion kilowatthours)



The Clean Power Plan leads to a decrease in coal-fired generation, reflecting both additional coal plant retirements and lower utilization rates for plants that remain in use. In the early stages of implementation, natural gas-fired generation is the primary replacement for coal, followed by a shift to renewables in the mid-2020s. The actual mix of additional renewables and gas-fired generation resulting from the Clean Power Plan will depend on CPP implementation decisions made by states, the availability of tax credits for renewables—which were extended by legislation enacted in December 2015, and fuel and technology costs.

Changes to the final CPP, made by the EPA rule in response to comments, relate to the structure and implementation of the CPP program rather than to its requirements. Significant changes from the proposed rule to the final rule include:

- More gradual implementation over the compliance period
- Increased emphasis on trading options, including examples of rules for rate-based and mass-based programs to speed the creation of interstate cooperative programs
- Reduced variability across states in the required CO2 emissions reductions, with the EPA basing its emission rate standards on CO2 averages determined at the electricity grid interconnection level rather than at the state level.

IEO2016 factors influencing trends in energy-related CO2 emissions

Many factors influence a country's level of CO2 emissions. Two key measures provide useful insights for the analysis of trends in energy-related emissions:

- The *carbon intensity of energy consumption* is a measure of the amount of CO2 associated with each unit of energy used. It directly links changes in CO2 emissions levels with changes in energy usage. Carbon emissions vary by energy source, with coal being the most carbon-intensive major fuel, followed by oil and natural gas. Nuclear power and some renewable energy sources (i.e., solar and wind) do not directly generate CO2 emissions. Consequently, changes in the fuel mix alter overall carbon intensity. Over time, declining carbon intensity can offset increasing energy consumption to some extent. If energy consumption increased and carbon intensity decreased by a proportional factor, energy-related CO2 emissions would remain constant. A decline in carbon intensity can indicate a shift away from fossil fuels, a shift towards less carbon-intensive fossil fuels, or both.

[343]U.S. Energy Information Administration, "Analysis of the Impacts of the Clean Power Plan" (Washington, DC: May 22, 2015), http://www.eia.gov/analysis/requests/powerplants/cleanplan/.

- The *energy intensity of economic activity* is a measure of energy consumption per unit of economic activity, as measured by GDP. It relates changes in energy consumption to changes in economic output. Increased energy use and economic growth generally occur together, although the degree to which they are linked varies across regions, stages of economic development, and the mix of products produced.

As with carbon intensity, regional energy intensities do not necessarily remain constant over time. Energy intensity can be indicative of the energy efficiency of an economy's capital stock (vehicles, appliances, manufacturing equipment, power plants, etc.). For example, if an old power plant is replaced with a more thermally efficient unit, it is possible to meet the same level of electricity demand with a lower level of primary energy consumption, thereby decreasing energy intensity.

Energy intensity is acutely affected by structural changes within an economy—in particular, the relative shares of its output sectors (manufacturing versus service, for example). Higher concentrations of energy-intensive industries, such as oil and natural gas extraction, will yield higher overall energy intensities, whereas countries with proportionately larger service sectors will tend to have lower energy intensities.

Carbon intensity multiplied by energy intensity provides a measure of CO2 emissions per dollar of GDP (CO2/GDP)—that is, the carbon intensity of economic output. Carbon intensity of output is another common measure used in analysis of changes in CO2 emissions, and it is sometimes used as a standalone measure. However, when the goal is to determine the relative strengths of forces driving changes in carbon intensity, disaggregation of the components helps to determine whether a change in carbon intensity is the result of a change in the country's fuel mix or a change in the relative energy intensity of its economic activity.

The Kaya decomposition of emissions trends

The Kaya Identity provides an intuitive approach to the interpretation of historical trends and future projections of energy-related CO2 emissions.[344] It can be used to decompose total CO2 emissions as the product of individual factors that explicitly link energy-related CO2 emissions to energy consumption, the level of economic output as measured by gross domestic product (GDP), and population size.

The Kaya Identity expresses total CO2 emissions as the product of (1) carbon intensity of energy consumption (CO2/E), (2) energy intensity of economic activity (E/GDP), (3) economic output per capita (GDP/POP), and (4) population (POP):

$$CO2 = (CO2 / E) \times (E / GDP) \times (GDP / POP) \times POP$$

Using 2012 data as an example, world energy-related CO2 emissions totaled 32.2 billion metric tons in that year, world energy consumption totaled 549 quadrillion Btu, world GDP totaled $94.46 trillion, and the total world population was 7.073 billion. Using those figures in the Kaya equation yields the following: 58.6 metric tons CO2 per billion Btu of energy *(CO2/E),* 5.8 thousand Btu of energy per dollar of GDP *(E/GDP),* and $13,355 output per capita *(GDP/POP).* Appendix J shows calculations of the Kaya factors for all IEO2016 regions over the projection period.

Of the four Kaya components, policymakers generally focus on the energy intensity of economic output *(E/GDP)* and CO2 intensity of the energy supply *(CO2/E).* Reducing growth in per-capita output may have a mitigating influence on emissions, but governments generally pursue policies to increase rather than reduce output per capita to advance economic objectives.

Policies related to energy intensity of GDP typically involve improvements to energy efficiency. However, the measure is also sensitive to shifts in the energy-intensive portion of a country's trade balance, and improvements may simply reflect a greater reliance on imports of manufactured goods. If the country producing the imported goods is less energy efficient, a greater reliance on imported goods could lead to a worldwide increase in energy consumption and related CO2 emissions. Policies related to the CO2 intensity of energy supply typically focus on promotion of low-carbon or zero-carbon sources of energy.

With all of the components of the Kaya identity having small annual percentage rates of change, the percentage rate of change in CO2 emission levels over time approximates the sum of the component percentage rate of change. Table 9-3 shows the average rates of change in total CO2 emissions and each individual Kaya component from 2012 to 2040 in the IEO2016 Reference case. The most significant driver of growth in energy-related CO2 emissions is economic output per capita. The average annual growth rate of output per capita for non-OECD countries (3.2% from 2012 to 2040) in particular dominates all other Kaya components in the 28-year projection. For OECD countries, on the other hand, the 1.6% average annual increase in output per capita is nearly offset by the 1.4% annual decline in energy intensity.

Except for Japan and Russia—where population is expected to decline from 2012 to 2040—population growth is also a contributing factor to emissions increases, along with output per capita. The Kaya identity separates population *(POP)* growth from output per capita *(GDP/POP)* so that the influence of the two components of total GDP growth can be measured. As indicated in Table 9-3, in all regions population growth is less than the growth of output per capita. For non-OECD countries, increases in output per capita coupled with population growth overwhelm improvements in energy intensity and carbon intensity. Although the same was true for the OECD countries from 1990 to 2012, the projection horizon shows OECD growth in output per capita and population largely balanced by reductions in energy intensity and carbon intensity (Figure 9-9, Figure 9-10, and Figure 9-11).

[344] See Intergovernmental Panel on Climate Change, "Emissions Scenarios," http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=50.

Over the 2012–40 projection period, the energy intensity of economic output declines in all IEO2016 regions. The trend is particularly pronounced in the non-OECD countries, where energy intensity of output decreases by an average of 2.2%/year, compared with a decrease of 1.4%/year in the OECD countries. Worldwide, the most significant decline in the energy intensity of output is projected for China, at 2.8%/year. However, that decline is offset by a projected increase in China's output per capita, averaging 4.6%/year over the same period.

Carbon intensity of energy supply is projected to decline in all IEO2016 regions from 2012 to 2040, but to a lesser extent than energy intensity. The combined decrease in carbon intensity for the non-OECD countries is slightly larger than the combined decrease for the OECD countries—0.5%/year versus 0.3%/year. With the effects of the U.S. CPP included, the rate of decline in carbon intensity for the OECD countries is 0.4%/year. China's projected decrease in energy intensity is the largest, averaging 0.8%/year. In most regions, decreases in the energy consumption shares for liquid fuels and coal (the most carbon-intensive fuels), combined with increases in the shares for renewable energy, nuclear power, and natural gas, reduce the global carbon intensity of energy supply.

Table 9-3. Average annual changes in Kaya factors by region and country in the Reference case with and without the U.S. Clean Power Plan (CPP), 2012–40 (percent per year)

Region/Country	Carbon intensity of energy supply *(CO2/E)*	Energy intensity of economic activity *(E/GDP)*	Output per capita *(GDP/POP)*	Population *(POP)*	Carbon dioxide emissions
OECD	**-0.3**	**-1.4**	**1.6**	**0.4**	**0.3**
OECD with CPP	**-0.4**	**-1.4**	**1.6**	**0.4**	**0.2**
OECD Americas	-0.3	-1.9	1.7	0.7	0.3
OECD Americas with CPP	-0.5	-1.9	1.7	0.7	0.1
United States	-0.2	-2.0	1.7	0.7	0.2
United States with CPPs	-0.5	-2.0	1.7	0.7	-0.1
Canada	-0.3	-1.3	1.2	0.8	0.5
Mexico/Chile	-0.5	-1.4	2.3	0.8	1.1
OECD Europe	-0.3	-1.1	1.5	0.2	0.2
OECD Asia	-0.5	-0.5	1.3	0.0	0.3
Japan	-0.5	-0.5	1.0	-0.4	-0.4
South Korea	-0.4	-0.6	1.8	0.2	1.0
Australia/New Zealand	-0.6	-1.1	1.2	1.3	0.8
Non-OECD	**-0.5**	**-2.2**	**3.2**	**1.0**	**1.5**
Non-OECD Europe and Eurasia	-0.2	-2.2	2.9	-0.1	0.3
Russia	-0.1	-1.7	2.4	-0.4	0.1
Other	-0.3	-2.8	3.6	0.1	0.5
Non-OECD Asia	-0.6	-2.4	4.1	0.6	1.5
China	-0.8	-2.8	4.6	0.1	1.0
India	-0.5	-2.3	4.7	0.8	2.7
Other	-0.2	-1.5	3.1	1.0	2.3
Middle East	-0.2	-1.3	2.0	1.7	2.2
Africa	-0.3	-2.2	2.7	2.1	2.3
Non-OECD Americas	-0.1	-1.1	1.7	0.9	1.4
Brazil	-0.2	-0.7	1.9	0.5	1.5
Other	**-0.1**	**-1.4**	**1.7**	**1.1**	**1.3**
Total World	**-0.4**	**-1.9**	**2.4**	**0.9**	**1.0**
Total World with CPP	**-0.4**	**-1.9**	**2.4**	**0.9**	**1.0**

Figure 9-9. OECD and non-OECD carbon intensity of energy supply, 1990–2040 (metric tons carbon per billion Btu)

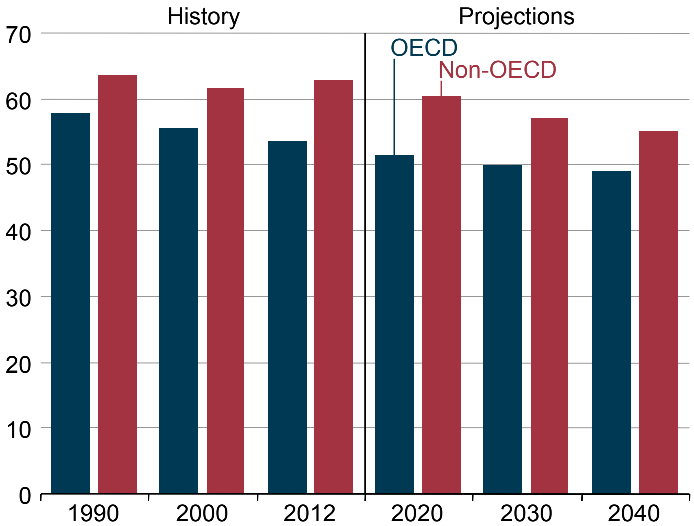


Figure 9-10. OECD and non-OECD energy intensity, 1990–2040 (thousand Btu per 2010 dollar of GDP)

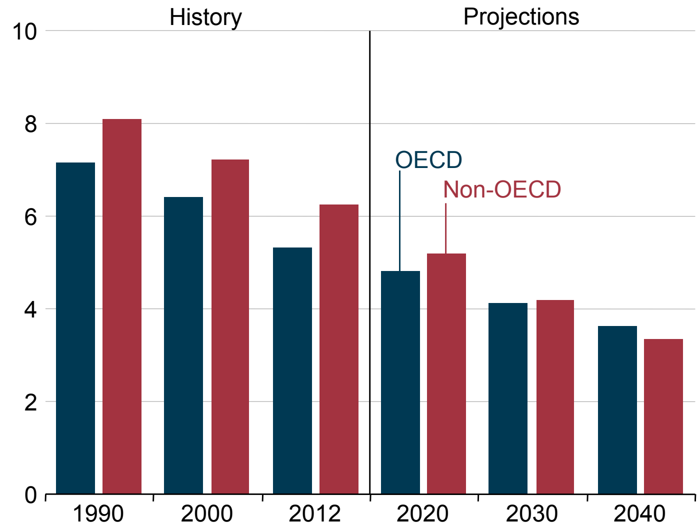


Figure 9-11. OECD and non-OECD carbon intensity of economic output, 1990–2040 (metric tons carbon per million 2010 dollars of gross domestic product)