



Independent Statistics & Analysis
U.S. Energy Information
Administration

International Energy Outlook 2021

with projections to 2050

Narrative



This report was prepared by the U.S. Energy Information Administration (EIA), the statistical and analytical agency within the U.S. Department of Energy. By law, EIA's data, analyses, and forecasts are independent of approval by any other officer or employee of the U.S. Government. The views in this report should not be construed as representing those of the U.S. Department of Energy or other federal agencies.

Introduction

Key takeaways from the Reference and side cases

If current policy and technology trends continue, global energy consumption and energy-related carbon dioxide emissions will increase through 2050 as a result of population and economic growth

- Liquid fuels remain the largest energy source in the Reference case, but renewable energy use grows to nearly the same level.
- Across all cases, end-use sectors in non-OECD countries drive the return of global energy use to pre-pandemic levels.
- By 2050, global energy use in the Reference case increases nearly 50% compared with 2020—mostly a result of non-OECD economic growth and population, particularly in Asia.
- In the Reference case, global emissions rise throughout the projection period, although slowed by regional policies, renewable growth, and increasing energy efficiency.

Renewables will be the primary source for new electricity generation, but natural gas, coal, and increasingly batteries will be used to help meet load and support grid reliability

- Increases in electricity generation are primarily from renewable generation sources.
- World coal-fired generation declines through 2030 in the Reference case, but it remains a significant part of the worldwide generation mix.
- Carbon dioxide (CO₂) emissions in the global electric power sector remain stable despite significant growth in electricity demand.

Oil and natural gas production will continue to grow, mainly to support increasing energy consumption in developing Asian economies

- Supply of petroleum and other liquids continues increasing in both OPEC and non-OPEC regions to meet growing world demand through 2050 across cases.
- Non-OECD Asia lacks adequate production to meet growing demand; most of the crude oil it uses comes from the Middle East.
- Natural gas production increases worldwide to help satisfy key demand markets.

The International Energy Outlook 2021 provides long-term world energy projections

- EIA's *International Energy Outlook* (IEO) presents an analysis of long-term world energy markets in 16 regions¹ through 2050.
- Reference case projections in each edition of the IEO are not predictions of what is most likely to happen, but rather they are modeled projections under assumptions that reflect current energy trends and relationships, existing laws and regulations, and select incremental economic and technological changes over time.
- We publish the IEO projections under the Department of Energy Organization Act of 1977, which requires that we analyze “international aspects, economic and otherwise, of the evolving energy

¹ https://www.eia.gov/outlooks/ieo/pdf/IEO2021_ChartLibrary_References.pdf

situation” and “long-term relationships between energy supply and consumption in the United States and world communities.”

- We develop the IEO using the World Energy Projection System (WEPS),² an integrated economic model that captures long-term relationships among energy supply, demand, and prices across regional markets under various assumptions.
- WEPS divides the world into 16 regions, which are generally determined based on a country’s economic size, OECD membership,³ location, and other factors. A region may contain one or more countries. Historically, OECD countries tend to have higher GDP per capita and energy patterns that reflect relatively more services and relatively less industrial activities within the economy, while the opposite tends to be true for non-OECD countries.
- U.S. projections in the IEO2021 reflect the published projections in the *Annual Energy Outlook 2021*,⁴ which assumes U.S. laws and regulations, current as of September 2020, remain unchanged.
- Energy market projections are uncertain because the events that shape the future developments in technology, demographic changes, economic trends, government policy, and resource availability that drive energy use are fluid.

The Reference case provides a baseline from which to measure the impact of various assumptions

- The IEO2021 Reference case reflects current trends and relationships among supply, demand, and prices in the future. It is a baseline case constructed to compare with cases that include alternative assumptions about economic drivers, prices, policy changes, or other determinants of the energy system in order to estimate the potential impact of these assumptions.
- The Reference case includes existing laws and regulations, and it reflects legislated energy sector policies that can be reasonably quantified in WEPS. More information on how we model climate policies is available in our companion article, *Climate Considerations in the International Energy Outlook (IEO2021)*.⁵
- The Reference case includes some anticipated changes over time:
 - Expected regional economic and demographic trends, based on the views of leading forecasters
 - Planned or known changes to infrastructure, both for new construction and announced retirements

² https://www.eia.gov/analysis/handbook/pdf/weps2020_overview.pdf

³ IEO2021 regions are based off of OECD membership as of April 30, 2021.

⁴ <https://www.eia.gov/outlooks/aeo/>

⁵ <https://www.eia.gov/outlooks/ieo/climate.php>

- Assumed incremental cost and performance improvements in established technologies based on historical trends
- The Reference case does not include some of the following future uncertainties:
 - Changes to national boundaries and international agreements
 - Major disruptive geopolitical or economic events
 - Future technological breakthroughs
 - Anticipated policy changes as reflected in laws, regulations, and stated targets

Side cases address two significant sources of uncertainty

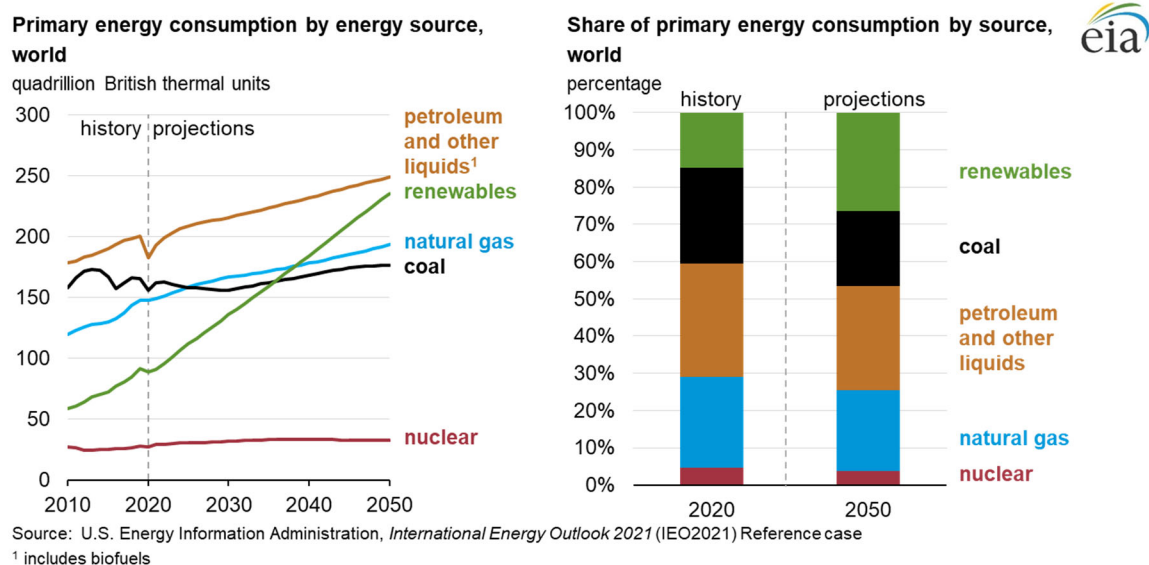
- To gauge the impact of economic growth on energy consumption, we adopted assumptions surrounding regional factors of growth in the High and Low Economic Growth cases. The resulting compound annual growth rates of global gross domestic product (GDP) during the projection period (2020–2050) vary from the Reference case as follows:
 - 3.7% per year, High Economic Growth case
 - 2.8% per year, Reference case
 - 2.0% per year, Low Economic Growth case
- The High and Low Oil Price cases build on the High and Low Economic Growth cases, respectively, to address the uncertainty associated with world energy prices. We altered the assumptions about oil supply to achieve higher and lower oil prices, as seen in the 2050 input price of North Sea Brent crude oil (in 2020 dollars):
 - \$176 per barrel, High Oil Price case
 - \$95 per barrel, Reference case
 - \$45 per barrel, Low Oil Price case

Consumption

Liquid fuels remain the largest energy source in the Reference case, but renewable energy use grows to nearly the same level

Renewable energy use is driven by favorable technology costs and government policy, but it does not replace petroleum and other liquid fuels absent future technology breakthroughs or significant policy changes

Figure 1.



In the Reference case, after a period of decline in coal consumption through 2030, consumption of all major fuels grows from 2030 to 2050. Renewable energy consumption more than doubles between 2020 and 2050, and renewable energy consumption nearly equals liquid fuels consumption by 2050. The rise of renewables—which account for 27% of global energy consumption in 2050 in the Reference case—results from falling technology costs and changing government policies, which in turn contribute to the electric power sector using renewable energy sources to meet growing electricity demand.

Coal's share of global energy use steadily declines through 2050. Coal consumption declines in absolute terms through 2030, in part as a result of low near-term natural gas prices. Policies—such as emissions trading programs in the European Union and South Korea—and slowing investment in coal power plants also play a role in the near-term decline of coal. However, countervailing pressures keep coal in the energy mix through 2050, including the expansion of coal-reliant heavy industry in India, the availability and security of local coal supply in some regions, and the projected growth of coal-fired generating plants in non-OECD Asia to fuel the region's growing economies.

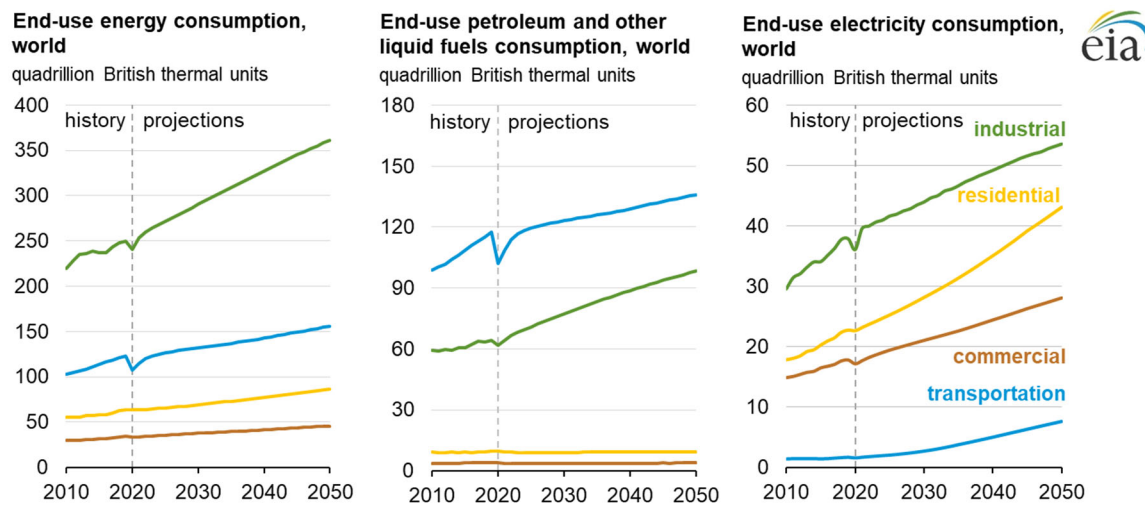
Although natural gas consumption grows by 31% through the projection period in our Reference case, renewables' share of energy consumption, which grows from 15% in 2020 to 27% in 2050, limits the share of global energy use fueled by natural gas, which decreases slightly from 24% to 22% over the

same period. Lower relative prices of natural gas in the near term as well as the need to provide back-up supply to intermittent renewables are important drivers in natural gas consumption.

Under current laws and regulations in our Reference case, we project growth in liquid fuels consumption to continue at a near constant pace through 2050. As travel increases as the effects of the COVID-19 pandemic lessen, the majority of passenger and freight vehicles continue to be fueled by liquid fuel-consuming internal combustion engines (ICEs). Industrial use of petroleum and other liquids, particularly for chemical feedstocks, also increases through the projection period.

Electricity use increases in all end-use sectors and grows faster than total energy consumption

Figure 2.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021 (IEO2021)* Reference case

Despite efficiency gains, worldwide end-use sectors increase energy consumption through 2050. We project demand for electricity to increase across all sectors, outpacing global population growth.

In homes, electricity use grows faster than any other energy sources, accounting for half of all household energy use by 2050 according to our Reference case. Electricity use in commercial buildings also grows. We project over 60% of commercial energy needs will be met by electricity in 2050. As household incomes⁶ and the service sector grow in the Reference case, standards of living increase and space-cooling technologies (for example, air conditioners) become more prevalent in buildings. As a result, the use of electricity in buildings grows quickly from a relatively large base in 2020, but it grows fastest in the transportation sector.

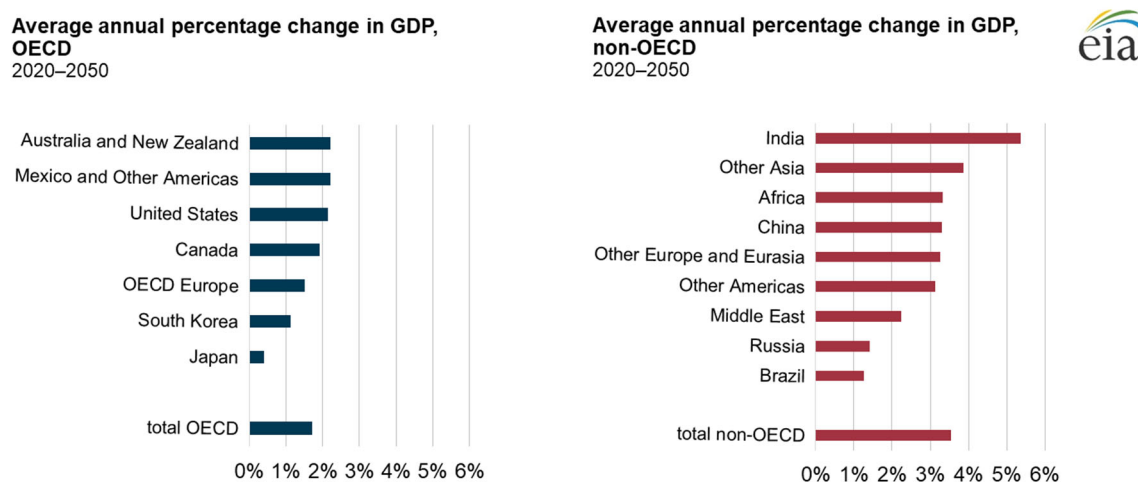
Petroleum liquids—such as motor gasoline, distillate, and jet fuel—continue to grow and to fulfill most demand for transportation energy over the next 30 years, as the world’s population grows and passenger and freight travel expand. Electricity use, however, starting from a relatively small base, grows almost six times faster than petroleum use over the same period.

⁶ Household income is the aggregate net income of all people in a country, also known as personal disposable income.

Plug-in electric vehicles (PEVs), which include both battery electric vehicles and plug-in hybrid electric vehicles, are the fastest-growing light-duty passenger fleet across OECD and non-OECD countries alike. In the Reference case, 138 internal combustion engine, or conventional, light-duty vehicles (LDVs) are on the road in 2020 for every PEV. By 2050, PEVs make up almost a third of the global light-duty stock. Electricity use grows to account for 5% of global transportation energy consumption by 2050 in the Reference case.

Developing Asia, led by India, drives economic growth in the IEO2021 Reference case as growth in China slows

Figure 3.



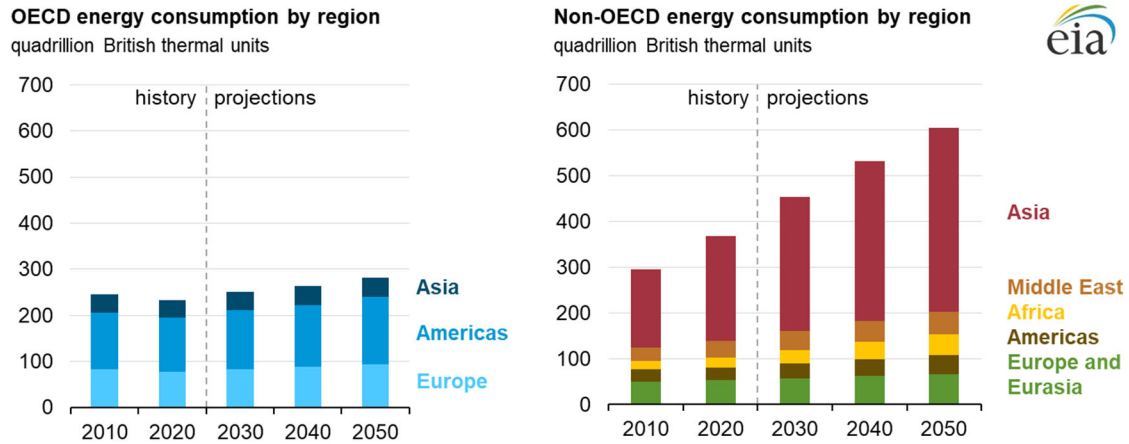
Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

Regional economic growth is a key driver of long-term energy consumption. The regions with the fastest-growing economies in the IEO2021 Reference case are non-OECD countries in Asia. India's growth is greatest, but the WEPS regions⁷ of Other non-OECD Asia, Africa, China, and Other non-OECD Europe and Eurasia remain leaders in economic growth as well. Although China continues to grow at an average rate equal to Africa and Other non-OECD Europe and Eurasia, its growth notably slows throughout the projection period. Together, these top five growth regions were home to 70% of the world's population in 2020 and 44% of GDP. By 2050, these shares grow to 73% and 59%, respectively.

Economic growth varies widely among Asian regions in the IEO2021 Reference case. Most notably, the projected GDP growth rate in China slows considerably compared with its growth rate from 2000 to 2010, when GDP increased by an average of over 10% per year. We also project slower economic growth for Japan and South Korea, illustrating the interconnectedness of Asian economies, as the decline in Chinese demand and trade for intermediate and finished goods, in addition to other structural and demographic factors, affects economic growth in these neighboring countries.

⁷ https://www.eia.gov/outlooks/ieo/pdf/IEO2021_ChartLibrary_References.pdf

Figure 4.

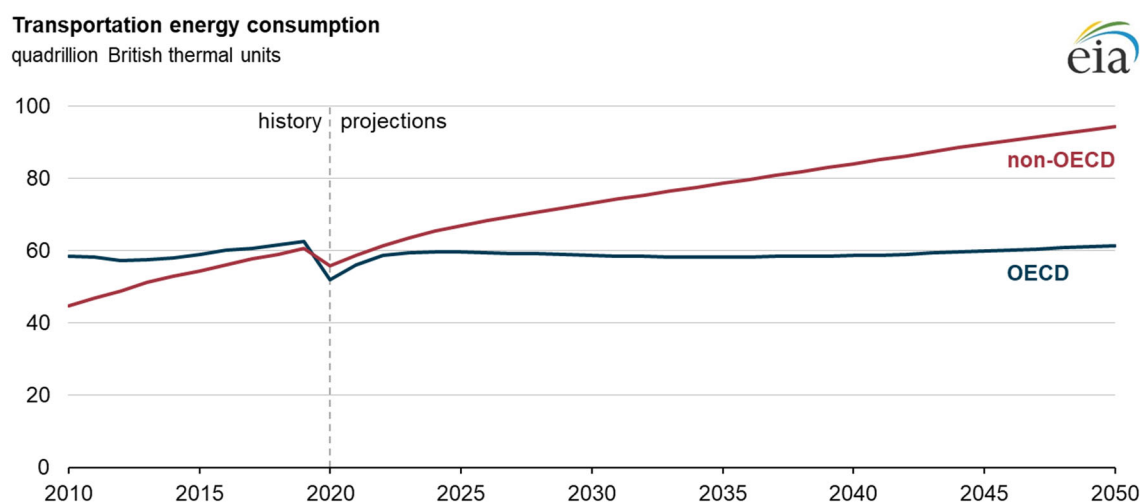


Rapid economic growth in non-OECD countries translates into more energy consumption. Although the Americas retain the largest share of OECD energy use, Asia consumes more than double the amount of energy than all the remaining non-OECD regions combined by 2050.

Across all cases, end-use sectors in non-OECD countries drive the return of global energy use to pre-pandemic levels

After offsetting pandemic-related energy consumption declines in 2020, non-OECD travel demand and population growth continue to support a return to 2019 energy consumption levels in the transportation sector

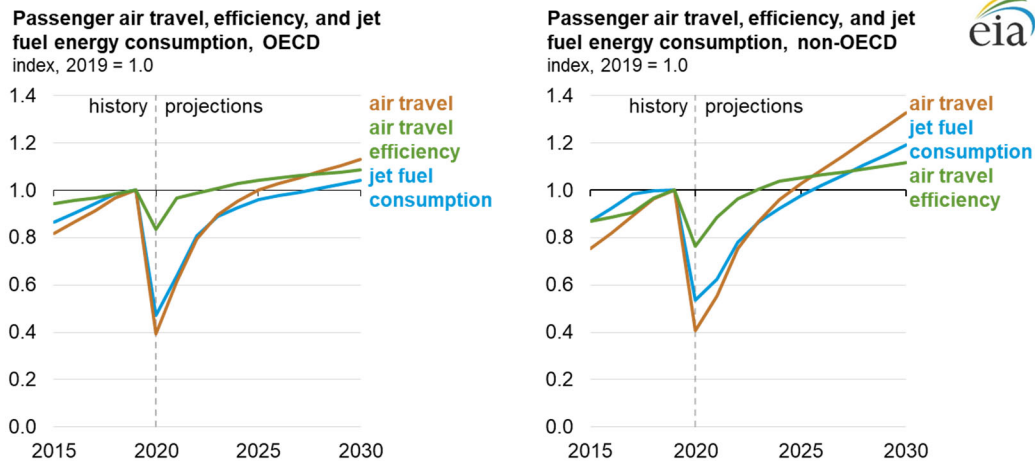
Figure 5.



Before the COVID-19 pandemic, energy consumption in the transportation sector of non-OECD countries had almost grown to the level of OECD countries. Energy consumption in both regions declined as a result of pandemic responses in 2020. A variety of factors, including varied responses to the pandemic, different modal mixes, and the minimal impact of the pandemic on the consumption of energy in China for transportation contribute to a faster return to the 2019 consumption level in non-OECD regions. In addition, increasing populations and travel demand offset declines during the COVID-19 pandemic and drive a faster return to pre-pandemic energy consumption levels in non-OECD countries. As a result, in the Reference case, non-OECD energy consumption in the transportation sector surpassed that of OECD countries for the first time in 2020. Although we project transportation energy consumption to return to 2019 levels by 2022 for non-OECD countries, we do not expect it to return to those levels for OECD countries partly because of increasingly strict fuel economy standards.

Global air travel—which accounted for 16% of global transportation energy consumption in 2019—significantly declined in 2020. The IEO2021 Reference case estimates that global jet fuel consumed for passenger air travel declined nearly 50% in 2020, compared with 2019 levels. Passenger travel dropped from an estimated 90% of global commercial jet fuel consumption in 2019 to 75% in 2020.

Figure 6.



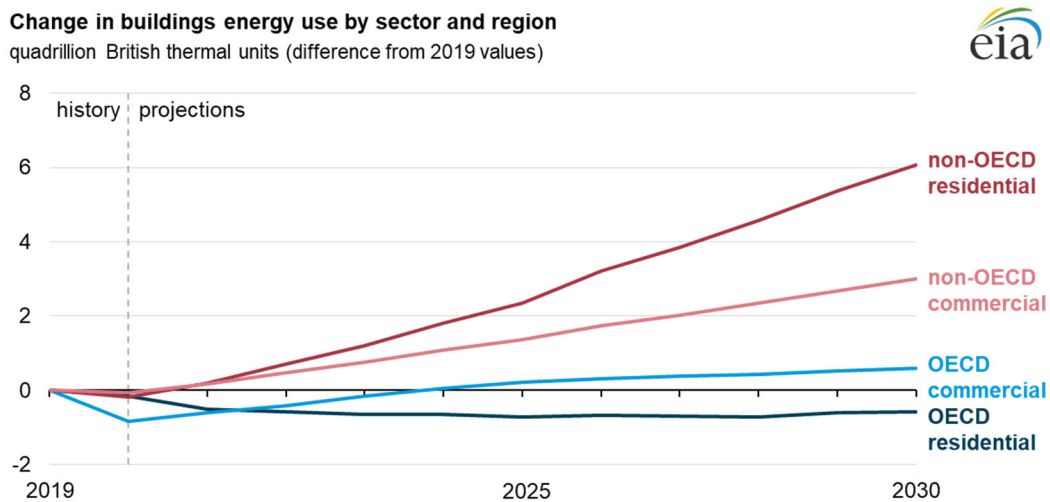
Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

We project aggregate travel demand to return to 2019 levels in 2026 for OECD countries and 2025 for non-OECD countries, while we project passenger jet fuel consumption to return to 2019 levels in 2028 and 2026, respectively.

The projected growth in jet fuel consumption relies on three components: travel per capita, population, and efficiency. We expect travel per capita and population to grow faster than efficiency in non-OECD countries, resulting in a return to 2019 jet fuel consumption levels in 2026. In contrast, efficiency increases in OECD countries offset slower travel and population growth until 2028. Fleet efficiency returns to 2019 levels by 2023 for both OECD and non-OECD countries.

Pandemic mitigation measures constrain average energy use in buildings more so in OECD than in non-OECD countries

Figure 7.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

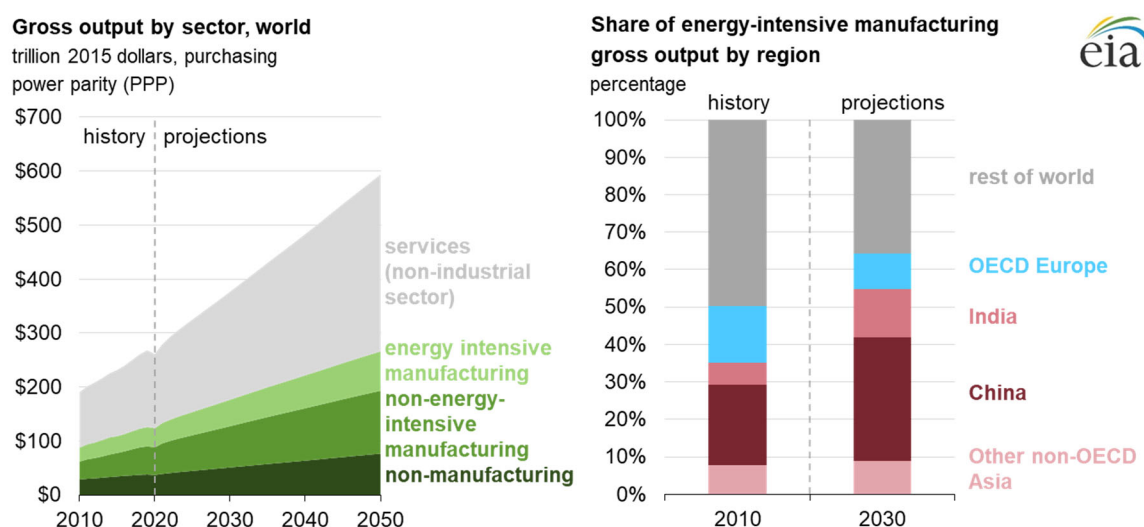
Overall consumption of energy in buildings declined in 2020 from 2019 levels across all OECD and non-OECD countries. On average, delivered energy consumption in buildings returns to pre-pandemic levels faster in non-OECD countries, by 2021. For OECD countries, we project pandemic impacts will extend through 2024 across the commercial buildings stock. OECD households don't resume 2019 levels of energy consumption until after 2030.

The economic output of the service sector is a key driver of consumption of energy in commercial buildings. Declines in commercial energy use in 2020 were steeper in OECD countries, on average, because pandemic mitigation measures hit the service sector harder. Non-OECD countries—China, in particular—experienced relatively minor impacts to the service sector, supporting a quicker return to 2019 levels of energy use in non-OECD buildings.

As a result of having a greater share of jobs that could be done from home, OECD countries generally consumed more household electricity in 2020 than in 2019; the opposite was true for non-OECD countries on average. Gains in energy efficiency and a stable population limit the pace of overall home energy use returning to 2019 levels in OECD countries, which the Reference case projects will occur after 2030.

Global industrial energy use returns to 2019 levels by 2021, as heavy manufacturing continues to move to non-OECD countries, especially India and other parts of Asia

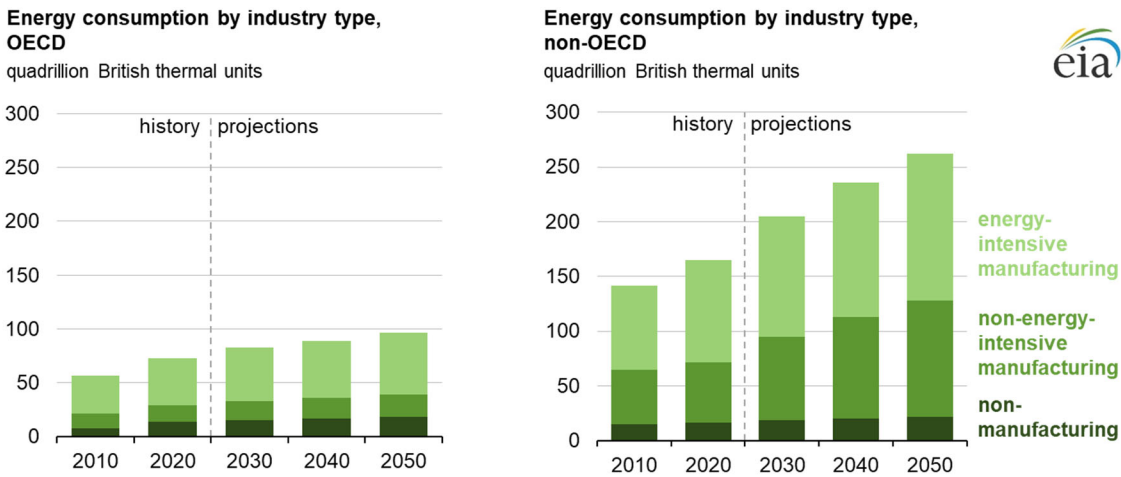
Figure 8.



Before 2030, heavy manufacturing—also called energy-intensive manufacturing—shifts away from OECD regions to non-OECD regions, especially India and Other non-OECD Asia where this sector is growing the fastest. Generally, heavy manufacturing produces goods that require the most energy to make and are often lower value, commoditized products, such as raw plastic, chemicals, or crude steel. Lighter manufacturing—also called non-energy-intensive manufacturing—produces higher-value products (often closer to finished products) for the consumer, such as computers, transportation equipment, plastic cups, or medicines. The industrial sector's main driver of energy consumption is

industry-specific gross output; growth in heavy manufacturing will increase energy demand by more than growth in lighter manufacturing.

Figure 9.

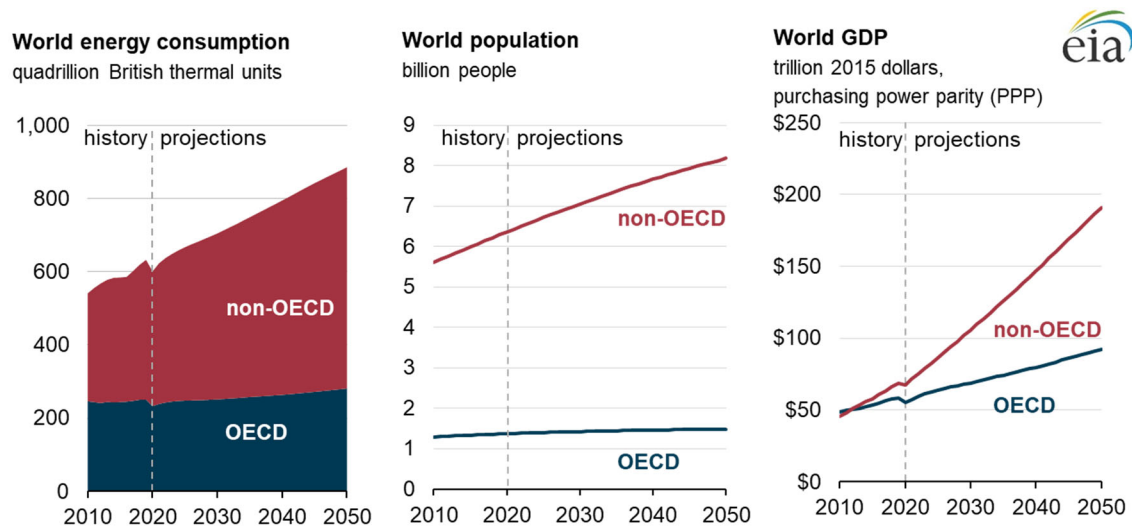


As a share of overall industrial energy consumption from 2020 to 2030, non-energy-intensive manufacturing is relatively flat at 21% in OECD countries, but it increases from 34% to 37% in non-OECD countries. Two main factors drive these trends. First, the demand for finished goods in non-OECD countries increases as populations grow and standards of living rise. This demand for goods creates markets for manufacturing supply chains located near the customer. So, the IEO2021 Reference case projects a return to the previous trend of relocating supply chains, which support a quick return to pre-pandemic levels in the global industrial sector. Second, energy efficiency gains in heavy industry contribute to the decrease in energy-intensive manufacturing’s share of energy consumption over time.

By 2050, global energy use in the Reference case increases nearly 50% compared with 2020—mostly a result of non-OECD economic growth and population, particularly in Asia

Non-OECD GDP is double OECD GDP by 2050, primarily as a result of fast-growing populations; however, large differences in standards of living remain

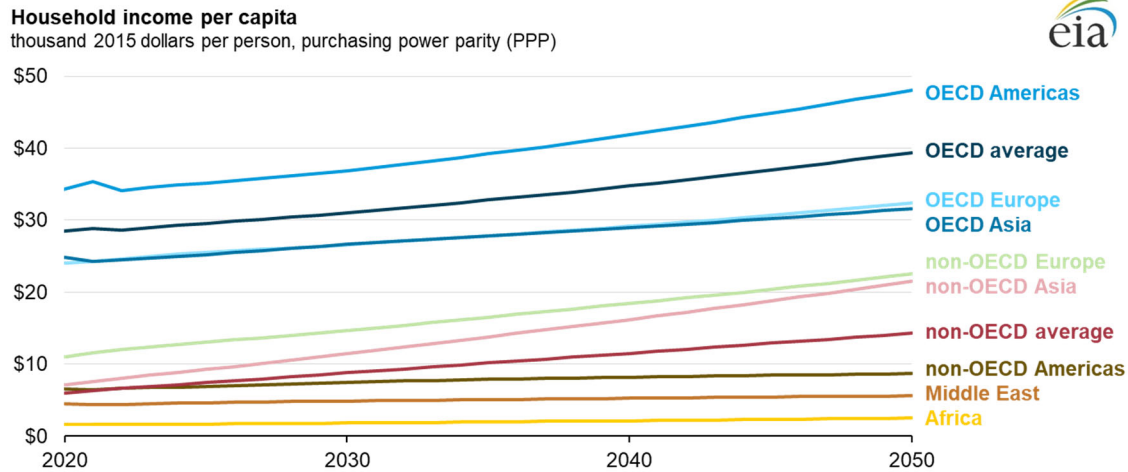
Figure 10.



In the IEO2021 Reference case, energy consumption continues to rise through 2050 in both OECD and non-OECD countries, largely as a result of increasing GDP and population. As standards of living increase, most notably in non-OECD Asian countries, demand for goods and the energy needed to manufacture those goods increase.

In the industrial sector, energy consumption grows, but the [energy intensity](#) in that sector (energy consumed per dollar of gross output from the industrial sector) decreases. Energy consumed for passenger travel in OECD countries remains below 2019 levels through 2050, but non-OECD energy consumption for passenger travel exceeds that of OECD countries by 2025. In buildings, electricity use in non-OECD countries more than doubles by 2050 compared with 2020 levels.

Figure 11.

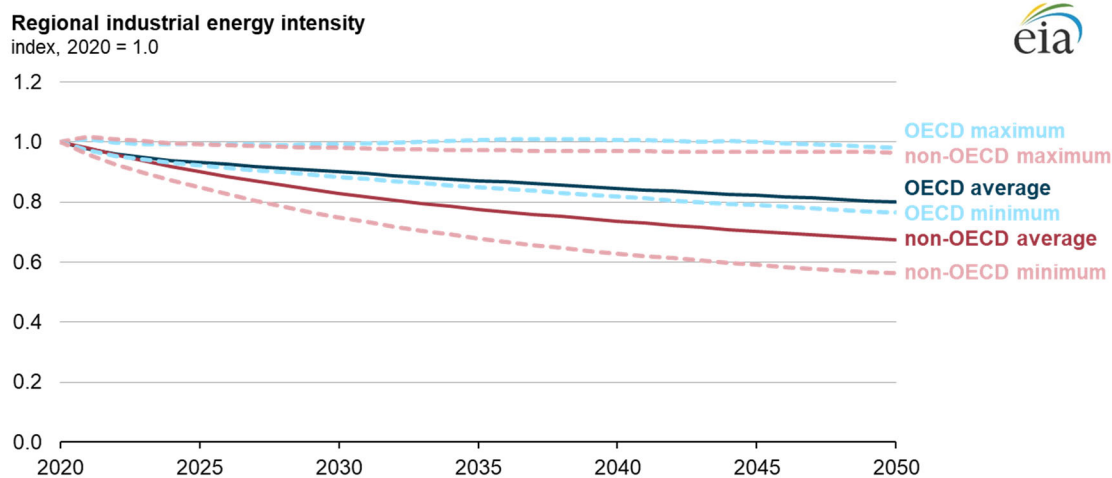


Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

Regionally, differences in GDP growth, economic structure, and standards of living directly influence how, where, and what energy is used. In the IEO2021 Reference case, the combined GDP of non-OECD economies grows quickly to twice that of the combined GDP of OECD countries by 2050. Although standards of living (as indicated by household income per capita) in non-OECD countries are rising the fastest, non-OECD economies average less than half of their OECD counterparts by 2050. Within the non-OECD countries, household income per capita is rising fastest in Asian economies.

Industrial sector energy use grows, despite decreasing energy intensity through 2050

Figure 12.

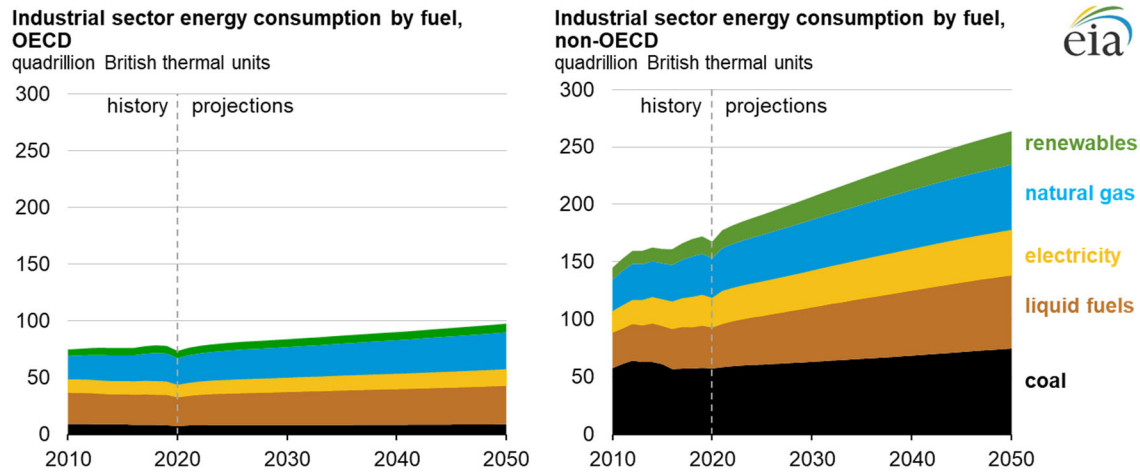


Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case
Note: Maximum and minimum refer to the highest or lowest IEO2021 region within or outside the OECD.

Energy intensity in the industrial sector—defined here as energy use per unit of gross output—generally decreases after 2020 in the IEO2021 Reference case because of changes to the composition of regional economies and increases in energy efficiency. Indexed to 2020, average energy intensities diverge

between OECD and non-OECD countries through 2050, as developing economies expand their industrial sectors and invest in technologically advanced, more-efficient capital.

Figure 13.

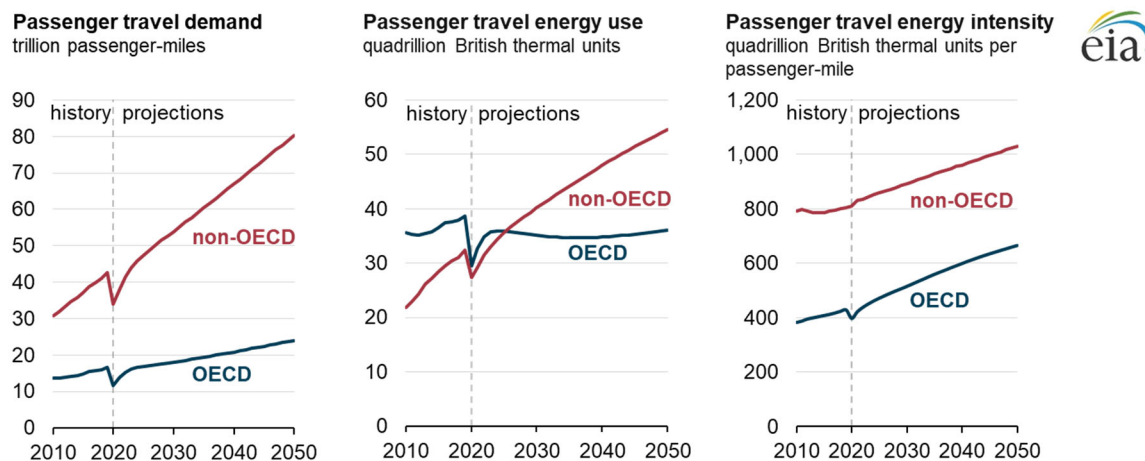


Source: U.S. Energy Information Administration, *International Energy Outlook 2021 (IEO2021)* Reference case

In the IEO2021 Reference case, industrial sector energy use in non-OECD countries is more than double that of OECD countries by 2050. Throughout the projection period, the use of energy in the industrial sectors of non-OECD countries increases among all fuel types. With such a large amount of energy consumption in the sector, fuel choices in the non-OECD countries heavily influence the global energy systems and therefore emissions.

In OECD countries, energy consumed for passenger travel remains below 2019 levels through 2050; non-OECD passenger travel energy consumption exceeds that of OECD countries by 2026

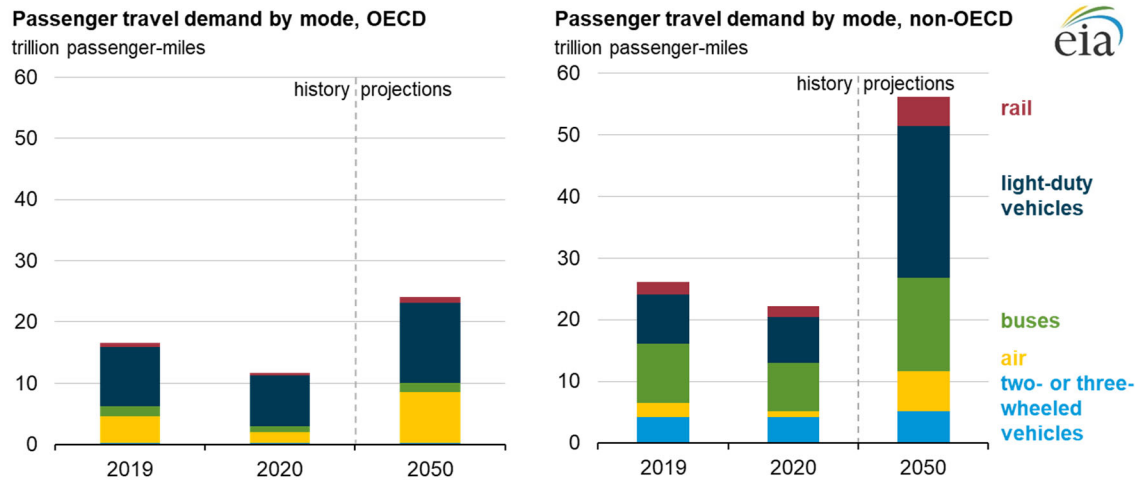
Figure 14.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021 (IEO2021)* Reference case

Aggregate global passenger travel demand (including light-duty vehicle [LDV], bus, two- and three-wheeler, rail, and air travel) continues historical growth trends through 2050 in the IEO2021 Reference case. After returning to 2019 levels in 2023, global travel nearly doubles from 44 trillion passenger-miles to 80 trillion passenger-miles by the end of the projection period. The increase in travel is largely a result of an increase in non-OECD LDV travel.

Figure 15.

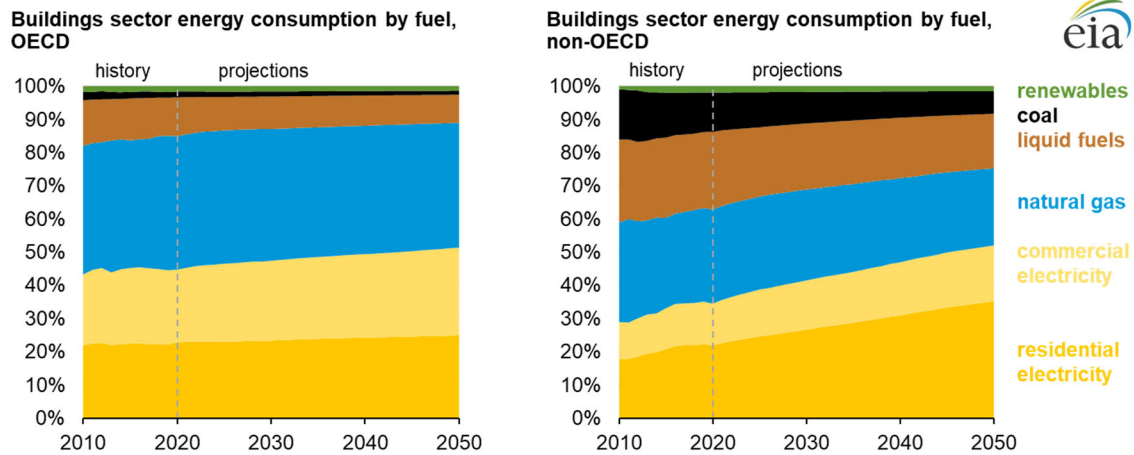


In the IEO2021 Reference case, travel demand depends on factors such as income, oil price, and employment. Average travel demand per capita in OECD countries continues to be more than double that of non-OECD countries. The difference in travel demand per capita growth between the OECD and non-OECD countries is tied to the difference in annual average population growth, which grows three times faster in non-OECD countries than in OECD countries between 2020 and 2050.

Total non-OECD passenger travel demand continues to outpace OECD travel through 2050; although, we project energy consumption for non-OECD passenger travel will not surpass that of the OECD until 2026. Historical non-OECD travel demand is met with energy-efficient travel modes on a per-passenger-mile basis (for example, two- or three-wheelers and buses), while a significant share of future travel demand will likely be met with a less efficient mix (for example, air and LDVs). We project air and LDV travel to grow faster than bus, two- and three-wheeler, or rail travel. The increasing non-OECD passenger travel energy consumption is a key driver in the continued growth in liquid fuels demand in the IEO2021 Reference case. In addition, this non-OECD shift in passenger transportation modes, coupled with OECD countries experiencing slower population growth and strict LDV fuel economy standards, results in diverging projections for non-OECD and OECD passenger travel energy use.

In 2050, electricity meets more than half of non-OECD buildings energy demand

Figure 16.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021 (IEO2021)* Reference case

The amount of energy buildings use rises proportionally with the growth of non-OECD energy consumption, maintaining a 13% share of energy use in the Reference case. However, buildings gain a 10% share of all electricity consumed across non-OECD countries over the next 30 years, and in 2050, buildings account for more than half of non-OECD electricity use. Electricity accounts for half of non-OECD energy use in buildings by 2040 and more than doubles by 2050 compared with 2020 levels.

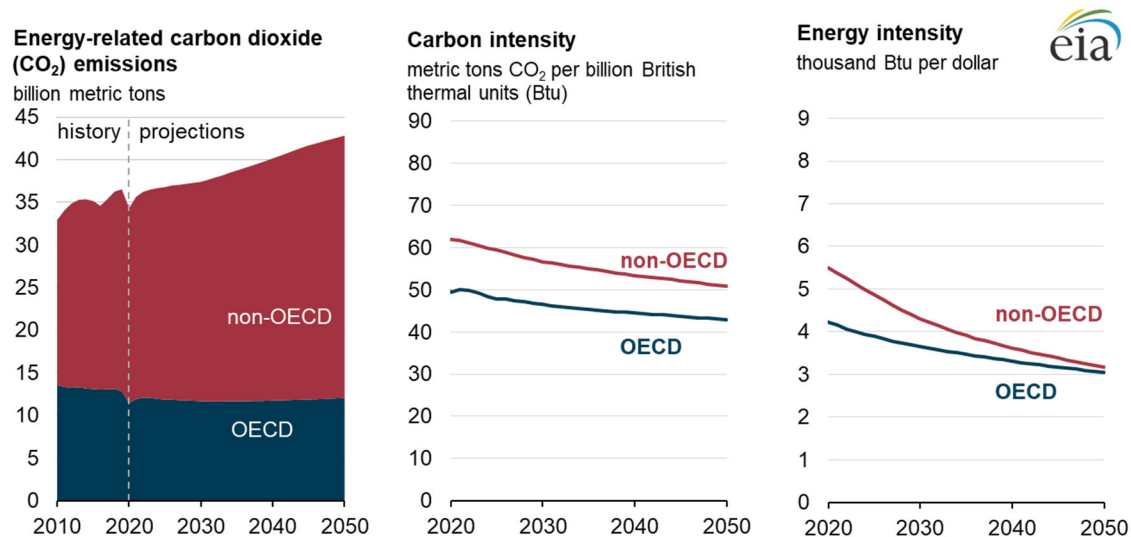
Non-OECD countries' electricity use in buildings exceeds electricity use across OECD countries' building stock for the first time in 2026. Generally, the OECD building stock exhibits less opportunities for expanding electrification because household income and population growth are less robust than in the non-OECD countries, resulting in less investment in newer capital stock and equipment.

We project electricity use in buildings to grow fastest in India, where the average rate of expanding electricity use (electrification) is 10 times faster than population growth. By 2050, household electricity use in India increases to more than five times 2020 levels, largely a result of increasing population and rising household income. Electricity use in commercial buildings almost quadruples as the service sector of India's economy expands.

In the Reference case, global emissions rise throughout the projection period, although slowed by regional policies, renewable growth, and increasing energy efficiency

Policies, fuel choice, technology, and economic factors decrease carbon intensity and energy intensity, but they do not halt emissions growth

Figure 17.

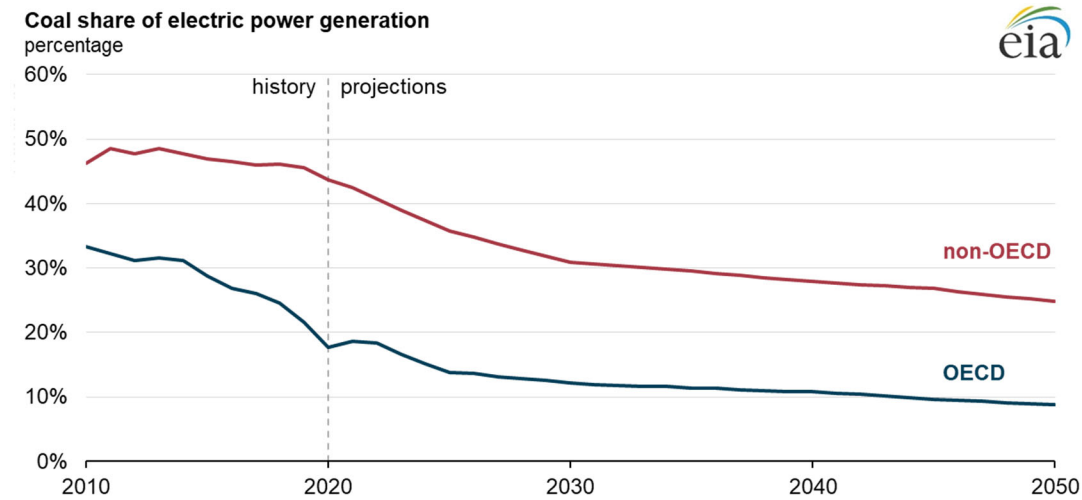


Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

Global energy-related carbon dioxide (CO₂) emissions rise through 2050 in the IEO2021 Reference case, largely driven by non-OECD countries where 2050 emissions increase by 35% over 2020 levels, compared with a 5% emissions growth in OECD countries. Energy-related CO₂ emissions tend to follow GDP and population growth, which typically correlate with increasing energy demand. However, changes in the fuel mix and energy efficiency directly affect the degree to which emissions correlate with energy consumption.

Carbon intensity and **energy intensity** are two useful indicators of the relationship between energy consumption, emissions, and economic activity. Carbon intensity (carbon emitted per unit of energy consumed) is largely determined by a region's fuel mix, and it decreases in both OECD and non-OECD countries in the Reference case over the projection period. Larger declines occur in non-OECD Asia because of an increasing share of renewable energy as well as technological efficiency improvements. However, the average carbon intensity across non-OECD countries remains higher than that of OECD countries through 2050, mainly because of a higher retention of fossil fuels—particularly coal, which has a higher carbon content than other fuels. On average, the share of electricity derived from coal across non-OECD countries is more than twice that of OECD countries over the projection period.

Figure 18.

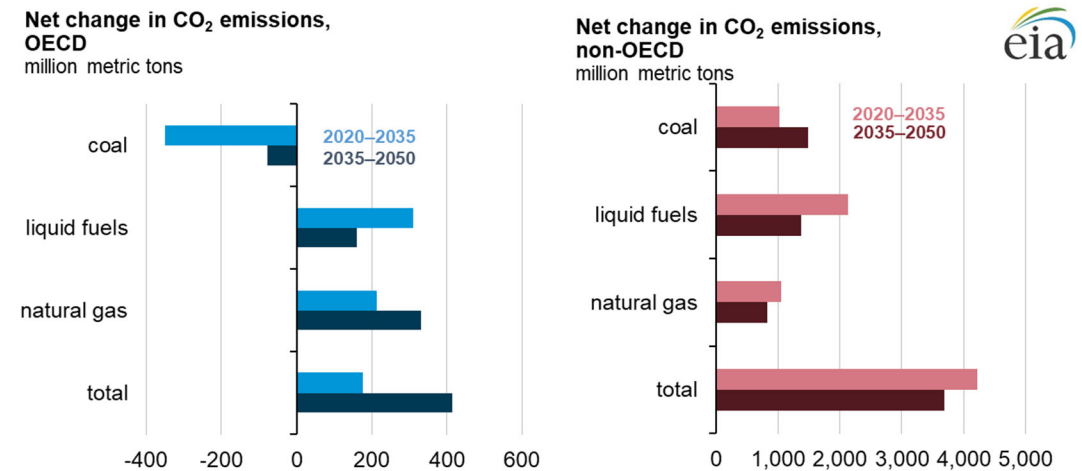


Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

Energy intensity—defined here as economy-wide energy consumed per dollar of GDP—also declines globally through 2050, and non-OECD countries experience the fastest reductions. Although energy consumption (the numerator of energy intensity) is reduced because of energy efficiency gains, steeper increases in non-OECD GDP (the denominator of energy intensity) are largely driving the falling energy intensity in these regions, especially in the near to mid term. Energy intensity between OECD and non-OECD countries becomes more comparable in the latter years of the projection period because technology use becomes more aligned as regional economic composition changes.

Near-term emissions reflect current policies, particularly in OECD countries, as well as GDP and population growth in non-OECD countries

Figure 19.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

Total energy-related CO₂ emissions increase in both OECD and non-OECD regions through 2050 in the IEO2021 Reference case. The Reference case represents an assessment of current laws and policies, including those directed at reducing CO₂ emissions. Mandated efficiency, fuel, and technology goals are generally more prevalent in OECD countries. We project that net CO₂ emissions across OECD countries increase by 175 million metric tons between 2020 and 2035 and then increase by over 400 million metric tons between 2035 and 2050 because, under existing laws and regulations, government climate policies do not explicitly increase in stringency after 2030. More information on how we model climate policies is available in our companion article, *Climate Considerations in the International Energy Outlook (IEO2021)*.

Energy-related CO₂ emissions grow much more rapidly in non-OECD countries, largely as a result of increases in energy demand associated with population and economic growth. Net CO₂ emissions across non-OECD countries increase by 4,200 million metric tons between 2020 and 2035, followed by a 3,700 million metric tons increase between 2035 and 2050. The relatively slower emissions growth in the second half of the projection period is largely linked to increases in renewable energy and energy efficiency.

Emerging policy directives that are not law, such as commitments made by China's government in 2020 to achieve carbon-neutral status by 2060, could contribute to lower emissions in the region, but we do not include them in the Reference case because they are not specific policies.

Heavy industry strongly influences regional emissions

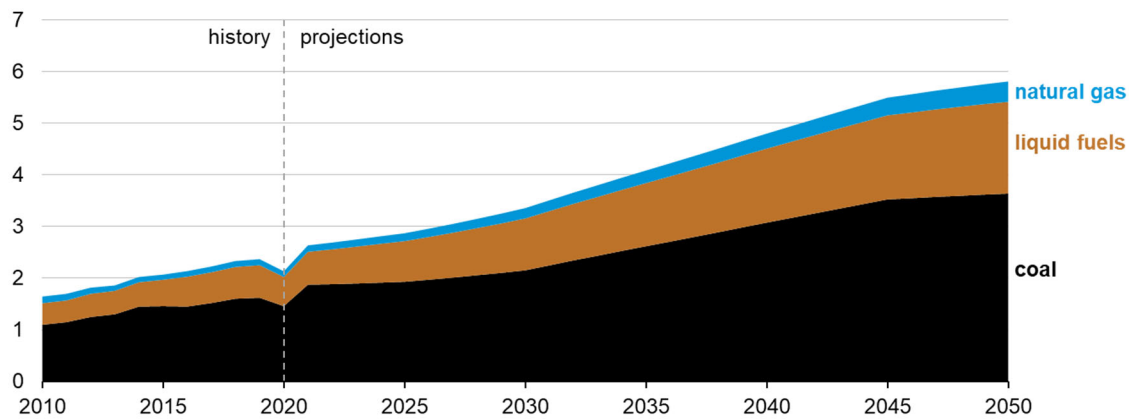
Growth in heavy industries—such as basic chemicals, non-metallic minerals, and steel—is a major component of overall economic growth in non-OECD economies because of the rapid expansion of physical assets and infrastructure. Energy-intensive manufacturing is difficult to decarbonize without major restructuring.

The strong growth in heavy industries in non-OECD countries generally outpaces incremental energy efficiency improvements, leading to higher emissions in the IEO2021 Reference case. As an example, the basic chemicals industry, which has the majority of its gross output in non-OECD countries, uses a high amount of natural gas and petroleum liquid feedstock. Reducing carbon intensity and emissions in this industry would require either a major structural shift in the production process or a shift to a more circular economy that relies less on commodity chemicals.

Similarly, the non-metallic minerals and steel industries rely heavily on coal. Incremental energy efficiency improvements in these industries would require difficult and costly structural changes, such as employing more recycling or material substitution.

Figure 20.

Energy-related carbon dioxide emissions by fuel type, India
billion metric tons



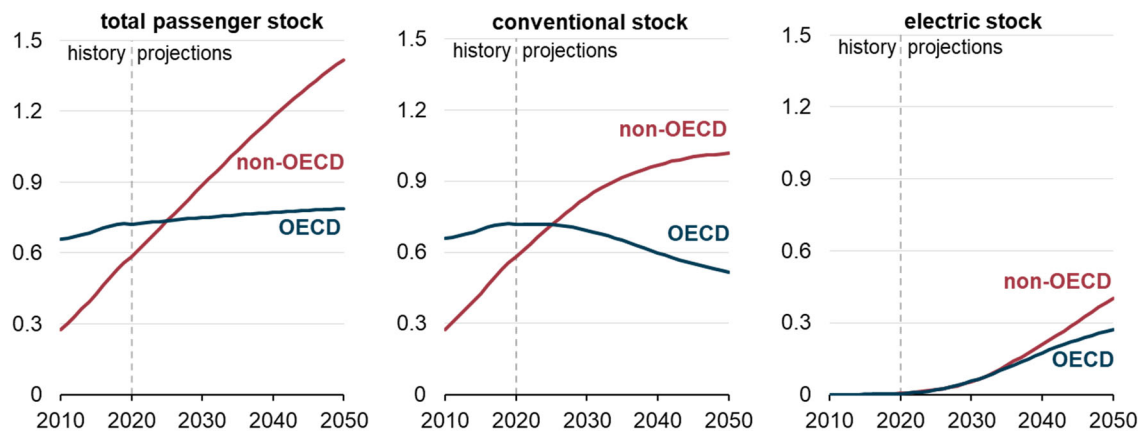
Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

India exemplifies the role that heavy industries play in non-OECD emission trends. India’s industrial sector is its largest consumer of coal, and the country’s coal emissions more than double over the projection period.

Electric vehicle stock contributes to reduced emissions, but represents 31% of total passenger travel stock by 2050

Figure 21.

Light-duty passenger vehicle stock
billions of passenger vehicles



Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

Note: Electric vehicles include all-electric vehicles and plug-in hybrid electric vehicles.

In the IEO2021 Reference case, increased economic activity, population, and private mobility—following the pandemic-related economic downturn in 2020—increase the existing global light-duty vehicle fleet through 2050. Rapid GDP per capita growth in some regions causes their LDV fleet to grow more quickly than population. Non-OECD regions— particularly China, India, and Other non-OECD Asia—will account for most of the growth, and the non-OECD LDV fleet will surpass that of OECD in 2026. We project the

non-OECD motorization rate to grow significantly from 92 vehicles per thousand people in 2020 to 173 vehicles per thousand people in 2050. We also expect ownership rates in the OECD regions to remain relatively flat, from 527 vehicles per thousand people to 533 vehicles per thousand people, over the same period.

The 2020 global LDV fleet primarily consists of conventional gasoline and diesel internal combustion engine vehicles, but sales of electric vehicles (EVs) grow in IEO2021. Recent technology and policy developments for alternative powered vehicles accelerate the growth in plug-in electric vehicle sales. In the IEO2021 Reference case, plug-in electric vehicles include both full battery electric vehicles (or all-electric vehicles) and plug-in hybrid electric vehicles that run on liquid fuels when batteries become depleted. The plug-in electric vehicle share of sales grows most quickly in OECD Europe, where we project that about 80% of passenger LDV sales in 2050 will be plug-in electric vehicles. We also expect OECD Europe to experience high plug-in electric vehicle penetration as a result of policies that encourage or require electric vehicle sales, including current EU fuel economy standards; country-level incentives that bring electric vehicle cost nearer to ICE cost-parity; and target dates for ICE new vehicle registration or sales bans.

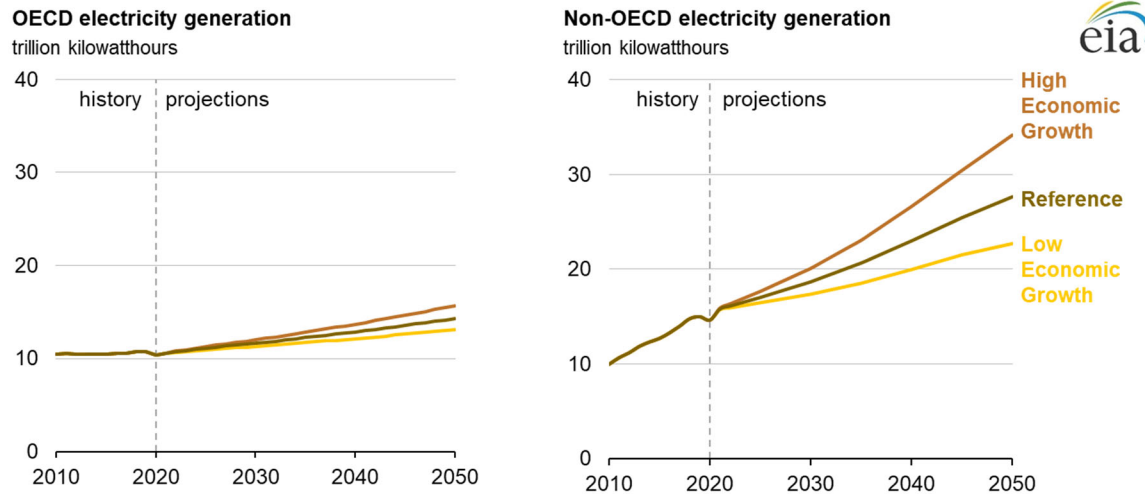
We project that electric vehicles will account for 31% of the global LDV fleet in 2050 and have fleet shares of 34% in OECD and 28% in non-OECD. Significant growth in electric vehicle sales and their share of sales throughout the projection period causes the ICE fleet to peak in 2023 for OECD regions and in 2038 globally. Continued electric vehicle sales growth in non-OECD countries slows ICE stock growth in those countries.

Electricity

Increases in electricity generation are primarily from renewable generation sources

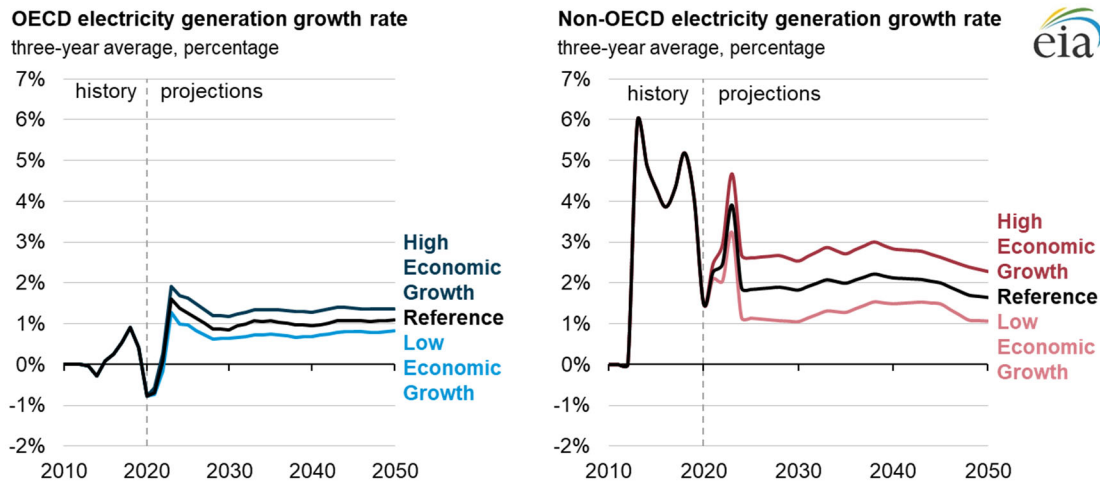
Electricity generation grows throughout the projection period; while electricity generation grows slowly in OECD regions, it almost doubles in non-OECD regions by 2050

Figure 22.



In OECD regions, end-use efficiency improvements contributed to keeping the three-year average growth in electricity generation below 1% per year from 2013 to 2019, before OECD generation dropped in 2020 as a result of the economic impacts from the COVID-19 pandemic. Generation growth resumes by 2023 and stays around 1% per year for the remainder of the projection period in the Reference case. It is only marginally higher or lower in the High and Low Economic Growth cases, respectively. The projected growth rate is higher than in the past decade as the price of electricity declines relative to other energy sources, as well as end-use sector shifts from fossil fuels consumption to consumption of electricity generated from lower-cost renewable sources.

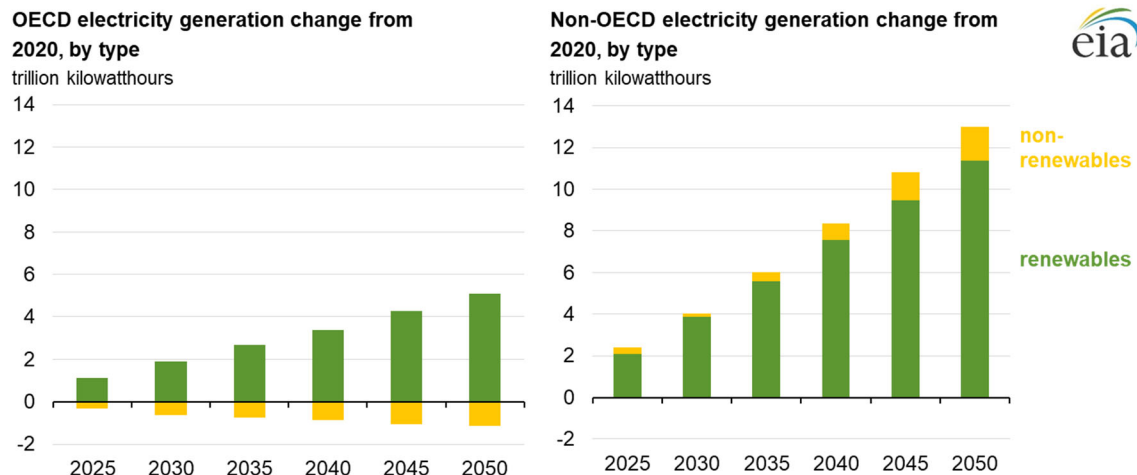
Figure 23.



Historically, non-OECD regions have experienced higher levels of electricity generation growth than OECD regions, as a larger share of the non-OECD population gained access to electric services. However, non-OECD regions also experienced a steep decline in electricity generation following the economic impacts of the COVID-19 pandemic. After a quick return to pre-pandemic levels, electricity generation growth in non-OECD regions remains faster than in OECD regions, but it slows throughout the projection period, in part because the share of the population without access to electricity decreases over time, leading to market saturation.

Renewable generation grows significantly and accounts for nearly all global generation increases through 2050 across cases

Figure 24.

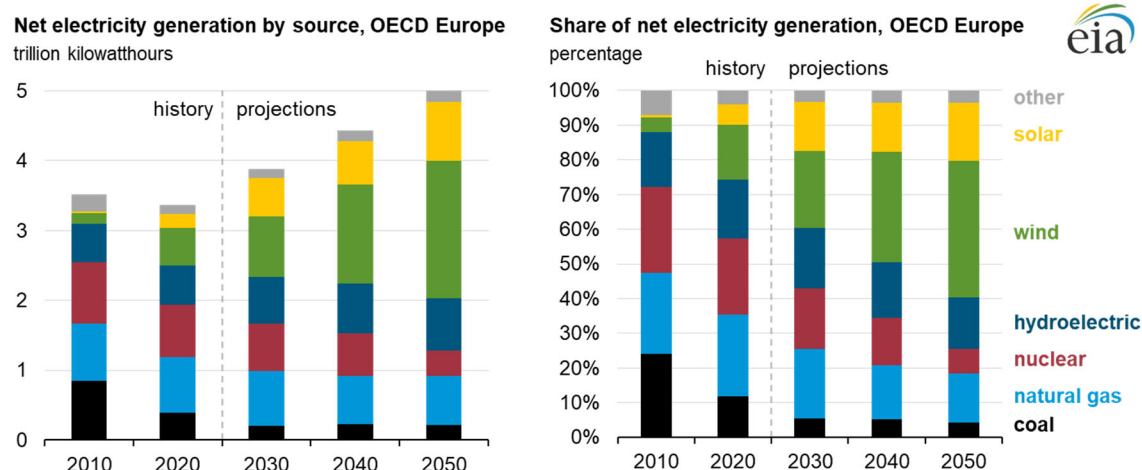


Globally, incremental electricity generation comes largely from renewable resources, beginning in 2025. As renewables—particularly solar and wind—become cost-competitive, the IEO2021 Reference case projects that all post-2020 electricity generation growth in OECD regions will come from those sources and that they will displace an increasing share of existing non-renewable, mostly fossil fuel-based, sources. In non-OECD regions, we project that electricity generation from renewable sources account for about 90% of generation increases from 2020 to 2050. Because electricity generation grows at almost twice the rate in non-OECD regions than in OECD regions in the Reference case, the non-OECD regions add over two times the generation from renewable sources compared with the OECD regions.

This projected growth in renewables is uncertain and may largely depend on changes to regulatory policies and market rules, large and cost-effective supply chains to support renewable installations, and a sufficient amount of conventional generation technologies or storage to back intermittent renewable capacity.

Policies contribute to displacement of non-renewable generation in Europe

Figure 25.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

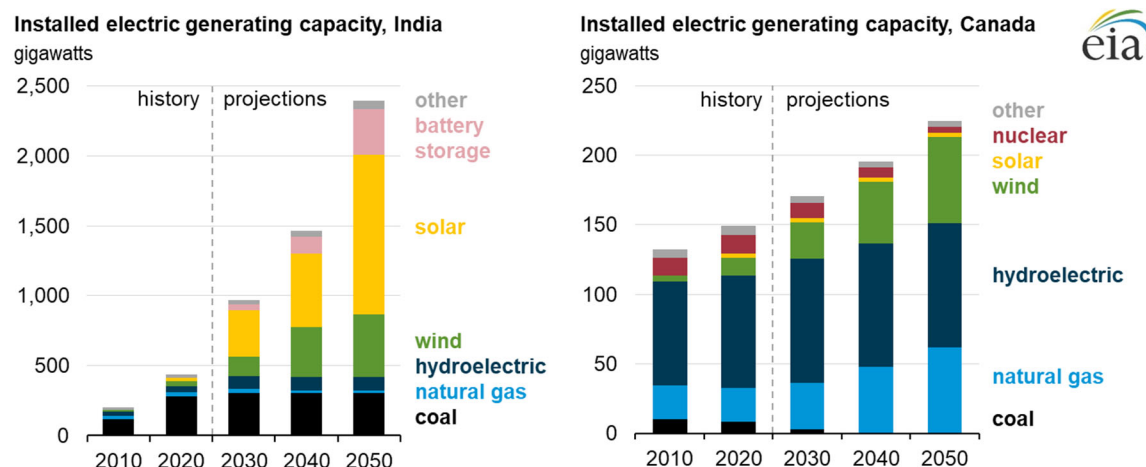
Although renewables have become cost-competitive with new fossil fuel generation, in OECD regions where electricity demand growth is slower than in non-OECD regions, renewable generation has less opportunity to grow without policies to encourage it. Policy incentives in OECD Europe in the form of a carbon cap and trade system are designed to facilitate generation from new renewable sources and displace existing non-renewable generation.⁸ In addition, individual countries within the region have plans to phase out nuclear generation, further contributing to the decline of existing non-renewable generating resources. Although worldwide nuclear generation increases by 15% throughout the projection period, nuclear generation in OECD regions decreases by almost one-third, half of which occurs in OECD Europe.

⁸ More information on how we model climate policies is available in our companion article, *Climate Considerations in the International Energy Outlook (IEO2021)*.

As coal-fired and nuclear generation decreases by almost one-third relative to 2020 levels, and natural gas-fired generation stays relatively flat, the share of renewables in the OECD Europe region increases from much less than half of the generation mix in 2020 to almost three-quarters by 2050. This increase occurs as the use of non-renewable energy resources shifts from being the primary source of electricity toward serving as reliability support for the rising amounts of renewable energy.

Growing intermittent capacity is supported by different technologies depending on each region's respective resources

Figure 26.



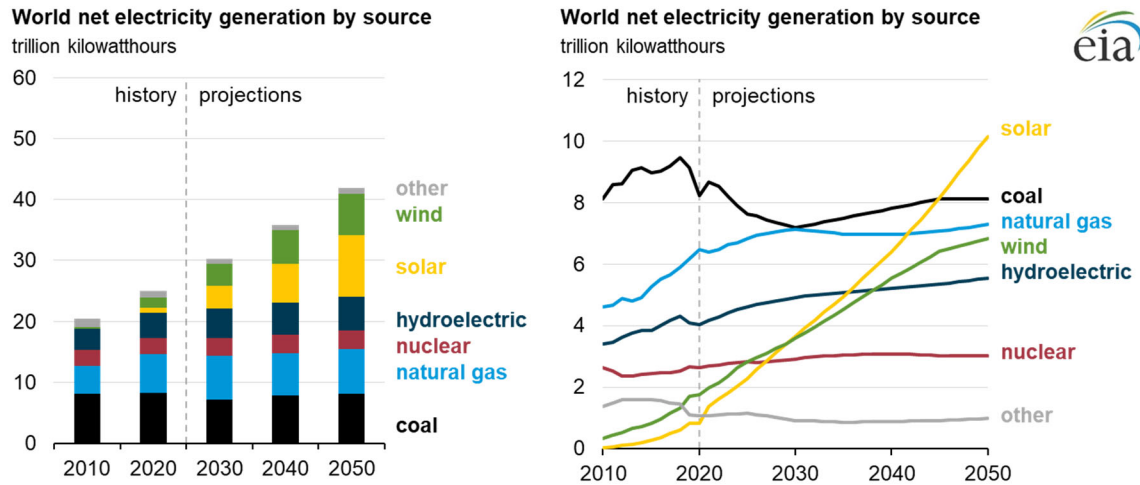
As larger amounts of intermittent generating capacity are incorporated into a region's electrical grid, a range of generating sources will be built or maintained to provide backup for solar and wind resources because their outputs can vary. Solar generation occurs only during daylight hours, regardless of the location of the installation site. The regularity of this resource, along with typically diurnal electricity demand is better supported by battery storage with a discharge capability of several hours. In contrast, wind generation tends to vary widely throughout the day and season, requiring the use of more conventionally fueled resources that are not energy constrained, such as natural gas turbine plants.

An example of these differences can be seen in India, where by 2050, we project intermittent generation—mostly solar—will account for two-thirds of the electricity generation mix. To accommodate that trend, about 330 gigawatts (GW), or about half of the world's projected battery storage capacity in 2050, will be required to support a system with such a high level of solar power generation. In contrast, Canada has vastly different solar resources because of its high latitude and limited sunlight in the winter and fall months, making wind more economic to build and operate than solar. By 2050, intermittent generation—almost exclusively from wind resources—accounts for about 25% of Canada's electricity generation mix. To ensure grid reliability with the growth in wind generation, natural gas-fired generating capacity will likely become the more economic choice.

World coal-fired generation declines through 2030 in the Reference case, but it remains a significant part of the worldwide generation mix

With expected rising natural gas prices after 2030, growth in natural gas-fired generation slows and generation from existing coal-fired plants becomes more economic

Figure 27.

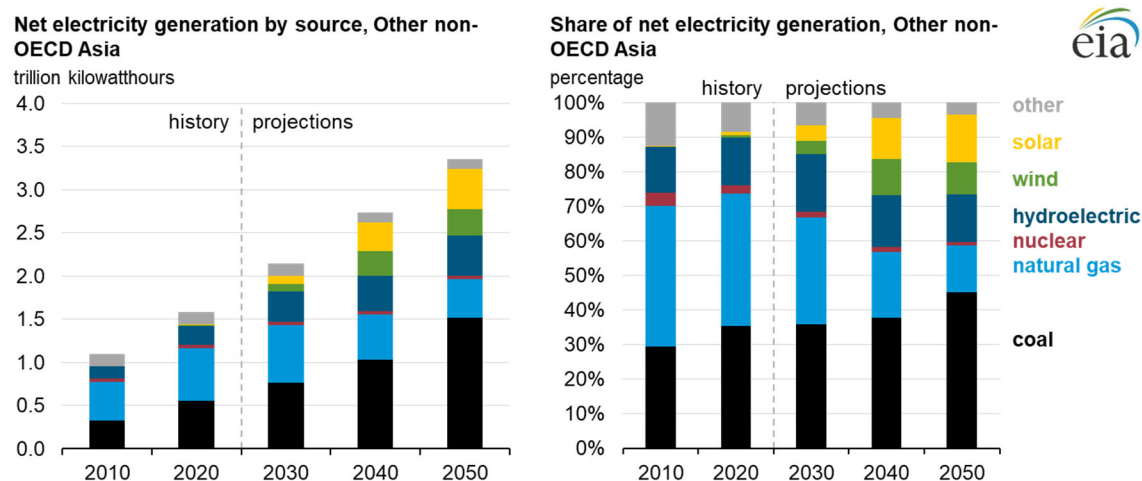


Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

Most of the world’s coal-fired generating units consist of boilers and steam turbines that can be 30% less efficient when compared with natural gas-fired combined-cycle units using the latest technology. Because natural gas generators are more efficient than coal-fired generators at converting fuel to electricity, natural gas-fired generation is often a lower cost option, even if the fuel price of natural gas is slightly higher than the fuel price of coal. However, rising natural gas prices after 2030—particularly in Asia and other areas that are reliant on higher-cost liquefied natural gas (LNG) resources—coupled with the absence of enforceable global emission-reduction policies or regulations, cause coal-fired generation to become more economic in supporting increased intermittent generation. This shift represents a reversal of the trend observed over recent decades. Even though the cost of mining coal will face some upward pressure after 2030, we project coal prices to remain lower relative to natural gas, providing a cost-competitive generation option to natural gas-fired power generation. Similarly, existing sources of coal-fired capacity continue to cost less than battery storage in some regions.

Coal continues to be heavily used as a fuel for generation in non-OECD Asia because it remains an abundant and inexpensive local natural resource

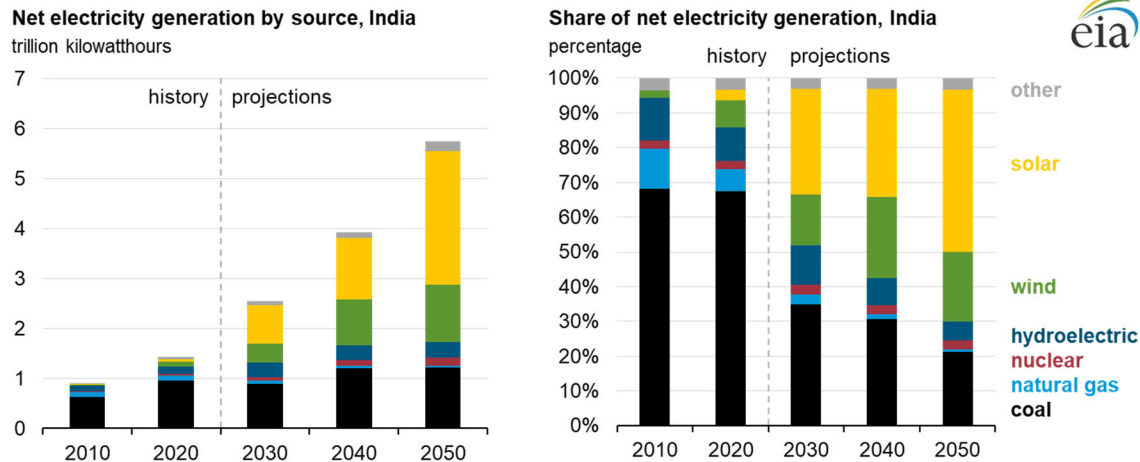
Figure 28.



Increases in coal-fired generation in Other non-OECD Asia—which includes Indonesia, Vietnam, and Thailand, among other countries—alone account for over three-quarters of the world’s coal-fired generation increases from 2030 through the end of the projection period. In Other non-OECD Asia, while renewable energy sources—primarily wind and solar—account for about 60% of the generation increase over the projection period, coal-fired generation accounts for nearly all of the remaining growth. This region is geographically diverse, and several of the countries in this region have limited domestic natural gas resources and have constrained access to natural gas pipelines and LNG regasification terminals. Without the presence of enforceable region-wide carbon emission reduction policies or regulations, abundant coal resources that can be competitively mined, combined with natural gas prices that are projected to increase after 2030, lead to coal-fired generation displacing some natural gas-fired generation from 2030 through the end of the projection period. As coal-fired generation steadily increases through 2050, coal’s share of the generation mix increases from about one-third in 2020 to almost half by the end of the projection period.

In regions with abundant renewable resources, such as India, coal often supplements high levels of intermittent renewable generation

Figure 29.

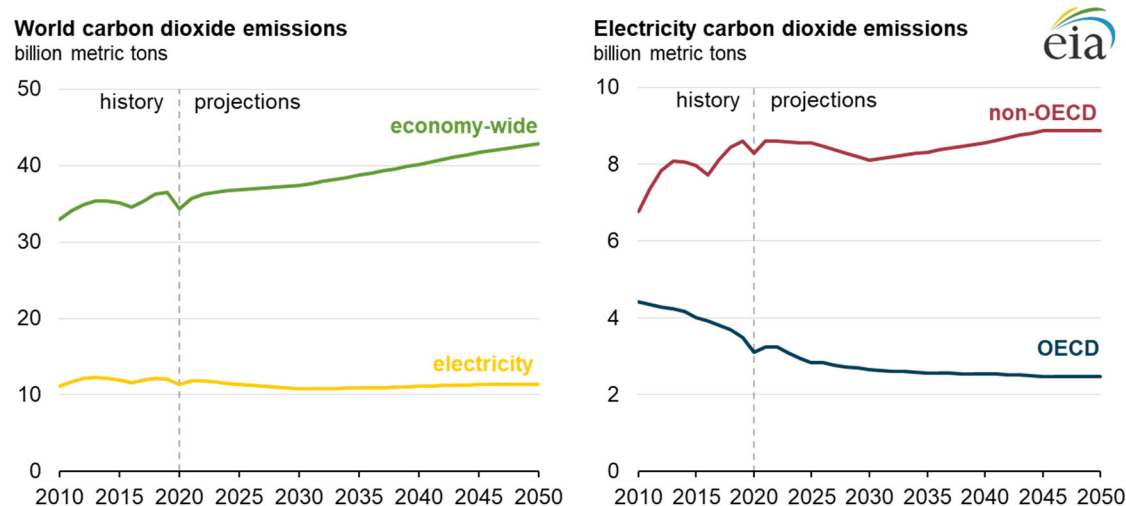


Although nearly 330 GW of battery storage is built in India in the Reference case—representing about half of the world’s projected battery storage capacity by 2050—we do not project battery capacity growing quickly enough to provide sufficient backup capability for the rapidly growing share of renewable sources in the region. As a result, coal-fired generation helps meet baseload and peak-period power demand. Coal-fired generation accounts for two-thirds of India’s generation mix in 2020. Even though coal-fired generation will likely increase by about 25% throughout the projection period, the Reference case projects that coal will account for less than one-quarter of India’s generation mix by 2050. By this time, wind and solar resources will account for two-thirds of India’s total generation mix.

CO₂ emissions in the global electric power sector remain stable despite significant growth in electricity demand

Although economy-wide global CO₂ emissions increase steadily through the IEO2021 Reference case projection period, emissions from the electric power sector remain flat over the same period, after peaks in the previous decade

Figure 30.

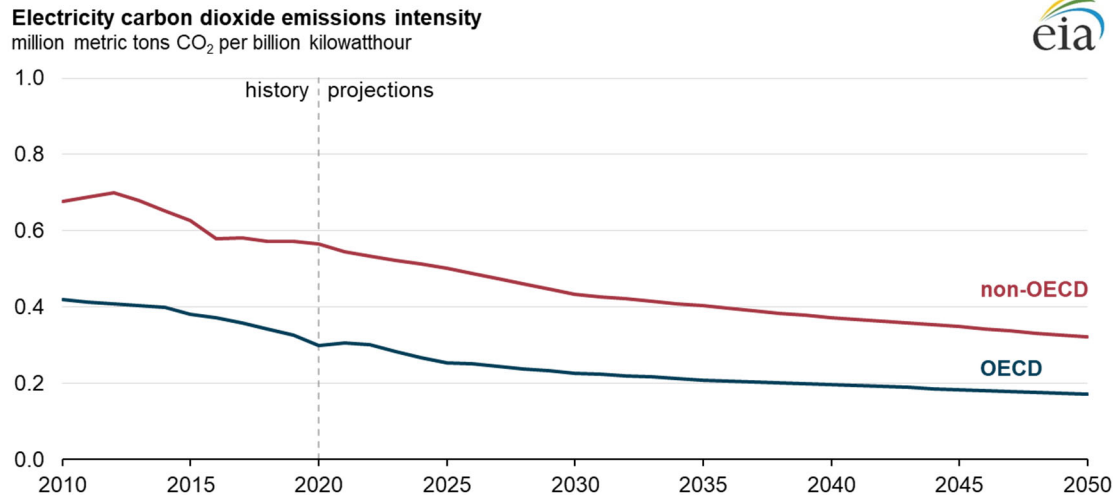


In the Reference case, world economy-wide CO₂ emissions—the result of fossil fuel consumption, which varies by region and sector—increase by 25% throughout the projection period, while emissions from electricity generation remain relatively flat. Emissions remain the same even though global electricity demand increases by over two-thirds over the same period. This stability is largely a result of the growth in generation from renewable energy resources. After 2030, as coal-fired generation begins to displace natural gas-fired generation, a slight increase in electric power sector emissions occurs, which is also moderated by the expansion in renewables generation.

Emissions from electricity generation in non-OECD regions increase by 7% by 2050, but they decline by 20% in OECD regions, despite a one-third increase in electricity demand. The difference is primarily a result of renewable sources displacing fossil fuel generation in OECD regions. This displacement follows both regional policies to encourage carbon-free generation and favorable economics for renewable resource installations, mostly wind and solar.

The carbon intensity of electricity generation drops more rapidly in non-OECD regions, but it remains at higher levels than in OECD regions

Figure 31.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

The carbon intensity of electricity generation was significantly lower in OECD regions than in non-OECD regions in 2020. Both economic and policy factors have contributed to this difference; lower-emitting resources—historically including nuclear power, and more recently, including a shift from coal-fired to natural gas-fired generation—have played a larger role in OECD regional power supplies. In 2020, generation from fossil fuel sources in non-OECD regions—primarily coal—accounted for two-thirds of the generation mix, but in OECD regions, generation from fossil fuel sources—primarily natural gas—account for only half of the generation mix.

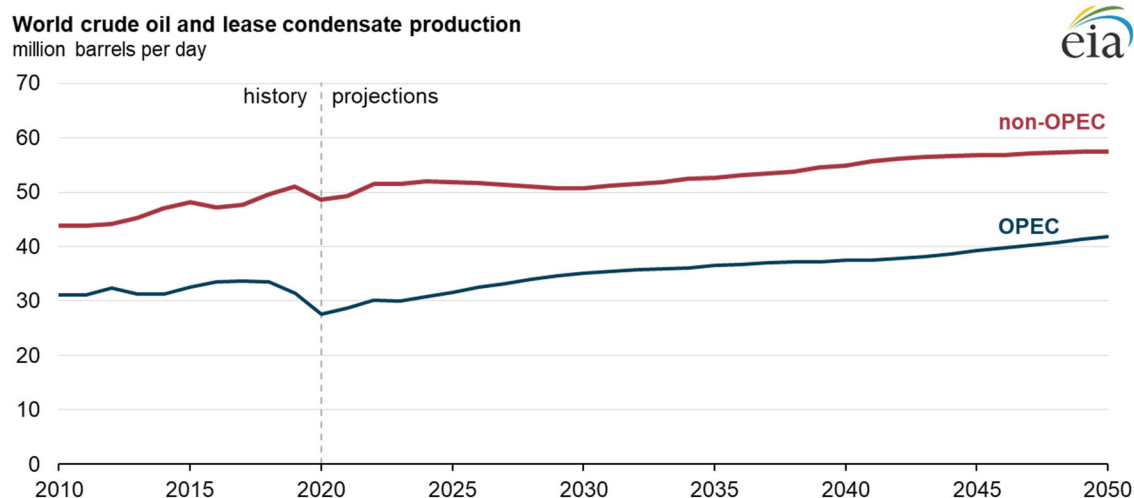
Although carbon intensity still remains lower in OECD regions, non-OECD regions close the gap somewhat by 2050, when their carbon intensity is about equal to the carbon intensity of OECD regions in 2020. In non-OECD regions, most of the 2020 fossil fuel mix comes from higher CO₂-emitting coal-fired generating sources, and non-OECD electricity demand grows at twice the rate of OECD regions. Because of these two factors, non-OECD regions have more of an opportunity to reduce their carbon intensity and we project this new electricity demand will be met through renewable generating sources. Although both OECD and non-OECD regions decrease their respective carbon intensities of generation by the same percentage, the absolute carbon intensity level in non-OECD regions decreases by almost twice that of OECD regions throughout the projection period, in part as a result of the shift away from nuclear generation in OECD regions.

Production

Supply of petroleum and other liquids continues increasing in both OPEC and non-OPEC regions to meet growing world demand through 2050 across cases

The Reference case projects continued growth in global liquid fuels consumption and production; High Economic Growth and High Oil Price side cases require unprecedented levels of petroleum and other liquids feedstock production

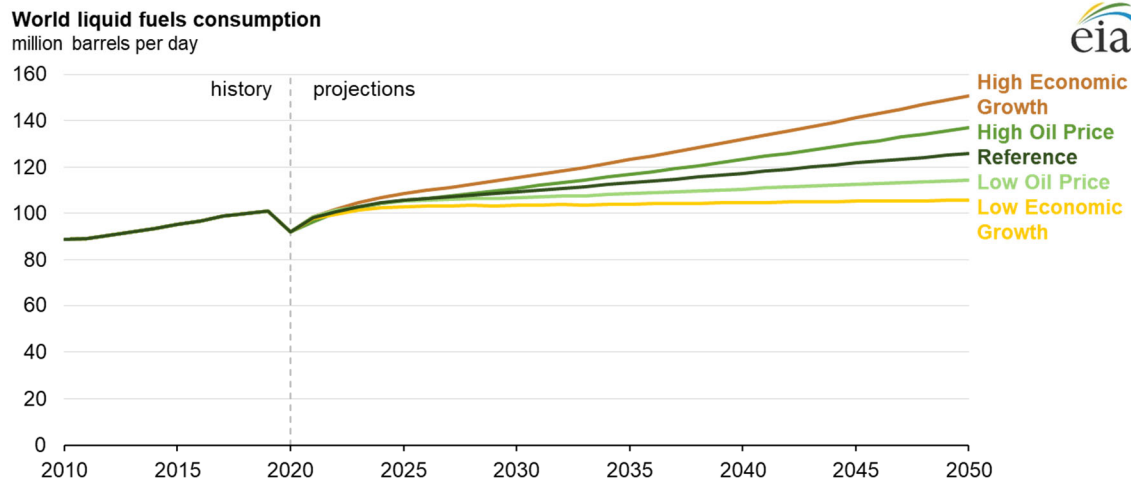
Figure 32.



To meet the anticipated growth in liquid fuels consumption in the Reference case, we expect a steady increase in crude oil and lease condensate production throughout the projection period. Crude oil is the primary raw material used in the petroleum refining process, and it is a necessary precursor for many finished petroleum products (for example, gasoline, diesel, fuel oil) demanded by all sectors of the economy.

In the Reference case, both OPEC and non-OPEC oil production grow over the projection period, but OPEC production grows at almost three times the rate of non-OPEC production between 2020 and 2050. To meet increasing demand, countries will need to rely on increased exploration (to identify additional resources), increased drilling (to harvest new and proven reserves), and technology advances (to achieve greater production yields).

Figure 33.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case, Economic Growth cases, and Oil price cases

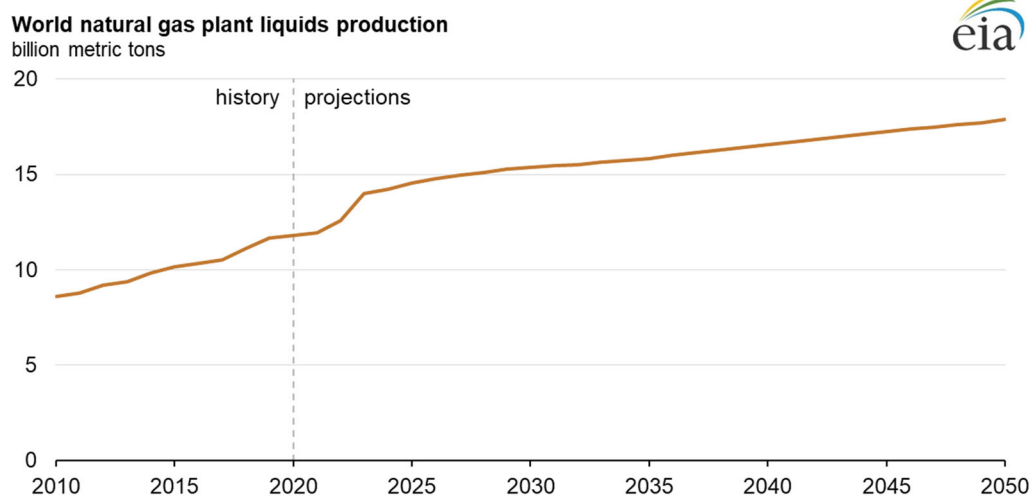
The IEO2021 side cases represent alternative assumptions about macroeconomic growth and crude oil prices. In all five of these cases, liquid fuels consumption is higher in 2050 than in 2020, reaching a high of 64% above 2020 levels in the High Economic Growth case. OPEC and non-OPEC resources are adequate to meet demand levels in all five cases. The IEO2021 Reference and side cases assume current laws and regulations, including for carbon emissions, and assume some level of geopolitical stability and cooperation to reach these levels of production.⁹

Although consumption in the Reference case reaches approximately 125 million barrels per day (b/d) by 2050, consumption is highest in the High Economic Growth case, where it reaches approximately 151 million b/d of total liquid fuels in 2050, exhibiting significant growth from current levels. Canada, Iran, Iraq, and Russia all have large undeveloped crude oil resources and so could expand production to help meet 2050 global demand in the High Economic Growth case. Although Saudi Arabia and the United States are also large resource holders, their resources have been more systematically developed and likely have less room to expand beyond their historical levels of production.

⁹ More information on how we model climate policies is available in our companion article, *Climate Considerations in the International Energy Outlook (IEO2021)*.

Worldwide production of natural gas plant liquids grows by over 50% by 2050, driven by industrial sector demand

Figure 34.



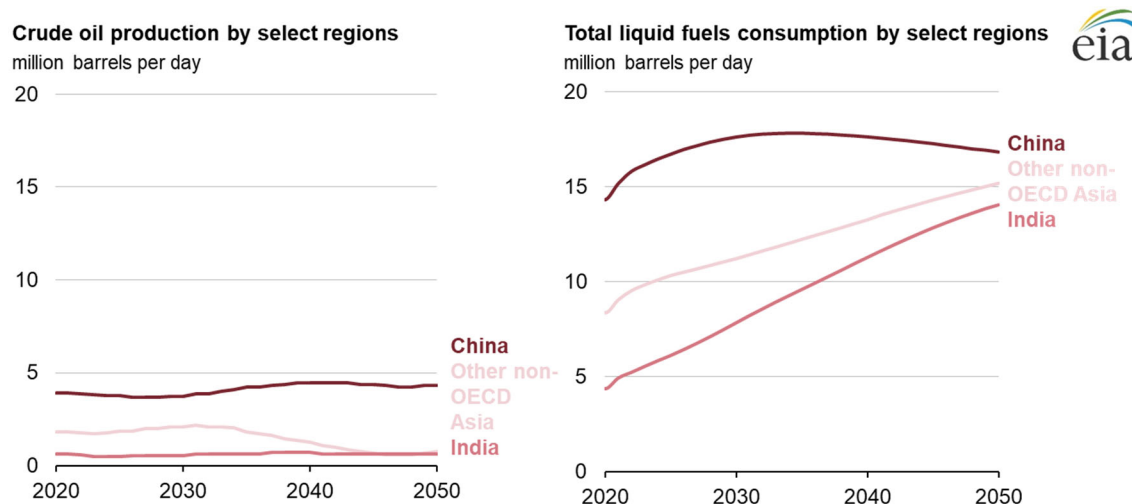
Natural gas plant liquids (NGPLs) are a coproduct of natural gas production, and in our Reference case, NGPL production grows approximately 50% by 2050—a faster rate than crude oil production—driven by high demand for NGPLs in the industrial sector. NGPLs include ethane, liquefied petroleum gases (propane, normal butane, and isobutane), and natural gasoline. These products commonly serve as industrial feedstocks across the world and are critical in the production of plastics and other petrochemicals. Ethane and propane are key industrial feedstocks used to produce ethylene and propylene, which support a wide variety of plastics, fibers, coatings, labels, packaging, cleaners, and other manufactured goods. Propane is also used as a residential heating source, for crop drying, and in the transportation sector. Normal butane, isobutane, and natural gasoline serve as industrial feedstocks. Normal butane and natural gasoline are also used in the transportation sector. In recent years, the infrastructure to process NGPLs and turn them into high-demand consumer and industrial materials has grown. This growth will support an increase in supply of NGPLs.

Non-OECD Asia lacks adequate production to meet growing demand; most of the crude oil it uses comes from the Middle East

Non-OECD Asia leads increased consumption of liquid fuels but has limited increases in regional crude oil production

In the Reference case, liquid fuels consumption grows the most in non-OECD Asia regions, where consumption nearly doubles from 2020 levels. The transportation and industrial sectors account for most of the projected growth.

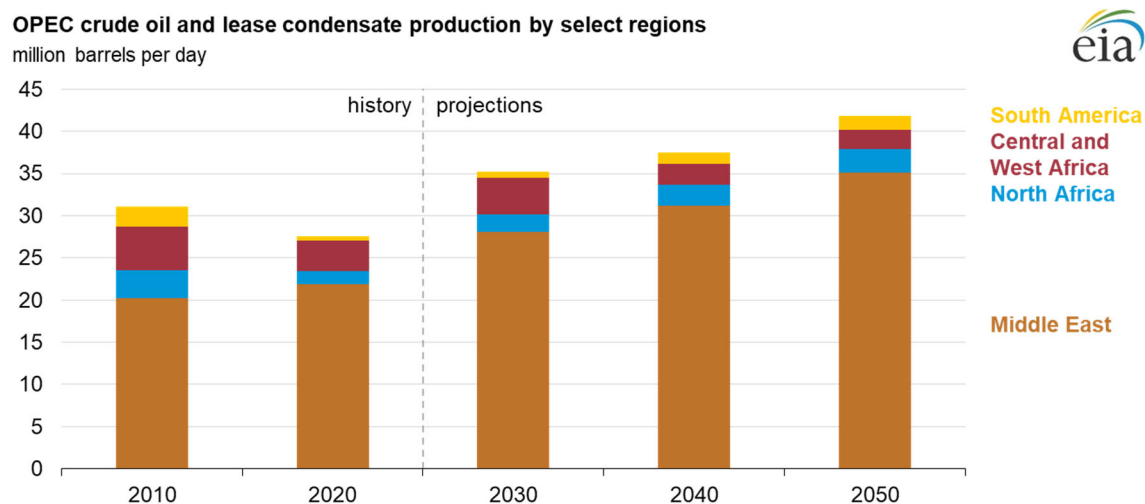
Figure 35.



This consumption growth primarily occurs in the rapidly developing economies of China, India, Indonesia, Thailand, and Other non-OECD Asia countries. In contrast, crude oil production is relatively flat in the largest countries of that region—China and India—through 2050, and production declines in Other non-OECD Asia after 2030. This disconnect between liquid fuels consumption and production is most notable in India, where 2050 consumption will be three times higher than 2020 levels, yet crude oil production will be lower in 2050 than in 2020. Similarly, while China increases crude oil production, this increase will not be sufficient to balance the liquid fuels consumption growth over the projection period. To compensate for this regional imbalance between oil consumption and production in the Reference case, non-OECD Asia supplements its local production with increased imports of crude oil or finished products. Furthermore, these regions might invest in additional infrastructure (such as import terminals or refineries) to continue to support their rapid consumption growth.

OPEC crude oil production increases through 2050, driven by high projected gains in Middle East production

Figure 36.

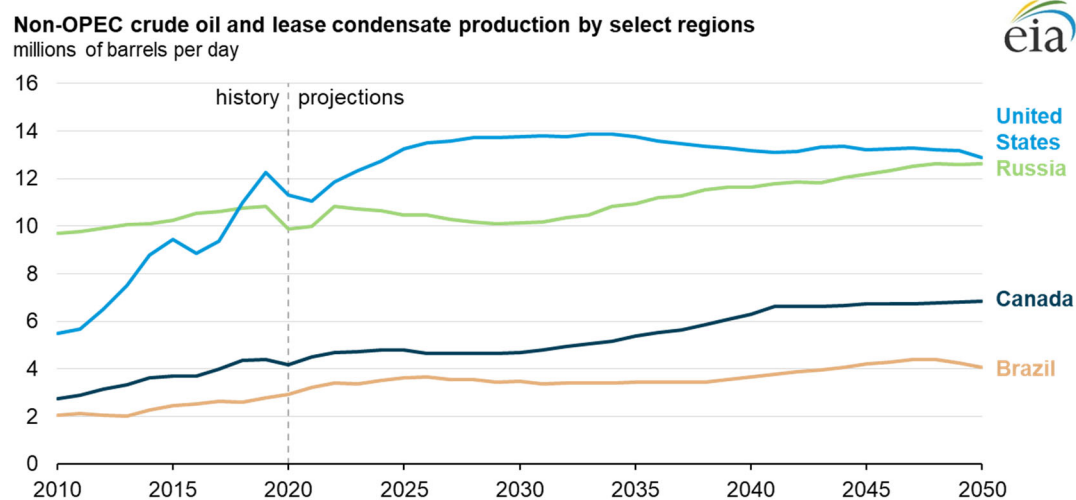


Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

In the Reference case, crude oil production in OPEC countries increases over the projection period. Compared with the four largest non-OPEC oil producers—Russia, the United States, Canada, and Brazil—OPEC crude oil production shows significant growth. Although OPEC member countries in Africa and South America contribute to this production, the Middle East drives increases in projected OPEC production, increasing production by more than 50% from 2020 to 2050 in this region. The combination of resources available in this region and the proximity of the Middle East to growing non-OECD economies in Asia contribute to the growth. The Middle East is already a prevalent supplier of crude oil to Asia, and we project it to remain so as demand for liquid fuels continues to increase and as many Asian refineries configure to process the Middle East’s crude oil.

The four largest non-OPEC oil producers increase production at modest rates, and U.S. production declines after 2030

Figure 37.



In the Reference case, non-OPEC crude oil and lease condensate production increases over the projection period. Russia's proximity to the growing non-OECD Asian markets provides a strong incentive to continue increasing production rates. By 2050, production in Russia will approach levels close to those of the United States. Meanwhile, the United States will increase production at a much more modest level. U.S. production will begin to decrease after 2030, and similarly, Canada's production growth will begin to subside after 2040. The leveling off of production in North America occurs as tight oil development moves into less productive areas and well productivity declines. The relatively high transportation costs associated with moving North America's crude oil to Asia also contributes to the leveling off in production. Additional production growth from Brazil relies on overall increasing oil prices and continued technological and efficiency improvements. Brazil's future production originates primarily in technically challenging offshore environments.

Natural gas production increases worldwide to help satisfy key demand markets

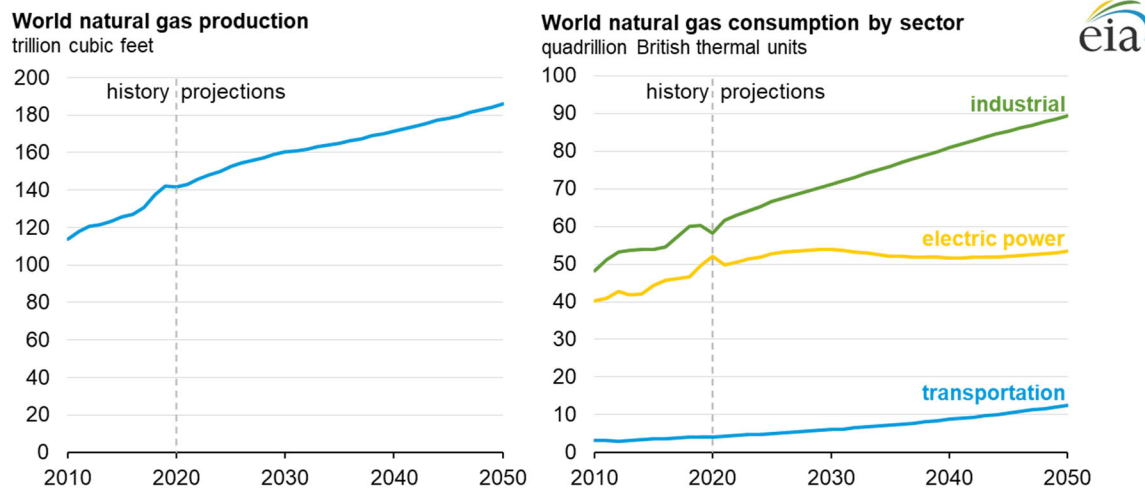
Global natural gas production continues to increase at a steady rate across the projection period, following production gains in the last decade

In the Reference case, global natural gas production steadily increases, growing by approximately 30% between 2020 and 2050. Before that, natural gas production grew by 25% between 2010 and 2020, with the aid of new recovery techniques and expanded infrastructure. Projected growth in global natural gas demand and the expansion of processing and transportation infrastructure around the world drives growth in natural gas production to 2050.

In addition, demand from the industrial sector—for both natural gas and NGPLs—supports growth in natural gas production, while growth is more limited in the electric power, transportation, and residential and commercial sectors. Although use of natural gas for electric power generation increased by almost 30% from 2010 to 2020, this growth will likely plateau in 2030. The role of natural gas in the electric power sector has become increasingly complex because of economic and policy trends that favor renewable energy.

Some future growth in natural gas production will likely coincide with crude oil production growth because crude oil production from low permeability, tight rock formations produces associated-dissolved natural gas (also called associated gas) which, in some areas, is captured and processed.

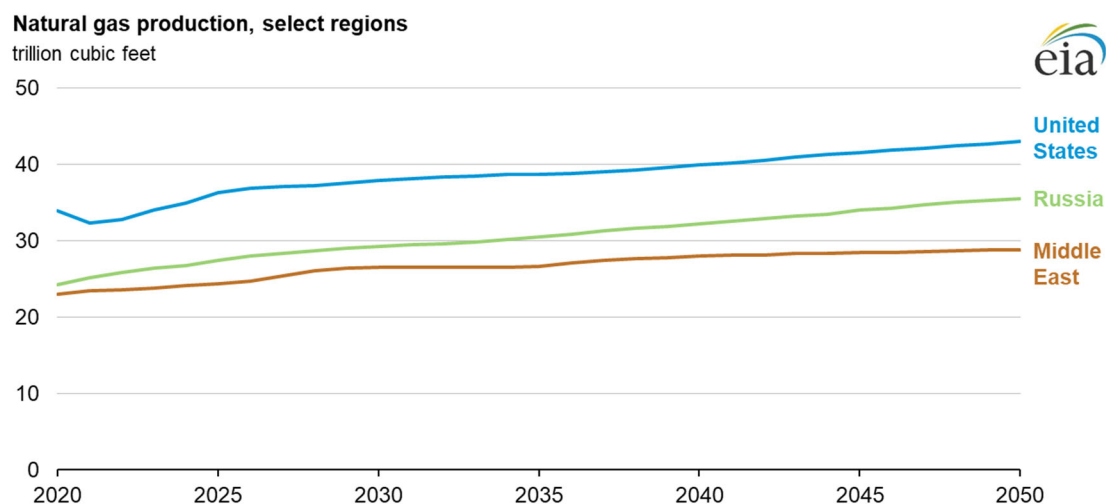
Figure 38.



Source: U.S. Energy Information Administration, *International Energy Outlook 2021* (IEO2021) Reference case

The United States, Russia, and the Middle East remain the largest natural gas producers and exporters through 2050

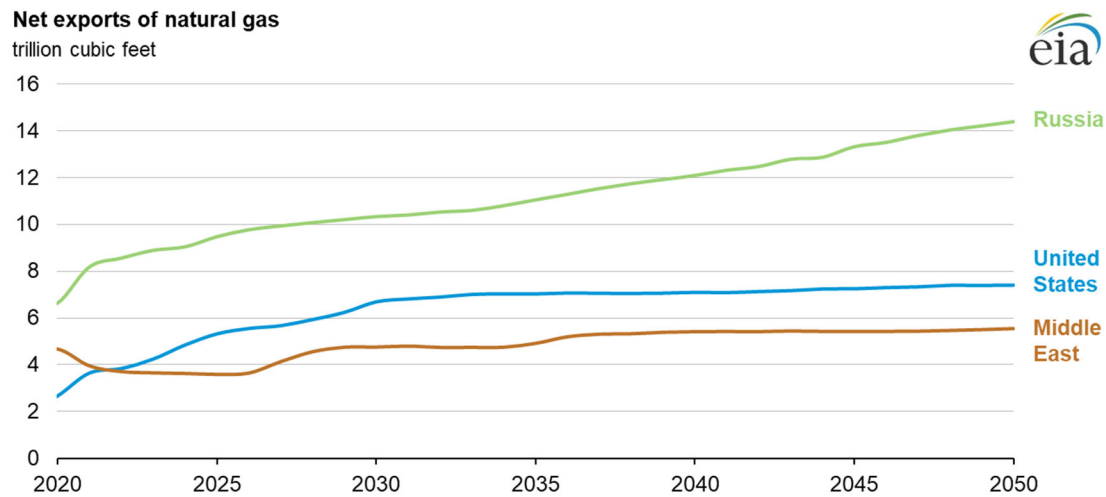
Figure 39.



The United States, Russia, and the Middle East are currently the largest producers of natural gas. In the Reference case, all three will continue to expand production throughout the projection period, and the United States will remain the largest producer worldwide, producing almost 43 trillion cubic feet (Tcf) in 2050.

The United States, Russia, and the Middle East all have large proven reserves of both natural gas and oil, along with the accompanying processing and transportation infrastructure to support steady production levels. In addition to meeting domestic demand, growing production in these regions serves growing demand for natural gas in the global market. The three largest producing regions all export more natural gas than they import; their exports go to key regions in Europe and Asia, where demand is greater than domestic supply. We project that the demand for natural gas from these regions grows further. The United States' and Russia's natural gas production grows by about 10 Tcf between 2020 and 2050 in the Reference case. Middle East natural gas production grows by about 5 Tcf over the same period.

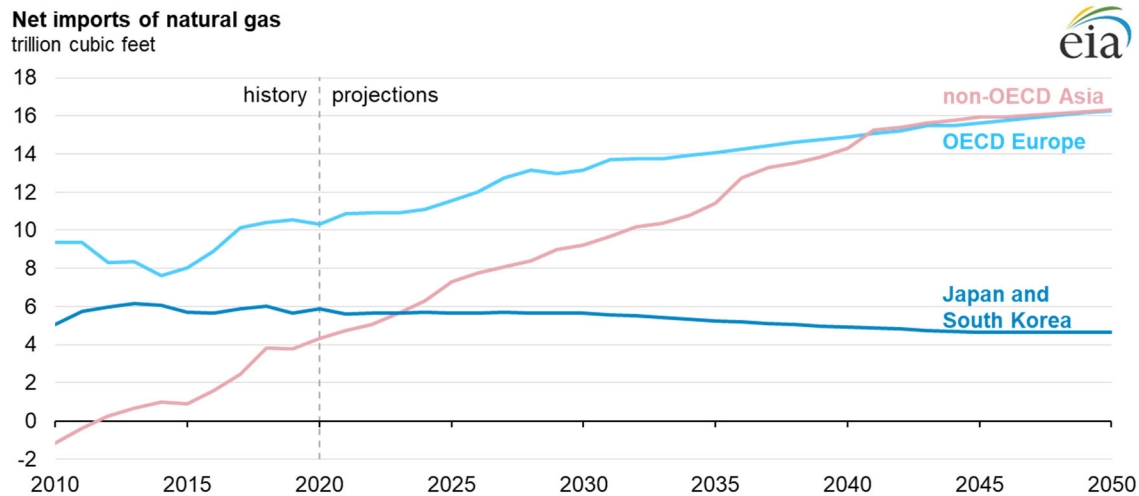
Figure 40.



In the Reference case, Russia, the United States, and the Middle East will all grow as net exporters throughout the projection period to provide natural gas to European and Asian markets. Russia, in particular, shows the most growth in net exports, more than doubling over the projection period to remain the largest net exporter of natural gas through 2050 at more than 14 Tcf. Because it is near Europe, China, and the rest of non-OECD Asia, Russia's net natural gas exports will grow through established pipeline infrastructure, potential future pipeline additions, and liquefied natural gas exports. The United States also shows rapid growth in net exports over the next 10 years, as it continues to expand its LNG infrastructure and produce natural gas at high volumes. LNG terminals and transportation vessels facilitate the overseas transport of natural gas between regions that are not connected by pipeline, creating an outlet for natural gas produced in the United States and the Middle East to reach overseas markets where it is in the highest demand.

Key destinations for natural gas exports are Europe and Asia, and non-OECD Asia grows the most

Figure 41.



In 2020, OECD Europe was the largest importer of natural gas, followed by Japan, South Korea, and non-OECD Asia. All of these regions are net importers due to their limited domestic supply of natural gas relative to their growing demand. These regions remain the largest natural gas export destinations through the projection period.

In the Reference case, both non-OECD Asia and OECD Europe increase their use of imported natural gas, and non-OECD Asia grows to become the largest net importer of natural gas by 2050—driven by continued economic growth in China and India. Net imports of natural gas into China, India, and other non-OECD Asian nations more than triple by 2050. Supply of natural gas in these markets arrives both via pipeline and as LNG exports from Russia. The regions also receive LNG exports from regions such as the United States, the Middle East, Australia, and Africa.