Independent Statistics and Analysis
U.S. Energy Information Administration

October 2023

International Energy Outlook 2023

IEO2023

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Administrator’s Forward

The global energy system is governed by complex dynamics that play out over time across regions and sectors of the economy. Projected increases in population and incomes drive our expectation of rising energy demand through 2050. However, we expect the increased energy demand to be moderated by reduced energy intensity: less energy will be required for each unit of economic activity. In addition, we expect reduced carbon intensity—largely driven by the wide-scale deployment of renewables for electricity generation—which will help limit global CO_2 emissions associated with what will be record-high energy demand. Our *International Energy Outlook 2023* (IEO2023) explains our findings and showcases key regional and sectoral variations. We use EIA's detailed World Energy Projection System to produce IEO2023, giving our readers a unique view into future global energy systems.

The challenge we face as modelers is to deliver actionable insights about the future in a world filled with uncertainty. To address that uncertainty, IEO2023 includes several projections—which we refer to as *cases*—each with different input assumptions. The cases we modeled focus on well-understood variables that can produce significant changes in global supply and demand patterns: macroeconomic growth, costs for zero-carbon generating technologies, and crude oil prices.

Although we model a number of cases, we do not try to comprehensively address all issues that could drive significant change, like in a forecast. In IEO2023, we do not incorporate deeply uncertain factors such as major new policy developments, technological breakthroughs, and geopolitical events, all of which can dramatically shift the course of energy system development. Instead, the cases included in IEO2023 build on recent trends and highlight the current trajectory of the global energy system.

Unmodeled surprises or breakthroughs that shift the trajectory of the global energy system will almost certainly happen. As Yogi Berra quipped, “The future ain’t what it used to be.” So, our modeled cases should not be interpreted as forecasts. Rather, IEO2023 provides a useful benchmark for decision makers around the world as they continue to shape our collective energy future.

In producing the IEO, we aim to be as transparent as possible. In addition to this written report, detailed model results are available on our website. Detailed documentation of the World Energy Projection System is also available on our website. In addition, the model source code is available for review, and we are actively working to make the model’s source code publicly available under an open source license. We are also working on expanding the capabilities of our model so that we can examine a wider range of cases in the future.

In closing, I’d like to thank our staff for their tremendous effort to produce this year’s IEO. I feel privileged to help lead such a talented team of experts.

Executive Summary

The *International Energy Outlook 2023* (IEO2023) explores long-term energy trends across the world through 2050. Since our last IEO two years ago, IEO2021, the global energy system has evolved against a backdrop of new energy policies, the transition to zero-carbon technologies, energy security concerns, and economic and population growth. While IEO2023 includes several cases to capture important drivers of change, the modeled cases represent a set of policy neutral baselines that place emphasis on the current trajectory of the global energy system.

Increasing population and income offset the effects of declining energy and carbon intensity on emissions.

Our projections highlight a key global insight—global energy-related CO_2 emissions will increase through 2050 in all IEO2023 cases except our Low Economic Growth case. Our projections indicate that resources, demand, and technology costs will drive the shift from fossil to non-fossil energy sources, but current policies are not enough to decrease global energy-sector emissions. This outcome is largely due to population growth, regional economic shifts toward more manufacturing, and increased energy consumption as living standards improve. Globally, we project increases in energy consumption to outpace efficiency improvements.

Increasing population and income offset the effects of declining energy and carbon intensity on emissions.

China remains the primary source of energy-related CO_2 emissions through 2050 across all cases, although its share of total global CO_2 emissions declines. Further, across all cases we project India to displace the United States and our Other Asia-Pacific modeling region[1] to displace Western Europe as the second- and third-highest emitters of energy-related CO_2 emissions by 2050, respectively.

Three different rates of macroeconomic growth underlie our energy projections across all modeled cases (Appendix A). Economic and population growth drive the increase in emissions, and we expect global gross domestic product (GDP) to more than double by 2050 in all of our IEO2023 cases, except the Low Economic Growth case. We project the Asia-Pacific region's GDP will grow faster than the global average, and a declining population will slow GDP growth in China relative to recent history. Population growth across our cases is concentrated in Africa, India, and Other Asia-Pacific, which combined, contribute 94% of the expected 1.7 billion people added to the global population by 2050 across all cases in our projections.

We project global industrial-sector energy consumption to grow between 9% and 62% and transportation-sector energy consumption to grow between 8% and 41% from 2022 to 2050, depending on the case. Increasing income and rapid population growth, particularly in India, Africa, and Other Asia-

[1] The Other Asia-Pacific region is an aggregation of 41 countries, including Indonesia, Thailand, Vietnam, and Malaysia. Full regional definitions used in the *International Energy Outlook 2023* appear in Appendix C.

Pacific, leads to continued growth in buildings' energy consumption in our projection. For example, in India, we project energy consumption in commercial and residential buildings to as much as triple in some cases between 2022 and 2050.

The intensity of energy-related CO_2 emissions (CO_2 emissions per unit of primary energy) decreases through 2050, despite overall emissions increases in our projections. The decreasing emissions intensity reflects a transition toward lower-carbon energy sources. These trends of decreasing emissions intensity could be offset by shifts toward increased manufacturing in certain regions. For example, we project that declines in energy intensity will be offset by sectoral shifts toward manufacturing and that industrial energy consumption grows the fastest in India, Other Asia-Pacific, Africa, and Other Americas. Across most of our cases, China is the region with the largest level of industrial energy consumption decline, reflecting the commercial service sector's growing share of China's economy and manufacturing's shrinking share of total industrial activity.

The shift to renewables to meet growing electricity demand is driven by regional resources, technology costs, and policy.

We project global electricity generation will increase by 30% to 76% in 2050 from 2022 (depending on the case) and will primarily be met by zero-carbon technologies across all cases. For all cases, we project that 81% to 95% of the new electric-generating capacity installed from 2022 to 2050 to meet new demand will be zero-carbon technologies. As a result, by 2050, the combined share of coal, natural gas, and petroleum liquids decrease to between 27% and 38% of the installed global generating capacity across our cases.

The shift to renewables to meet growing electricity demand is driven by regional resources, technology costs, and policy.

In Western Europe and China, zero-carbon technology capacity increases faster early in the projection period because of policy, rapid demand growth, and energy security considerations that favor locally available resources such as wind, solar, and battery storage prompt more of these types of installations and planned builds. India and Africa show rapid growth in zero-carbon technology later in the projection period. Cost variations for zero-carbon technologies in our projections have the most significant impact on the energy mix and emissions in China and Other Asia-Pacific, where coal generation is most prevalent.

We project electric vehicles (EVs) to account for between 29% and 54% of global new vehicle sales by 2050; China and Western Europe account for between 58% and 77% of those EV sales across all cases. Continued increases in EV adoption leads to a projected peak in the global fleet of internal combustion engine light-duty vehicles (LDVs) between 2027 and 2033.

Energy security concerns hasten a transition from fossil fuels in some countries, although they drive increased fossil fuel consumption in others.

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Natural gas and crude oil supply, consumption, and trade patterns evolve in our projections to meet growing demand against the backdrop of Russia's full-scale invasion of Ukraine, which we assume will continue to limit Russia's exports to Western markets. The Middle East and North America are the primary regions to increase natural gas production and exports to meet growing international demand, mainly in Asia and Europe. Near- to mid-term (2023–2035) growth in crude oil production is met by non-OPEC regions, particularly in North and South America. OPEC regains market share as other regions reach peak production, generally between 2030 and 2040 in our projection. We project reduced gasoline demand due to rising EV sales and rising demand for jet fuel due to global economic growth, which will drive changes in refineries. Refineries are currently configured to meet gasoline and distillate demand and cannot easily change the petroleum ratio of products they produce. To address the shift in global products demand, refineries need to adjust crude oil inputs, resulting in a transition from light crude oil to medium crude oil in our projections.

Baseline projections, not forecasts

Many aspects of the global energy system over the next three decades are deeply uncertain. Although the IEO2023 cases—which vary assumptions related to macroeconomic growth, technology costs, and fuel prices—help to capture the range in possible outcomes, many unmodeled issues remain that could drive significant change across the global energy system.

Key among the unmodeled issues: our model does not assume future policy. We assume current policies, as of March 2023, remain in place. Specifically, in IEO2023, policies without enforcement mechanisms are discounted, and those with expiration dates expire as indicated. For the United States, we only consider policies implemented by November 2022 because IEO2023 uses our *Annual Energy Outlook 2023* to model the U.S. energy system. Since November 2022, U.S. government agencies have implemented provisions associated with the Inflation Reduction Act, although not all are finalized.

Therefore, our projections should not be interpreted as forecasts. Our projections represent a set of policy-neutral baselines against which future policy action can be evaluated. When interpreting our results, keep in mind the caveats associated with our analysis.

Introduction

The *International Energy Outlook 2023* (IEO2023) explores long-term energy trends across the world. IEO2023 analyzes long-term world energy markets in 16 regions through 2050. We developed IEO2023 using the World Energy Projection System (WEPS),[2] an integrated economic model that captures long-term relationships between energy supply, demand, and prices across regional markets.

IEO2023 identifies three key findings:

- **Increasing population and income offset the effects of declining energy and carbon intensity on emissions.**
- **The shift to renewables to meet growing electricity demand is driven by regional resources, technology costs, and policy.**
- **Energy security concerns hasten a transition from fossil fuels in some countries, although they drive increased fossil fuel consumption in others.**

We explore the three key findings in separate sections of this report, each containing a series of in-depth explanations that include region- and sector-specific insights across modeled cases. IEO2023 includes a series of cases that reflect different assumptions related to macroeconomic growth, technology costs, and fuel prices, although the future remains significantly uncertain. Therefore, our cases should not be interpreted as predictions. One important source of uncertainty is future policy implementation around the world. Our IEO2023 cases are based on current laws and regulations as of March 2023. In particular, U.S. projections in IEO2023 are the published projections in the *Annual Energy Outlook 2023* (AEO2023), which assumes U.S. laws and regulations as of November 2022 remain unchanged. Our projections provide a range of outcomes in a world of frozen policy that are intended to help inform decision makers as they plan for the future.

IEO2023 cases do include some anticipated changes over time:

- Expected regional economic and demographic trends based on the views of leading forecasters
- Planned or known changes to infrastructure for new construction and announced retirements
- Assumed cost and performance improvements in established technologies based on historical trends

Sources of uncertainty

Energy market projections are inherently uncertain because many of the events that will shape future energy markets—including developments in policy, technology, demographics, and resources—are

[2] U.S. Energy Information Administration. [World Energy Projection System (WEPS): Overview](). Part of the *Handbook of Energy Modeling Methods.* 2021.

unknown. Many sources of uncertainty exist beyond the ones we test explicitly, including new policies, unforeseen geopolitical events, and rapid technological innovation. Innovation is particularly relevant for technologies in the earliest stages of development.

Any future legislation would further affect technology trajectories and emissions pathways. We reflect legislated and enacted energy sector policies that can be reasonably quantified in WEPS. Policies with expiration dates expire rather than being replaced or extended. Policies without enforcement mechanisms are evaluated and, in some cases, assumed to be only partially met. More information on how we model climate policies is available in our companion article, *Climate Considerations in the International Energy Outlook 2023*.

Since we released the most recent IEO in late 2021, the world has changed. We have had significant national and international short-term market volatility associated with economic growth as the world reemerges from the COVID-19 pandemic and with the political instability associated with Russia's full-scale invasion of Ukraine. Appendix B discusses the assumptions we made around the invasion and how we represented it in our analysis, including:

- An economic recovery starting around 2030.
- Two nuclear power plants that are located in military conflict zones in Ukraine resume full operation by 2034.
- Western Europe and the United States suspend imports of crude oil and petroleum liquids from Russia, beginning in 2023 and lasting through 2050.
- The outage of Nordstream natural gas pipelines continues through 2050.

We continuously monitor such developments and consider how they may affect our long-term projections.

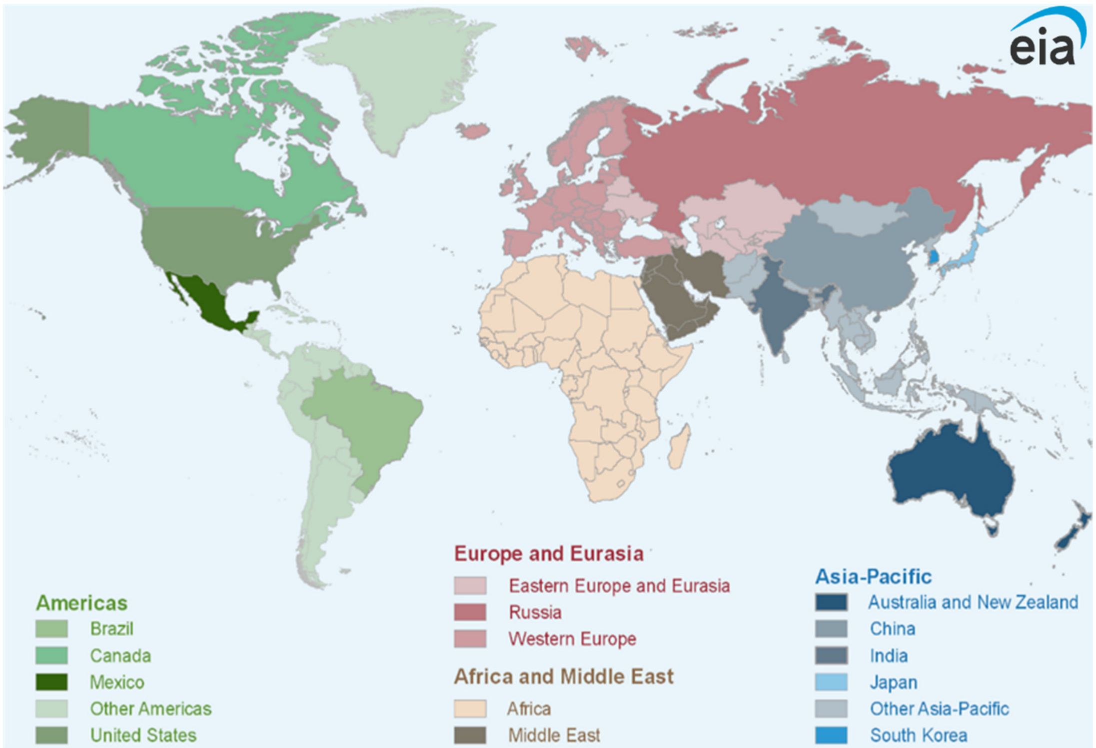
IEO2023 explores key areas of uncertainty about how energy markets will develop through a Reference case and the following six side cases, including two new side cases in this IEO that focus on higher and lower zero-carbon technology costs:

- High and Low Economic Growth cases
- High and Low Oil Price cases
- High and Low Zero-Carbon Technology Cost cases

As in AEO2023, our graphs emphasize the range of results, denoted by shaded areas, across all modeled cases. We derive our key analytical insights by assessing the results across cases and examining how overall trends may vary under the different assumptions.

In IEO2023, we used a new regional representation to group countries in the World Energy Projection System (WEPS). The new regional groupings are based solely on geography. Figure 1 shows a map of our new 16 regions and 4 superregions (that is, Americas, Europe and Eurasia, Africa and Middle East, and Asia-Pacific). A table of the countries assigned to each region is available in Appendix C.

Figure 1
Map of *International Energy Outlook 2023* regions



Data source: U.S. Energy Information Administration

Some components of uncertainty in the IEO are magnified by the global focus. For example, both short-term and long-term projections of GDP are more uncertain in economies with lower GDP per capita than in economies with a higher GDP per capita (Appendix A). Similarly, although we assume implemented laws and regulations in the United States will be enforced, policy norms vary around the world. The balance between energy security, climate policies, and economic growth also vary in different regions of the world and can be influenced by as-yet-unknown geopolitical events. Our IEO cases explore some components of this uncertainty.

1

Increasing population and income offset the effects of declining energy and carbon intensity on emissions.

The future trajectory of global energy consumption and emissions will be determined by complex and interrelated dynamics that play out across regions, sectors, and time. Global energy consumption increases 34% from 638 quadrillion British thermal units (quads) in 2022 to 855 quads in 2050 in the Reference case and varies between 739 quads and 999 quads by 2050 across the other cases.[3] Corresponding energy-related CO_2 emissions rise 15% from 35.7 billion metric tons in 2022 to 41.0 billion metric tons in the Reference case, and they vary between 35.1 billion metric tons (a decrease from 2022 levels) and 47.9 billion metric tons by 2050 in the other cases.[4]

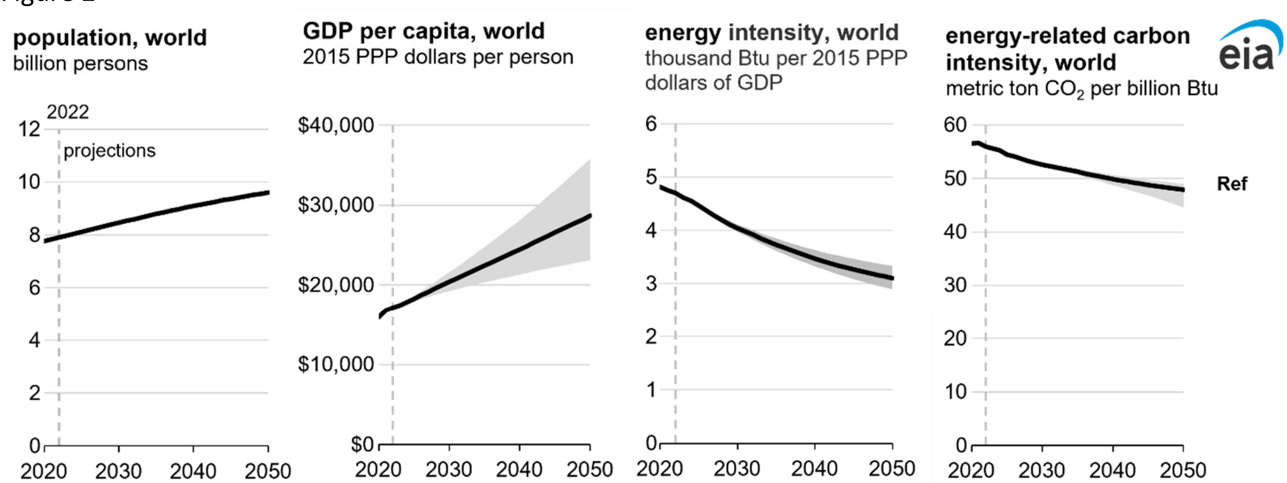
To better illustrate the basic dynamics that drive global primary energy consumption and energy-related CO_2 emissions, Figure 2 represents our model projections as a series of four driving factors: population, average income (per capita GDP), energy intensity (energy per

[3] In 2023, we began changing our accounting for renewable energy—the way we convert kilowatthours generated from renewable energy to British thermal units—to change the basis for our conversion from fossil fuel equivalency to captured energy. In IEO2023, electricity generation from renewable sources (such as hydroelectric, wind, or solar) is converted using our original fossil fuel equivalency approach. The renewable generation is converted to British thermal units at a rate of 8,124 British thermal units per kilowatthour, which reflects the average projected conversion efficiency of the U.S. fossil-fuel fired electric-generating fleet in the *Annual Energy Outlook 2021* over the projection period (2022–2050). We will be reporting electricity generation from renewable sources using the captured energy approach in future editions of the IEO.

[4] When quantifying energy-related CO_2 emissions, we only tally those generated when the energy is used. This measure does not include emissions associated with producing the energy—such as methane leaks for flaring.

dollar GDP), and carbon intensity (CO_2 emissions per unit of primary energy).

Figure 2



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases. Our global population assumptions do not vary across side cases. GDP=gross domestic product; PPP=purchasing power parity; Btu=British thermal units; Ref=Reference case.

At a given point in time, the product of the first three factors yields total primary energy consumption, and the product of all four factors yields total energy-related CO_2 emissions. Quantifying emissions this way is known as the Kaya Identity,[5] which provides a useful conceptual framework for thinking about the high-level factors that drive changes in emissions.

Growth in the first two components—population and GDP per capita—place upward pressure on energy-related CO_2 emissions, and projected decreases in the third and fourth components—energy and carbon intensity—place downward pressure (Figure 2).

The first four sections in this chapter provide additional insight at the global level. We begin by analyzing the two factors of the Kaya identity that continue to drive global emissions though 2050: population and GDP per capita. We round out our global overview by discussing global energy consumption by fuel type, sector, and emissions worldwide.

Because regions and sectors vary significantly, the last five sections examine the dynamics driving energy consumption. These sections focus on fuel and technology pathways, which inform the energy- and carbon-intensity factors of the Kaya identity and how the ongoing declines of these factors moderate emissions growth. These sections highlight the value of our detailed World Energy Projection System (WEPS) model, which explores the complex interconnections of macroeconomic drivers and technology evolution over time, producing global total energy consumption and emissions (Figure 3).

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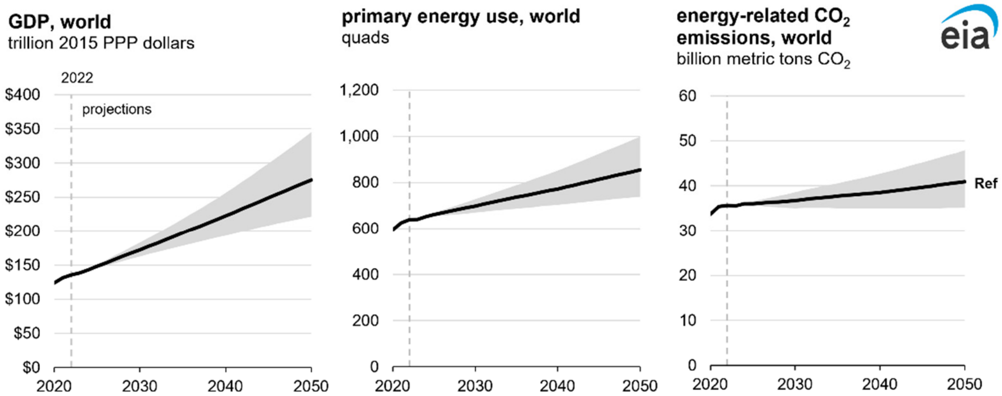
[5] Kaya, Y., 1990: *Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios*. Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris.

Figure 3



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases. Ref=Reference case; GDP=gross domestic product; quads=quadrillion British thermal units; PPP=purchasing power parity.

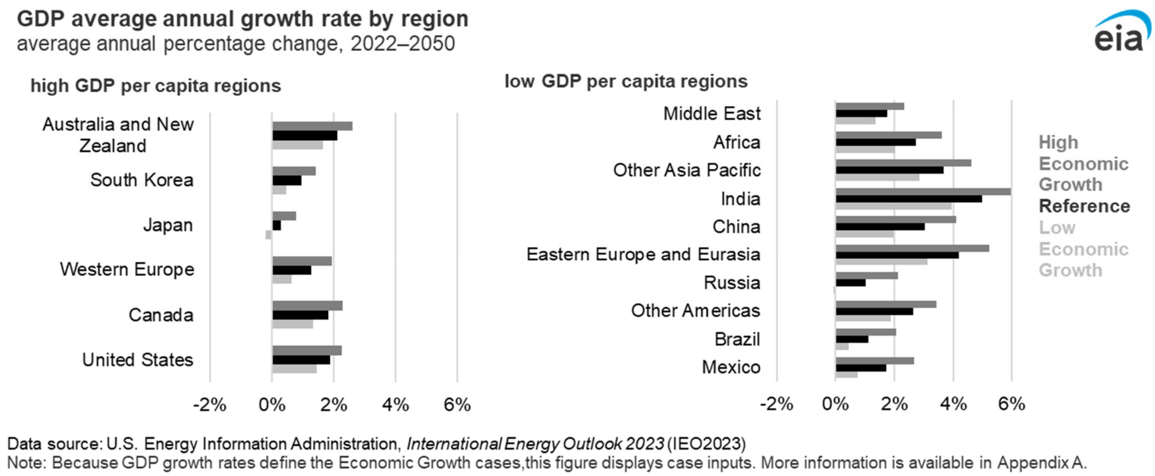
GDP growth and population trends are major drivers of energy market projections

IEO2023 assumes that, as incomes and population rise over time, energy consumption increases as more people can afford to drive, use commercial services, demand goods, and control building temperatures. Macroeconomic projections, specifically population and GDP trends, are key drivers of the energy consumption and production results in WEPS.

Global population increases from 7.9 billion in 2022 to 9.6 billion in 2050, an average growth rate of 0.7%, and does not vary across cases. The regions with the largest population increases by 2050 are Africa (1 billion), the Other Asia-Pacific region (306 million), and India (249 million) across all cases. Falling populations in China, Japan, Russia, and South Korea will weigh on GDP growth as the labor force shrinks.

Global GDP grows annually at an average rate of 2.6% in the Reference case, from approximately $136 trillion to $275 trillion in real 2015 purchasing power parity (PPP) adjusted U.S. dollars (USD), from 2022 to 2050. Global GDP in 2050 rises to a range of $221 trillion (2015 PPP USD) in the Low Economic Growth case to $345 trillion (2015 PPP USD) in the High Economic Growth case. Developing Asia, specifically India and our Other Asia-Pacific region, contributes the most to global economic growth (Figure 4). We project China to retain the highest GDP in 2050 despite slower growth relative to historical rates.

Figure 4



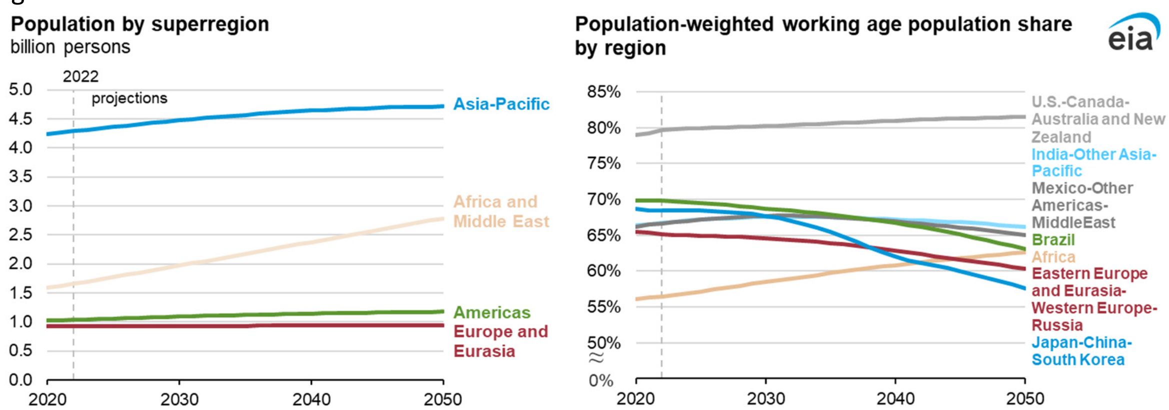
GDP and population growth affect energy consumption in several ways. First, economic activity is reallocated across sectors as GDP per capita increases. As household incomes rise, wealthier consumers shift their consumption toward energy-intensive goods and services. Because energy intensities vary from one sector to another, this reallocation tends to raise total energy consumption.

Second, technology and energy efficiency improvements often accompany economic growth. Improvements in energy efficiency reduce energy consumption per unit of output; we discuss these energy and economic mechanisms across sectors in greater detail next.

The tension between changes in sector composition due to rising incomes and population as well as energy efficiency determines the overall impact on total energy consumption. Globally, we project that increases in energy consumption per person will outweigh the pace of efficiency improvements.

Third, demographic trends affect economic activity and are important drivers of total energy consumption. We project the labor force as a share of the population will decrease in many regions, which tends to lower average productivity and GDP per capita (Figure 5). These demographic factors vary by region and are reflected in our macroeconomic projections for population and GDP growth. Our global population assumptions do not vary across side cases.

Figure 5

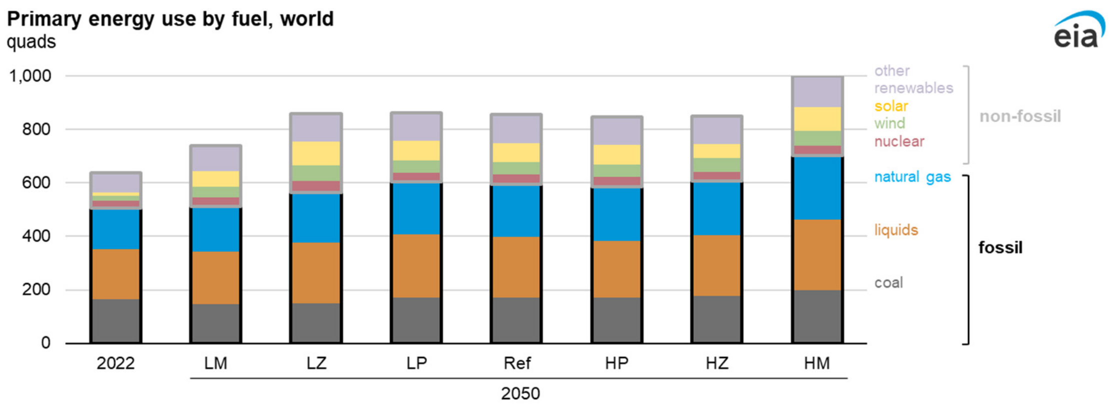


Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Only Reference case results are shown because global population assumptions are the same for all cases.

Renewable energy grows the fastest as a share of primary energy consumption across all cases due to current policy and cost drivers

Across all IEO2023 cases, energy consumption increases globally, driven by demographic and macroeconomic trends. The increased consumption coupled with current policy and energy security concerns drive non-fossil fuel sources to gain a larger share of the increasing primary energy consumption worldwide (Figure 6). Renewable energy consumption, particularly solar and wind, grows faster than any other energy source, and the non-fossil fuel share of primary energy grows from 21% in 2022 to a range of 29% to 34% in 2050 across the cases. The projected rise in renewable energy consumption is largely driven by its increased use for electric power generation.

Figure 6



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Biofuels are included in the "other renewables" category. Quads=quadrillion British thermal units; HZ=High Zero-Carbon Technology Cost case; LZ=Low Zero-Carbon Technology Cost case; HM=High Economic Growth case; LM=Low Economic Growth case; HP=High Oil Price case; LP=Low Oil Price case; Ref=Reference case.

Natural gas is the fastest-growing fossil fuel globally; consumption grows from 153 quads in 2022 to a range of 170 quads to 241 quads by 2050 across cases, an 11% to 57% increase. Growth in natural gas consumption is widely distributed regionally, but it is most notable in India, the Other Asia-Pacific region, China, Africa, Russia, the Middle East, and the Other Americas region. The projected rise in natural gas consumption is most pronounced in the electric power sector, where it replaces retiring coal-fired generation, and the industrial sector, where it primarily fuels expanding industrial production.

Starting from 166 quads in 2020, global coal consumption grows in some cases while it decreases in others. From 2022 to 2050, the largest growth (19%) is in the High Economic Growth case, and the largest decrease (13%) in coal consumption is in the Low Economic Growth case. Coal consumption varies by region, increasing in Africa, India, and the Other Asia-Pacific region and decreasing in China and the United States.

Global demand grows fastest in the industrial and residential sectors

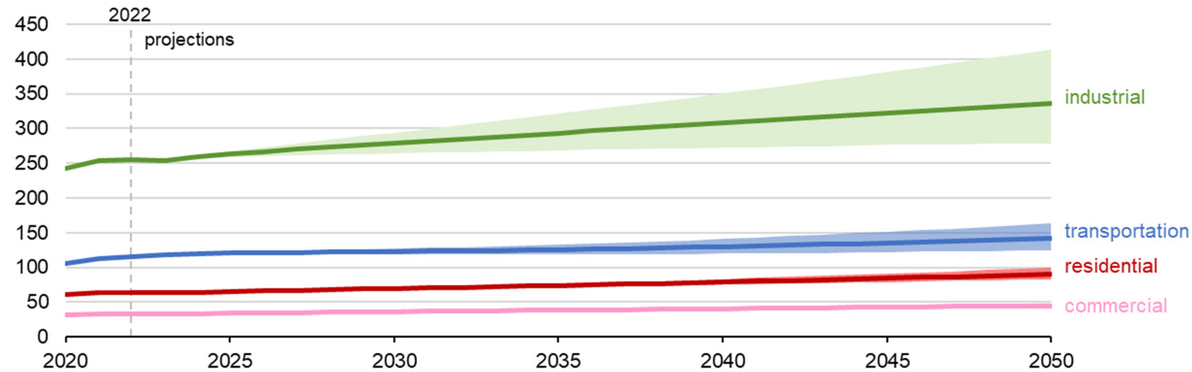
Across all cases, end-use consumption, not including electricity-related losses, grows through 2050 across all sectors (Figure 7). The industrial sector grows by the greatest amount across most cases—ranging from a relatively flat increase of 24 quads in the Low Economic Growth case to as much as a 159-quad increase in the High Economic Growth case over 2022 to 2050. The industrial sector has the widest range of consumption across cases due to a broad range of industrial gross output assumptions across our cases and a sensitivity to macroeconomic drivers.

Consumption grows at the fastest pace in the residential sector, averaging 1.0% to 1.6% per year over the same period across all cases.

Figure 7

Total energy consumption by sector, world

quads



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Quads=quadrillion British thermal units. Each line represents IEO2023 Reference case projections. Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases.

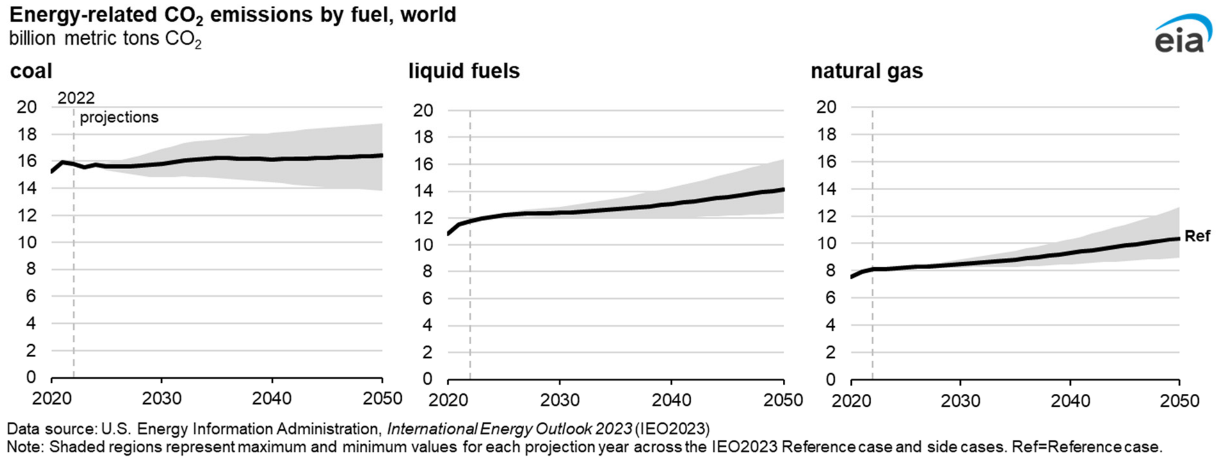
Global energy-related CO_2 emissions increase through 2050 in most cases, but carbon intensity declines in all cases

Global energy-related CO_2 emissions in 2050 are higher than in 2022 in all cases except the Low Economic Growth case. In the High Economic Growth case, emissions rise from 35.7 billion metric tons in 2022 to up to 47.9 billion metric tons in 2050 (Figure 3). In the Low Economic Growth case, global energy-related CO_2 emissions fall to 35.1 billion metric tons by 2050. Economic activity (the product of population and GDP per capita), the fuel choices supporting that activity, and the energy and carbon intensity of that activity drive the range of projections. The largest differences in economic activity are between the High and Low Economic Growth cases, and the largest differences in carbon intensity are between the High and Low Zero-Carbon Technology Cost (ZTC) cases.

Our projections indicate that resources, demand, and technology costs will drive the shift from fossil fuel to non-fossil fuel energy sources, but current policies alone will not decrease global energy-sector emissions.

Changes to the fossil fuel consumption mix—which is heavily determined by relative fuel prices—decrease global emissions intensity across all cases. Rapid growth of renewable power sources in the electric power sector further decreases emissions intensity, and the largest effects occur in the Low ZTC case. Within fossil fuels, liquid fuels and natural gas gain a larger share of fossil fuel consumption, lowering global emissions intensity because they emit less CO_2 than coal when combusted. Contrary to the global trend, regions with access to affordable coal, such as the Other Asia-Pacific region, consume more coal as a share of total fossil fuel consumption. Coal remains the number one source of energy-related CO_2 emissions, followed by liquid fuels and natural gas (Figure 8).

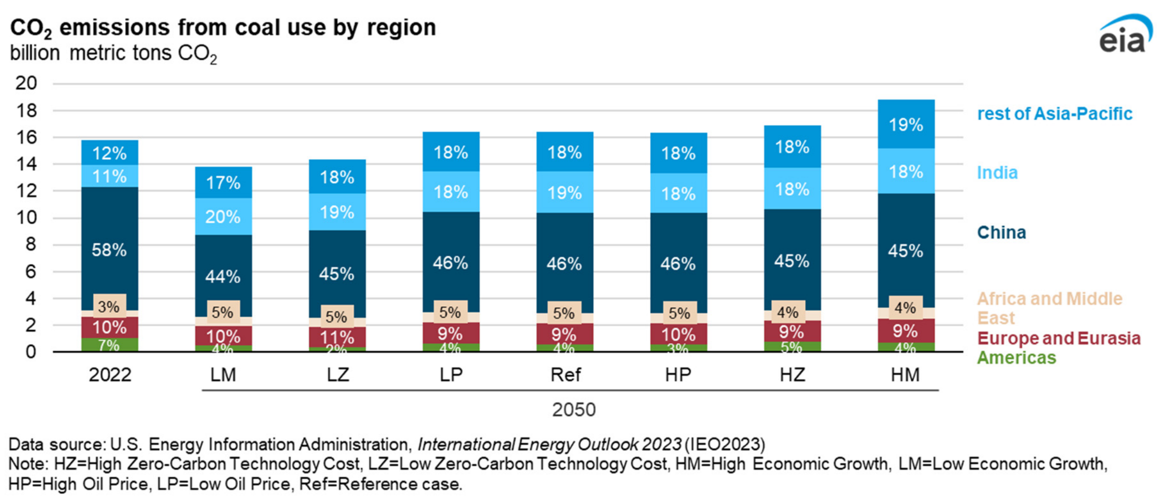
Figure 8.



On a regional level, China remains the top source of energy-related CO_2 emissions, although its share of the global total declines. Meanwhile, the shares of global emissions increase from India and the Other Asia-Pacific region, and these two regions displace the United States and Western Europe to become the second- and third-highest emitters of energy-related CO_2 emissions, respectively.

CO_2 emissions from coal combustion fall as a share of total energy-related CO_2 emissions from 47% in 2022 to a range of 37% to 41% in 2050 across all cases. Declining coal emissions in China and the United States primarily drive the global decline, with additional, smaller declines in Western Europe, Canada, and Japan. Although China has the largest decline in emissions from coal, it remains the number one source of emissions from coal, ranging from 44% to 46% of the global total in 2050 across cases (Figure 9).

Figure 9.



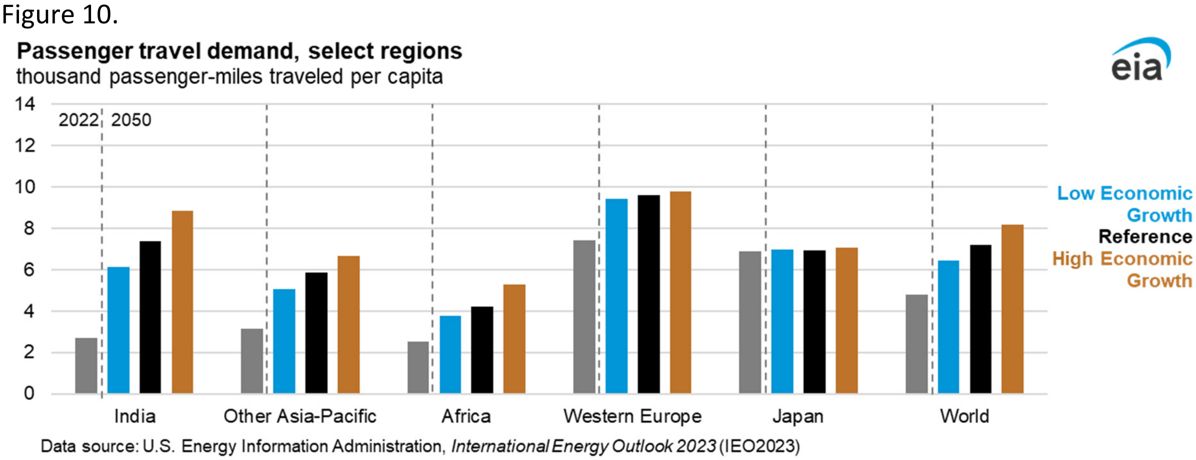
Carbon emissions increase in the transportation sector due to growing travel demand, regional variation in electrification, and slow turnover of the existing fleet

Increasing demand for passenger and freight travel drives global transportation energy consumption, which grows by 8% to 41% across cases between 2022 and 2050. Steady population increases coupled with rising incomes, employment, and industrial output increase travel demand.

Demand for passenger travel, as measured in passenger miles traveled, increases by 64%–108% across cases from 2022 to 2050 primarily due to growth in both population and income. This increase corresponds to an increase in both the number of people traveling and the miles traveled by each person. Global population growth is responsible for about one-third of the projected increase in passenger travel demand between 2022 and 2050; in Africa, population growth is responsible for more than one-half of the projected increase in passenger travel demand in the region between 2022 and 2050.

Global per capita travel demand is highly sensitive to changes in disposable income per capita and employment. We project that the global average passenger miles traveled per person will increase 51% between 2022 and 2050 in the Reference case, varying between 35% in the Low Economic Growth case and 71% in the High Economic Growth case. Much of this growth is concentrated in India and the Other Asia-Pacific region, where disposable income and employment grow significantly across all cases. Regions with slower income growth—and with lower absolute income per capita, such as Africa and the Other Americas region—continue to have growing travel demand, due to increases in employment, but to a lesser degree. In regions where both income and employment grow more slowly, such as Canada, South Korea, the United States, Western Europe, and Japan, per-capita travel demand growth is lower (Figure 10).

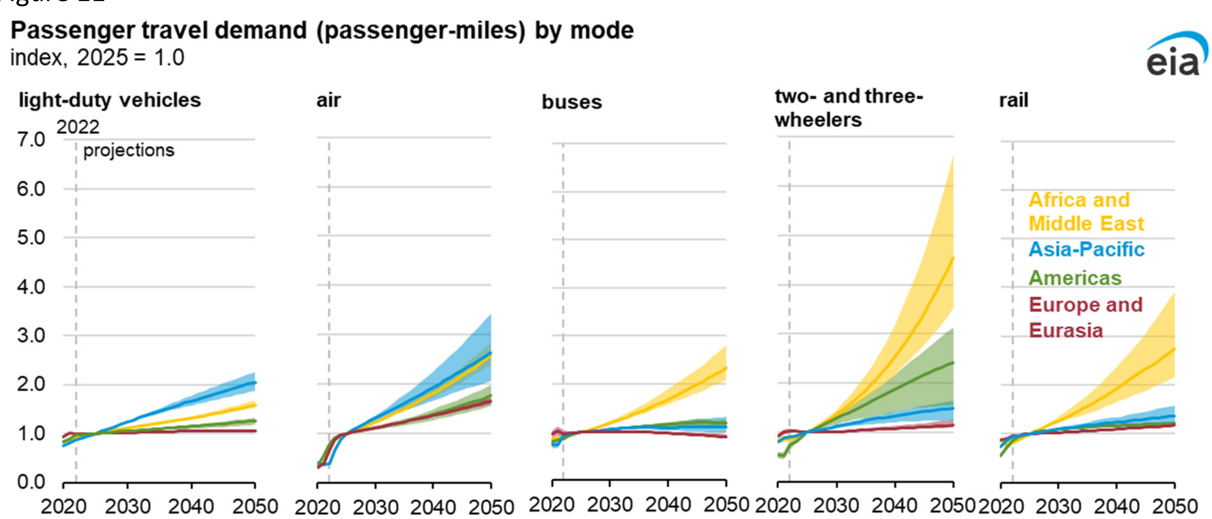
Figure 10.



Travel demand for less efficient modes of transportation grows in regions as incomes increase. Rising incomes in several regions enable travelers to shift from inexpensive but more efficient modes (such as two- and three-wheelers, buses, and rail) to more convenient but less efficient modes (such as light-duty vehicles [LDVs]), especially in China, India, and the Other Asia-Pacific region. Aircraft travel, which is highly sensitive to changes in income, is noticeably increasing across all regions. In regions with slower income growth, such as Africa and the Other Americas region, use of two- and three-wheelers persists and grows more than aircraft and LDV travel. This trend occurs across our four superregions as growth from a 2025 baseline—which is when we project travel to return to pre-pandemic levels (Figure 11). For example, we project LDV travel demand in the Asia-Pacific superregion—which includes China and India—to double, and we project two- and three-wheeler and rail travel demand to increase by less than 50% across all cases. We see the opposite in the Africa and Middle East superregion, where we project two- and three-wheeler travel demand to grow over three times the 2025 level, and LDV travel demand to increase by less than 70% across all cases. We also project travel demand to increase across all superregions, modes, years, and cases, except for bus travel, which plateaus or starts to decline in all superregions but Africa and the Middle East.

Continued increases in electric vehicle adoption lead to a projected peak between 2027 and 2033 in the global fleet of internal combustion engine light-duty vehicles.

Figure 11



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Each line represents IEO2023 Reference case projections. Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases.

The aggregate increase in LDV travel leads the global on-road LDV fleet to grow from about 1.4 billion vehicles in 2022 to more than 2.0 billion vehicles by 2048 in the Reference case, with all but the Low Economic Growth case exceeding 2.0 billion vehicles by 2050.

Efficiency improvements within each powertrain technology offset a significant portion of the energy consumption from travel demand growth and the wider shift into less-efficient modes of travel.

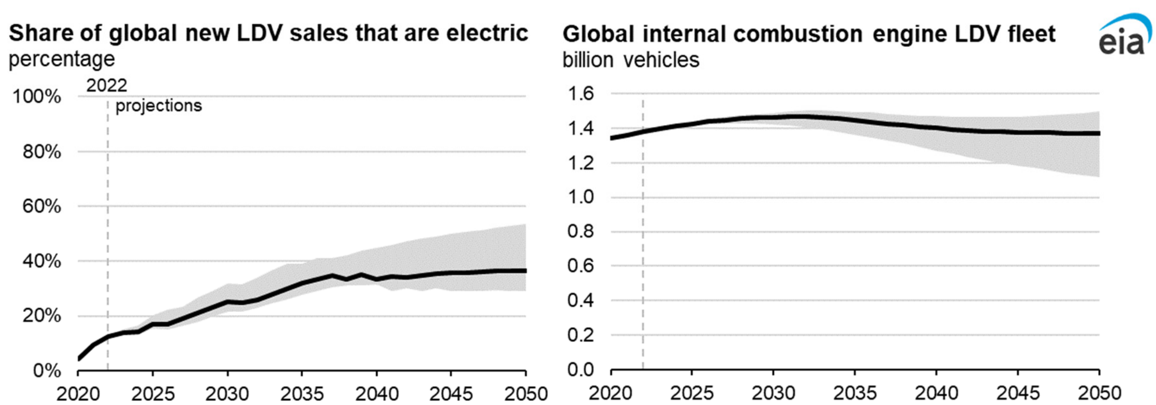
Efficiency of the global LDV fleet increases by over 40% between 2022 and 2050 in all cases, reaching a global average of between 42 miles per gallon and 52 miles per gallon across cases. Average efficiency continues to increase due to improvements within each individual powertrain type (for example, gasoline internal combustion engine, gasoline hybrid, battery electric) as well as a sales shift from less efficient to more efficient powertrains, primarily electric vehicles (EVs). We apply implemented and enforceable fuel economy standards that vary regionally, but we do not include government and industry aspirations and intentions in our projections. Stricter standards—such as those in Canada, China, South Korea, Japan, Australia and New Zealand, and parts of the European Union—drive efficiency improvements in conventional internal combustion engine (ICE) vehicles through the mid-2030s. The advanced technology required to achieve this efficiency also increases ICE vehicle purchase prices.

Electric vehicle sales grow due to current policy incentives, efficiency standards, favorable electricity prices, and decreasing battery costs

Purchase incentives for EVs—such as those in Canada, China, several countries in the European Union, Japan, South Korea, and the United States—increase EV sales in the near term. In the longer term, declining battery prices lead to additional growth in EV adoption even as current fuel economy standards level off.

EVs (which include battery electric and plug-in hybrid electric vehicles) account for 29% to 54% of global new vehicle sales by 2050, reaching cumulative sales between 465 million and 832 million battery electric vehicles as well as between 218 million and 241 million plug-in hybrid electric vehicles over the projection period (2022 to 2050) (Figure 12). China and Western Europe account for 58% to 77% of those EV sales because of supportive policy and the size of their LDV market; the two regions account for between 37% and 40% of all global LDV sales between 2022 and 2050.

Figure 12.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases.
LDV=light-duty vehicle; Ref=reference case.

Continued increases in EV adoption lead to a peak in the global fleet of ICE LDVs between 2027 and 2033 in all cases (Figure 12); in the High Economic Growth and Low Oil Price cases the ICE fleet reverses the decline in 2043 and starts growing again. Slow turnover of LDVs means more than 1.1 billion ICEs are still on the road by 2050 in all cases.

Technical Note 1: EV penetration

We determine the non-U.S. share of electric vehicle (EV) sales in our projection using a multinomial logit function that includes comparative vehicle purchase price, cost to drive, model availability, and fuel availability. Growing EV sales drive growth in the number of EV models available and access to EV charging infrastructure, which both support further increases in EV sales. In our projection, the purchase price and cost to drive factors are affected by enacted and enforceable regional purchase incentives and fuel economy standards, declining battery costs, and electricity and gasoline prices. We do not include stated aspirations and ambitions for EV market penetration rates that are not supported by enforceable laws or regulations in our projections.

U.S. projections in IEO2023 are from our AEO2023. The National Energy Modeling System (NEMS), which produces the projections in the AEO, has a detailed representation of the U.S. light-duty vehicle market, policies, and technological development. AEO2023 results include the Inflation Reduction Act, specifically the Clean Vehicle Credit, as well as the latest finalized Corporate Average Fuel Economy (CAFE) standards for model years 2024–2026. Specific assumptions are discussed in AEO2023.

We include policies in many regions that provide incentives and rebates for consumers that purchase or lease EVs. These incentives vary by country and regionally within countries. For example, the iZEV program in Canada provides EV purchasers with point-of-sale incentives ranging from CA $2,500 to CA $5,000, depending on the powertrain type (battery electric or plug-in hybrid) and driving range of the vehicle (more or less than 50 kilometers). Some Canadian provinces provide separate incentive programs that offer additional rebates to EV purchasers. China, South Korea, Japan, Australia and New Zealand, and parts of the European Union have similar programs but with their own requirements and incentives.

Enforceable fuel economy standards are also modeled regionally in our projections. Many of the regions listed above have enforced stricter fuel economy standards. Stricter standards result in increased ICE vehicle efficiency but also result in higher ICE vehicle purchase price, reducing the ICE vehicle sales share in favor of EVs. Over time, these standards plateau, but their impact on adopting efficiency-improving technologies is long term.

The combination of incentive policies and stricter fuel economy standards increases EV sales, which produces a feedback loop through our learning algorithm that drives down battery costs and results in greater EV adoption in the long term. We base projected battery cost declines on the historical relationship between production costs and cumulative production, modeled using a learning rate.

We can estimate whether EVs reach cost parity with ICE vehicles within our projection window using several factors, including:

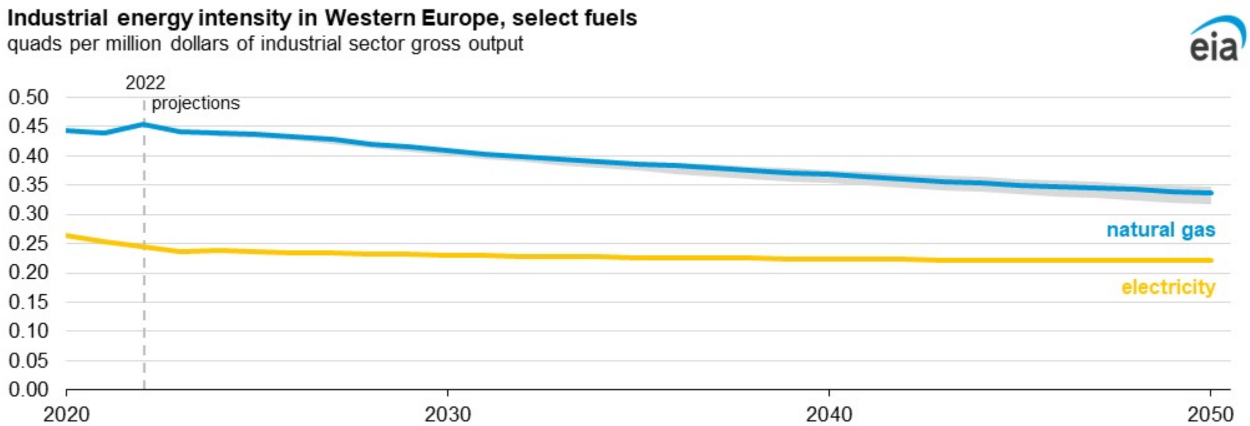
- Enacted and enforceable regional purchase incentives
- Enacted and enforceable fuel economy standards
- Declining battery costs
- Favorable electricity and gasoline prices modeled in our projection

You can find more details in our model documentation.

Energy security and decarbonization policies in the buildings and industrial sectors of Western Europe slow natural gas consumption growth, accelerating the use of electricity

Current European Union policies aim to decrease carbon intensity and to limit imports of fossil fuels from Russia, driving electrification and decarbonization in the industrial, buildings, and district heat sectors. In the industrial sector, stricter efficiency policies lead to declining energy intensity. Total industrial energy intensity across all fuels in Western Europe decreases by 18% to 20% from 2022 to 2050 across all cases (Figure 13).

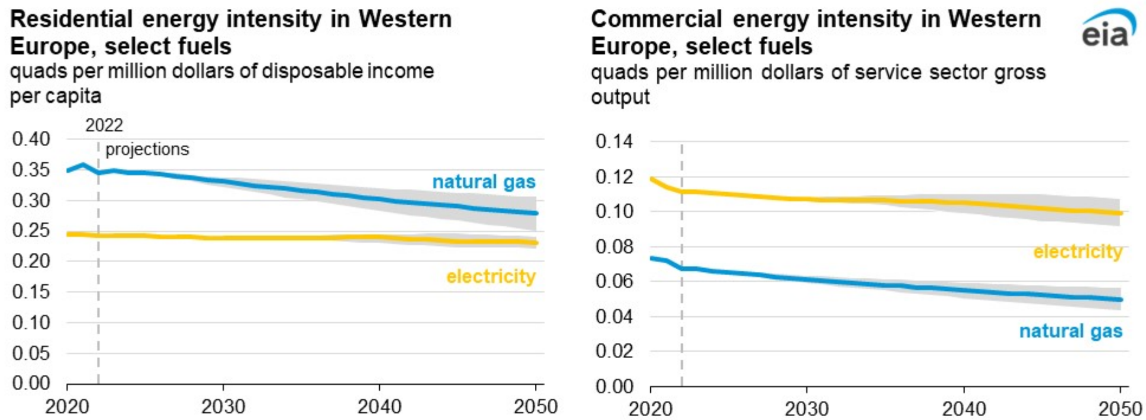
Figure 13.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Each line represents IEO2023 Reference case projections. Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and Economic Growth side cases. The industrial intensity of electricity use rounds to approximately the same value through the projection period across all cases. Quads=quadrillion British thermal units.

In Western Europe, industrial, residential, and commercial energy consumption grows more slowly than economic indicators of sector growth. For example, energy consumption in homes in Western Europe grows more slowly than disposable incomes. Across the IEO2023 Reference case and Economic Growth cases, which are our bounding cases for both economic output and energy use, the amount of energy consumed per dollar of output in the commercial and industrial sectors declines faster for natural gas than for electricity. Although this effect is most pronounced for the industrial sector, the intensity of natural gas use in buildings (particularly residential buildings) declines more rapidly than the intensity of electricity use in buildings (Figure 14). This difference is, in part, due to policies prioritizing the use of electricity over other energy sources in the region.

Figure 14.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Each line represents IEO2023 Reference case projections. Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and Economic Growth side cases. Quads=quadrillion British thermal units.

Buildings accounted for 47% of natural gas consumption in Western Europe and 61% of the region's electricity consumption in 2022, a share we project to decline slightly over time as electricity use for transportation increases through 2050. Buildings' share of electricity use in Western Europe declines fastest in the IEO2023 High Economic Growth case—down to 56% by 2050—as increasing incomes support faster adoption of electric vehicles (EVs). With a greater number of EVs on the road, we project that the transportation sector will have a larger share of the electricity used in end-use sectors.

Despite faster growth in electricity use in the transportation sector, buildings continue to make up over one-half of Western Europe's electricity consumption across all cases, in part because European countries have enacted laws and incentives to slow growth in natural gas consumption. However, stable natural gas prices contribute to the slight decline to modest growth in natural gas consumption in all end-use sectors combined over the projection period, ranging from a decline of 3% to an increase of 19% from 2022 to 2050 across all cases.

> In Western Europe, electricity use in buildings grows as much as five times as quickly as natural gas consumption through 2050 because of near-term policies enacted to reduce the natural gas imported from Russia.

In Western Europe, electricity use in buildings grows three to five times as quickly as natural gas consumption through 2050 across all cases because of near-term policies enacted to reduce natural gas imported from Russia. In the winter of 2022, many Western European countries implemented laws and incentives to reduce natural gas consumption in homes, in commercial buildings, and in the industrial sector. In addition, countries developed enhanced building energy codes and the made funds available to complete energy retrofits, intended to support the EU's ability to meet energy efficiency targets through 2030. Policymakers design these measures to shape long-term behavioral change, to ensure that efficiency tempers expanding energy demand, and to prioritize carbon-neutral energy sources. One example is government-sponsored subsidies for installing energy efficient and non-fossil fuel equipment, such as an incentive in France to offset the cost of heat pumps. Such programs provide incentives to purchase electric technologies over natural gas equipment as consumers replace or purchase new heating and cooling systems.

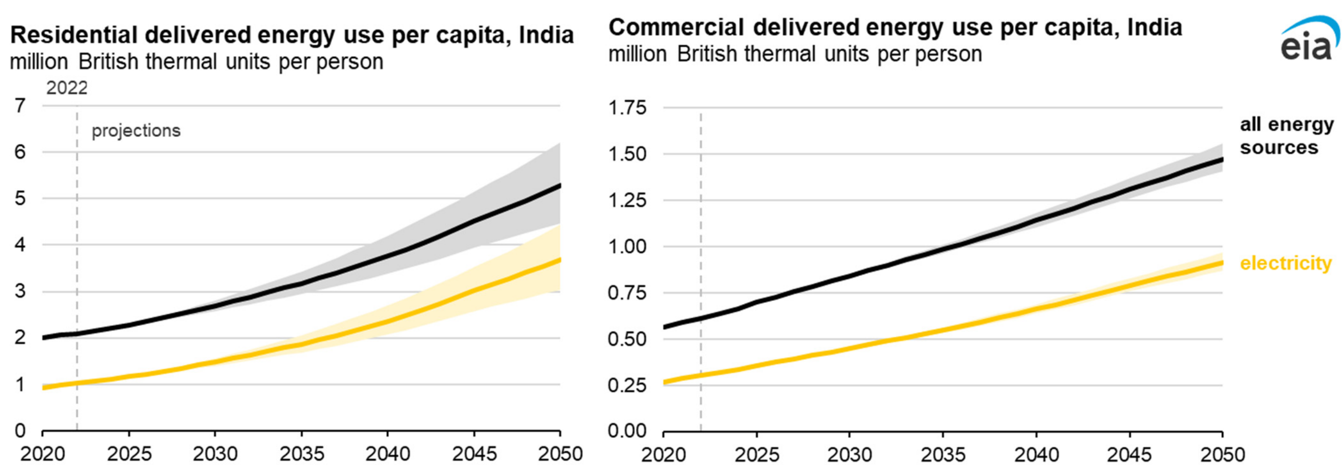
For centralized district heat plants—which provide space and water heating in residential and commercial buildings and process heat and steam for the industrial sector—we project that generation resources will increasingly shift to renewable sources through 2030. Across all cases, biomass-fired heat displaces natural gas and coal consumption for district heating as EU member countries conform with the district heating provisions of the Renewable Energy Directive.

Across all cases, in 2050, biomass accounts for 29% to 38% of heat generation that meets industrial sector demand for heat and steam in Western Europe, excluding the share of heat generated from combined-heat-and-power (CHP) or cogeneration sources, which generate both electricity and useable heat. Accounting for fuel use by CHP sources, we project renewable sources, including biomass, to account for 23% to 25% of heat generated for all sectors in district energy networks in 2050 across cases.

As India's economy expands, building electrification supports a rapidly expanding service sector; home energy use triples

Our projection for energy consumption in India exemplifies the relationship among energy consumption, income, and service sector growth. Increases in disposable income and rapid population growth lead to significant increases in residential energy use, which triples over the projection period. Commercial energy consumption increases as the sector expands to meet growing demand for services. This contributes to increases in buildings' energy consumption overall, which almost triples by 2050 relative to 2022 across all IEO2023 cases (Figure 15). Electrification of the building stock supports broader electricity use, which increases more than any other energy source in the residential and commercial sectors.

Figure 15.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Each line represents IEO2023 Reference case projections. Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases. Ref=Reference case.

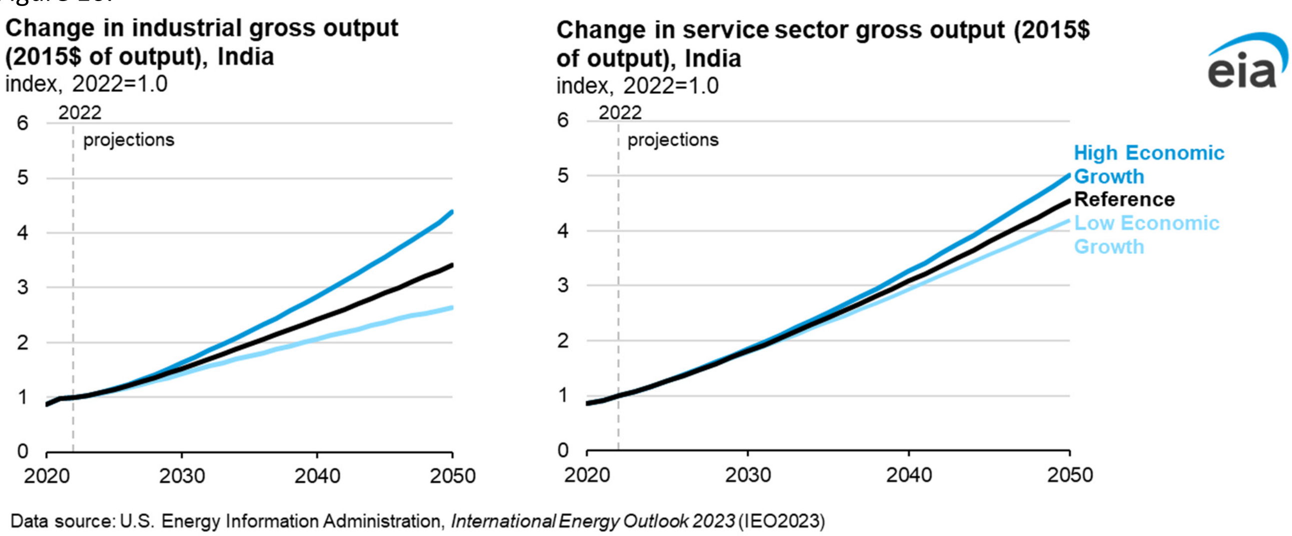
In India, in the High Economic Growth case, electricity use in buildings grows nearly five times 2022 levels by 2050 as total building energy consumption triples over the same period. Even in the Low Economic Growth case, commercial energy consumption more than doubles by 2050, led by business expansions and increases in warehousing and retail sales, education, and other services. Across all cases, after 2035, commercial and residential electricity use grows even faster as average electricity prices for all consumers decline through 2050.

Population growth increases building energy consumption in India. On a per capita basis, total delivered energy consumption more than doubles from 2022 to 2050 in the commercial sector and increases by two to three times in Indian homes across our range of cases.

In India, electricity use in buildings in the residential sector grows faster than in other sectors because of increased demand for air conditioning, electric appliances, and other devices. Disposable income grows faster in India than anywhere else in the world, increasing, on average, 3% to 5% annually. Compared with 2022, we project that even in the Low Economic Growth case, with incomes growing more slowly than in our Reference case, each person in India will use nearly three times as much residential electricity, on average by 2050.

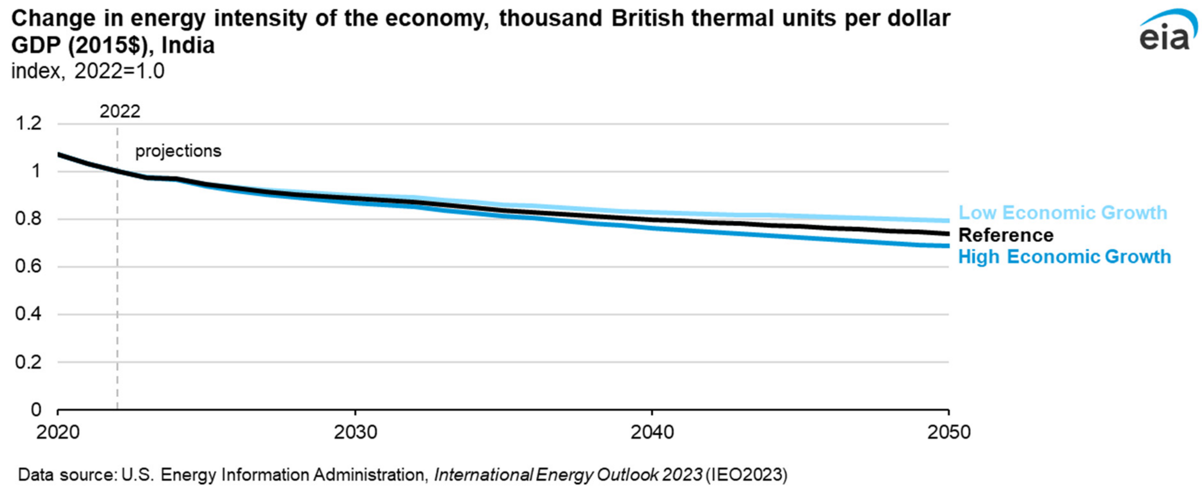
In the High Economic Growth case, by 2050, India's energy consumption across all end-use sectors more than triples relative to 2022. Growth in the commercial sector outpaces overall industrial growth from 2022 to 2050 (Figure 16).

Figure 16.



India transitions to a service-oriented economy slightly faster in the High Economic Growth case, reducing the overall energy intensity of the economy relative to the Reference case. This outcome occurs not only because the economy grows faster than energy consumption in the High Economic Growth case, but also because the commercial sector is less energy intensive than the industrial sector. Economy wide, the energy intensity of consumption in India declines to 2.61 thousand British thermal units (Btu) per dollar of GDP (2015 PPP USD) in the High Economic Growth case, reaching the lowest energy intensity in India in any IEO2023 case (Figure 17).

Figure 17.



Declining energy intensity in the industrial sector results from increasing efficiency in the manufacturing subsector, increased recycling in the primary metals industries, and continued advances in energy-efficient technologies

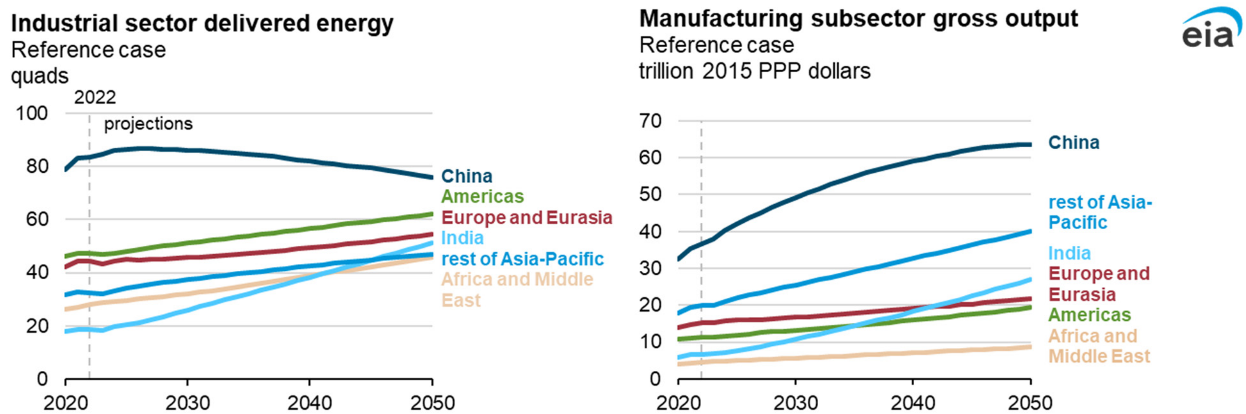
Global energy consumption in the industrial sector—which includes both manufacturing and non-manufacturing (construction, agriculture, and mining) industries—varies widely across cases. As industrial gross output grows, energy consumption increases between 9% and 63% by 2050, from 257 quadrillion British thermal units (quads) in 2022. Growth in industrial energy consumption varies across regions, with the fastest growth in India and three of our multi-country regions—Africa, Other Asia-Pacific, and Other Americas (Figure 18). Much of the growth in these regions' industrial sectors occurs in the manufacturing subsector, especially in energy-intensive industries such as primary metals, chemicals, and non-metallic minerals. China is the region with the largest decline in industrial sector energy consumption, despite its overall increasing industrial gross output, partially because of a shift in growth to less energy-intensive industries and realized energy efficiency improvements in its primary metals industry.

> Although growth in industrial energy consumption varies across regions, industrial energy intensity declines globally through 2050, in part, because of increases in efficiency.

Over time, as GDP per capita increases, economic activity is reallocated across sectors in a systematic way. Generally, agriculture's share of gross output, value added, and employment declines, and the service sector's share increases. Initially, manufacturing's share of gross output, value added, and employment grows but eventually peaks at intermediate stages of economic development. This process produces changes in sector composition that are reflected in the energy intensity of each region.

Industrial energy intensity—measured as the ratio of industrial energy consumption to output (dollar value of shipments)—declines globally from 2022 to 2050, in part, because of increases in efficiency. Industrial energy intensity also varies by region because of differences in the pace of energy efficiency advancements, specific activities within each subsector, and the evolution of the sector composition. Changes to industrial technologies and the composition across regions reflect our current understanding of national and regional policies, supply chains, and commercially viable technology. We don't include revolutionary technological breakthroughs or policies that are not codified and enforceable.

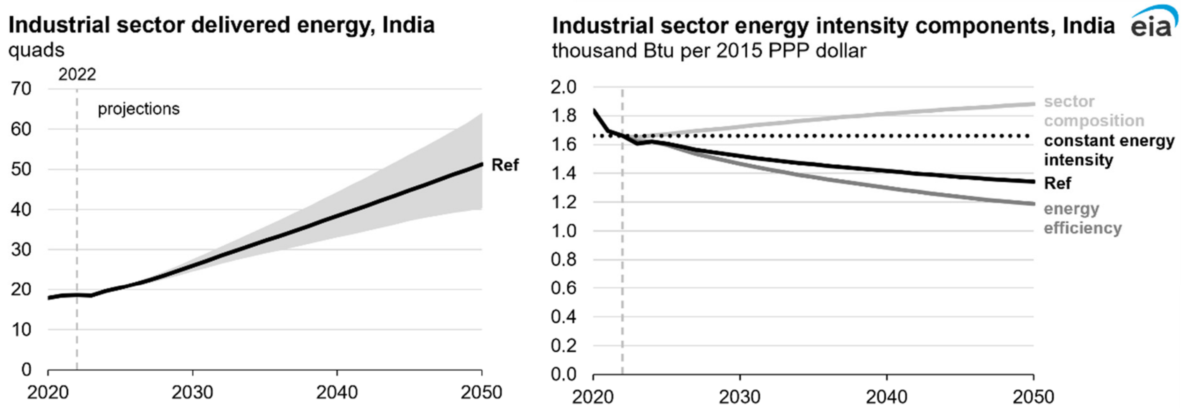
Figure 18.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Quads=quadrillion British thermal units; PPP=purchasing power parity.

India is the fastest-growing region in terms of GDP and GDP per capita across all cases. The country's manufacturing subsector grows from $6.7 trillion (2015 PPP USD) in 2022 to a range of $20.9 trillion (2015 PPP USD) in the Low Economic Growth Case to $34.7 trillion (2015 PPP USD) in the High Economic Growth Case. As a result, industrial energy consumption in India increases from 18.6 quads in 2022 to a range from 40.2 quads in the Low Economic Growth case to 64.1 quads in the High Economic Growth case in 2050 (Figure 19). Growth in the manufacturing sector outpaces other sectors and, as a result, grows as a share of total industrial gross output in all the IEO cases. We project India's manufacturing activity, a relatively energy-intensive subsector, to grow from 60% of the country's total industrial gross output (as measured in 2015 PPP USD) in 2022 to 71% of total industrial gross output in 2050 across all side cases.

Figure 19

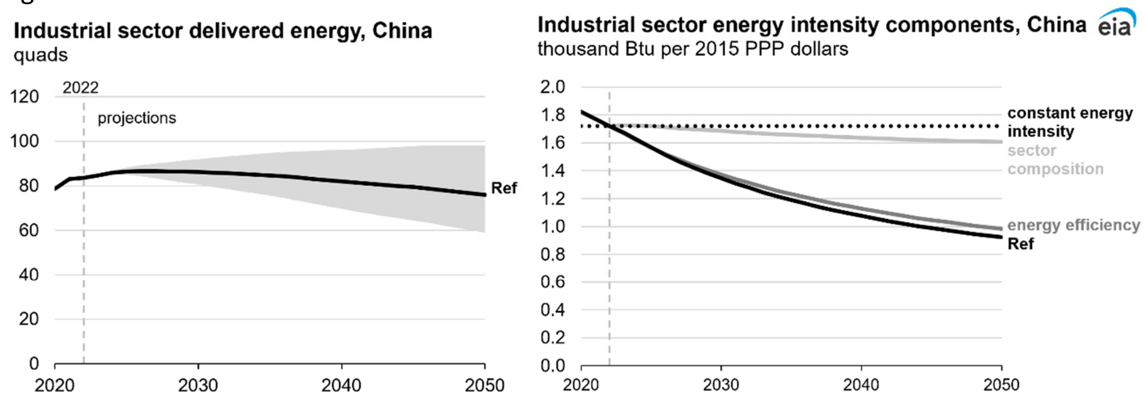


Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases. The *constant energy intensity* line shows industrial energy intensity fixed at 2022 levels. The *sector composition* line shows changes in aggregate industrial energy intensity caused only by changes in industrial sector composition while holding sector-level energy intensities constant at 2022 levels. The *energy efficiency* line shows changes in aggregate industrial energy intensity caused only by changes in sector-level energy intensities while holding sector composition constant at 2022 levels. Ref=Reference case; Quads=quadrillion British thermal units; Btu=British thermal units; PPP=purchasing power parity.

Figure 19 shows India's industrial energy intensity and how changes in sector composition and energy efficiency affect it. Technology and efficiency developments reduce energy use, while changes in India's industrial sectoral composition drive additional energy consumption. The net effect is a decline in industrial energy intensity in India.

In contrast to India, China's industrial energy consumption declines in all cases except the High Economic Growth case (Figure 20). Energy consumption decreases partly because many of the industries in China increase energy efficiency by implementing more recycling and technology advancements. Although we project energy-intensive manufacturing declines as a share of China's industrial activity, this sectoral shift only mildly contributes to the overall decline in industrial energy consumption. Overall, manufacturing gross output—when measured in 2015 PPP USD—made up 49% of all gross output in China in 2022, but it decreases in our projection to 41% in 2050 in all IEO2023 side cases.

Figure 20.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases. The *constant energy intensity* line shows industrial energy intensity fixed at 2022 levels. The *sector composition* line shows changes in aggregate industrial energy intensity caused only by changes in industrial sector composition while holding sector-level energy intensities constant at 2022 levels. The *energy efficiency* line shows changes in aggregate industrial energy intensity caused only by changes in sector-level energy intensities while holding sector composition constant at 2022 levels. Ref=Reference case; Quads=quadrillion British thermal units; Btu=British thermal units; PPP=purchasing power parity.

The different trajectories of industrial energy consumption in China and India are also motivated by their primary metals industry, which is made up of steel—the top energy consumer of the primary metals industry—and non-ferrous metals, such as aluminum. In aggregate, the two countries' primary metals industries contributed about 6% of total global emissions in 2022. In China, unlike India, we project that the gross output of the iron and steel industry will decline over the long term, and the country could significantly increase production of recycled steel, which is significantly less energy intensive.[6] We assume steel produced by the more energy-intensive coal-based basic oxygen furnace process declines to 40% for all cases by 2050, down from 88% in 2022. For the Reference case, this change will reduce steel industry coal demand in 2050 by 71% relative to 2022. China's steel industry gross output falls by 25% over the same period in the Reference case, with 2050 steel industry gross output ranging from $0.9 trillion (2015 PPP USD) in the Low Economic Growth case to $1.7 trillion (2015 PPP USD) in the High Economic Growth case (Figure 21).

Due to this change in steel production processes in China, coal consumption by its steel industry ranges from 4.0 quads in the Low Economic Growth case to 7.8 quads in the High Economic Growth case in 2050. This decline in metallurgical coal consumption decreases domestic coal production by a range of 38% to 94% across cases. This decrease affects coal imports, which vary from a 65% decrease to a 4% increase across cases compared with 2022. Coal production in China declines faster than coal imports because of higher costs for mining and transporting domestically sourced coal, continuing the country's need for imports from regions such as Australia and Russia.

[6] For more details on steelmaking processes, see *IEO2021 Issues in Focus: Energy Implications of Potential Iron- and Steel-Sector Decarbonization Pathways*.

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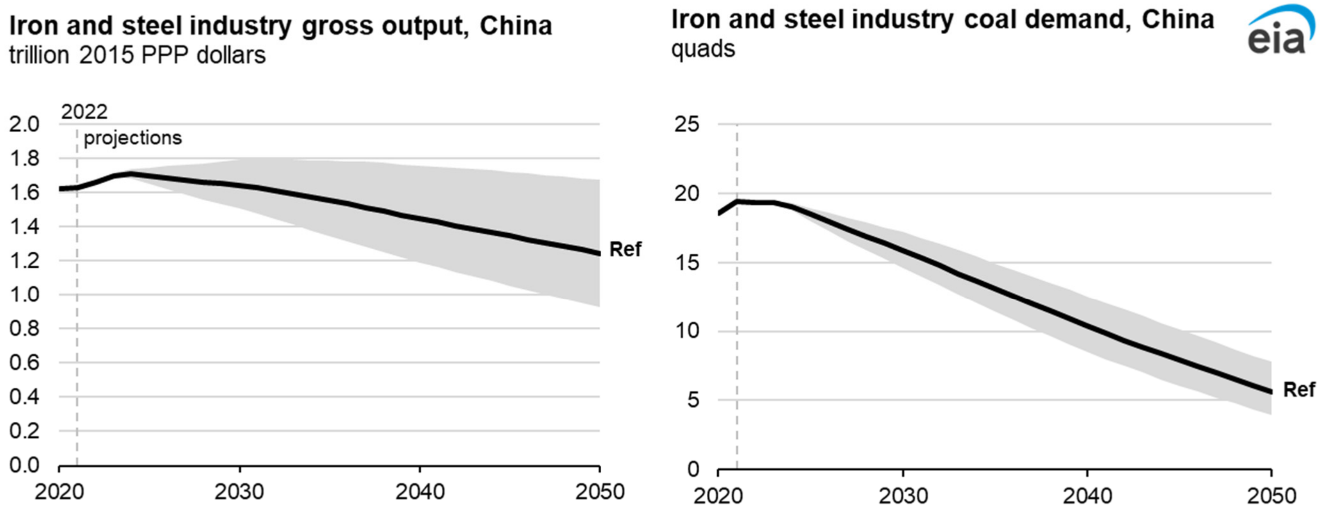
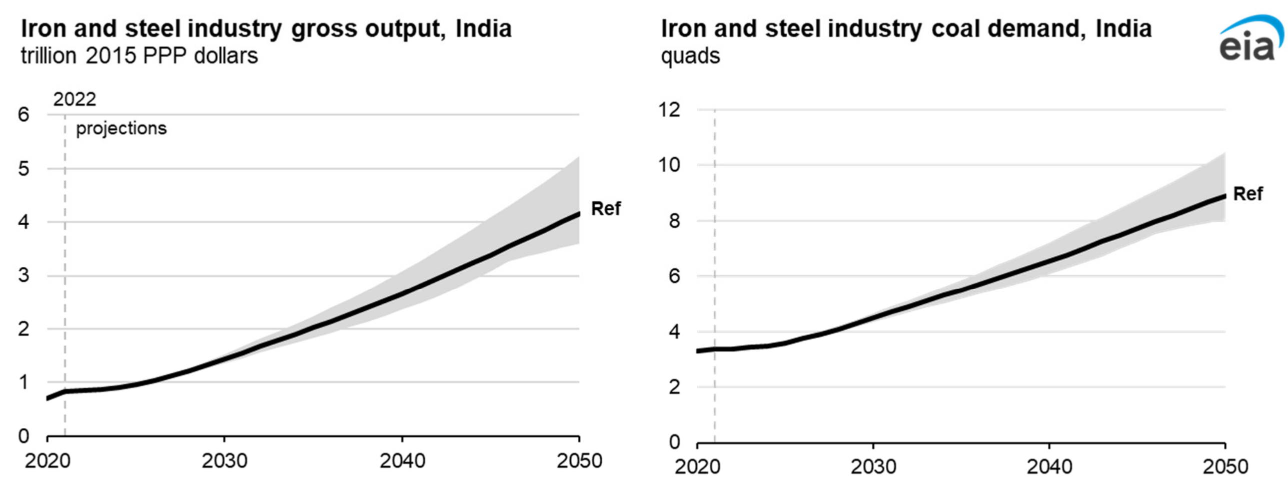
Figure 21.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases.
Quads=quadrillion British thermal units; PPP=purchasing power parity. Ref=Reference case.

Although India faces similar coal production challenges as China, the growing coal demand in India increases domestic coal production through 2050 (Figure 22). The increasing coal demand is driven by the increasing gross output and the industry's unique and heavy reliance on coal to make iron ore using direct reduced iron (DRI). From 2022 to 2050, India's metallurgical coal production increases by 10% to 28%, and coal imports increase by 120%–202% across cases. India receives imports from regions such as Australia and Africa, and potentially Canada and the United States, as demand for metallurgical coal rises.

Figure 22.

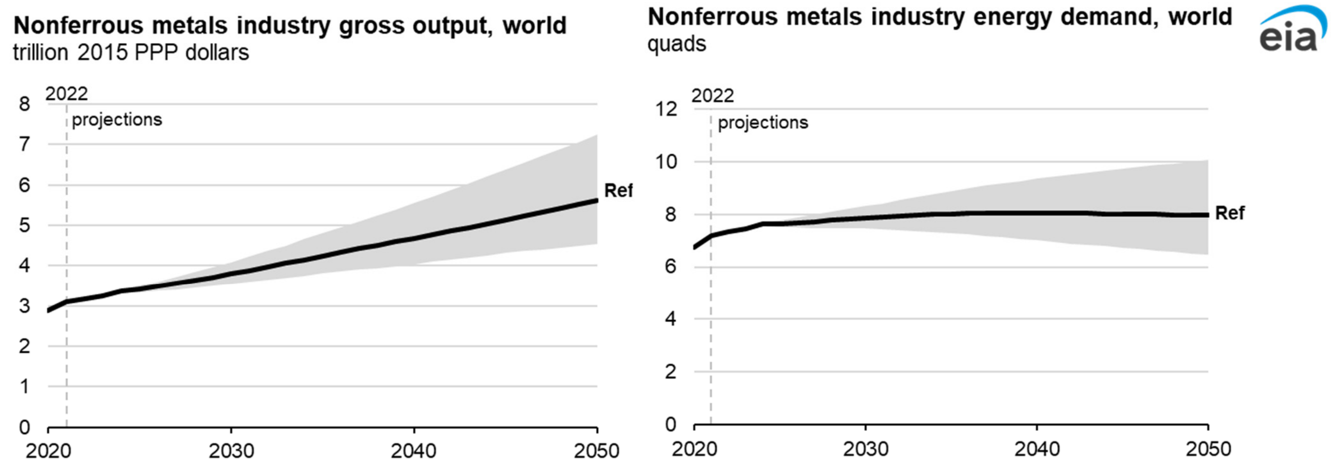


Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases.
Quads=quadrillion British thermal units; PPP=purchasing power parity; Ref=Reference case.

In addition to the iron and steel industry, energy efficiency increases in the aluminum industry (the largest component of the nonferrous metals industry) mostly as a result of the switch from primary to secondary aluminum production. Secondary aluminum is made by remelting recycled aluminum or scrap from production. Globally, we project the aluminum industry will grow by approximately 76% from 2022 to 2050 in the Reference case, while the aluminum industry's energy demand will rise by only 9% (Figure 23). The High and Low Economic Growth cases project different futures for the aluminum industry. Gross output reaches \$7.3 trillion (2015 PPP USD), and energy demand reaches 10 quads in 2050 in the High Economic Growth case. Gross output reaches \$4.5 trillion (2015 PPP USD), and energy demand reaches 6.5 quads in 2050 in the Low Economic Growth case.

Production of secondary aluminum, which requires about 90% to 95% less energy than primary aluminum, contributes to the decline of energy demand growth relative to the industry's gross output.

Figure 23.



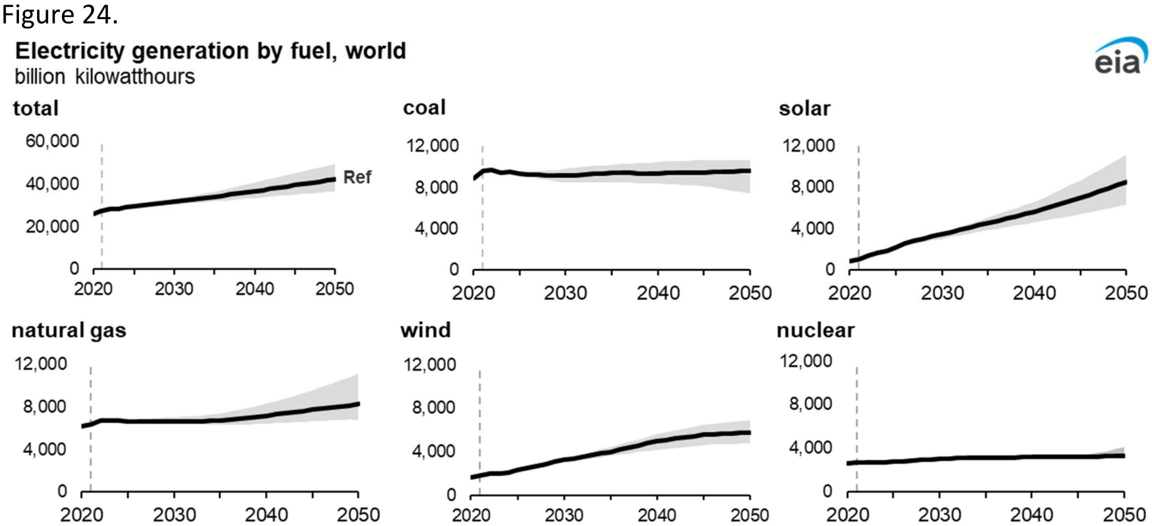
Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases. The nonferrous metals industry includes all metals in the industrial sector other than iron and steel—including aluminum (which comprises the majority of energy consumed in this industry) as well as copper, zinc, and tin. Quads=quadrillion British thermal; PPP=purchasing power parity; Ref=Reference case.

2

The shift to renewables to meet growing electricity demand is driven by regional resources, technology costs, and policy.

We project electricity generation worldwide will increase 30% to 76% in 2050 relative to 2022 across all cases (Figure 24). By 2050, zero-carbon generating technologies—renewables and nuclear—supply electricity for 54% to 67% of the total demand across cases. Across most years, the Low Zero-Carbon Technology Cost (ZTC) case projects the most wind and solar generation across the globe. This case assumes a more rapid capital cost decline than in the Reference case for a subset of zero-carbon technologies, including storage (Appendix A). Other cases, such as the High Economic Growth case, also show significant growth in renewable generation, suggesting that the cost competitiveness of renewables is more prominent when serving higher incremental demand. The rest of the demand is mainly met by coal and natural gas.

Figure 24.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases. Ref=Reference case.

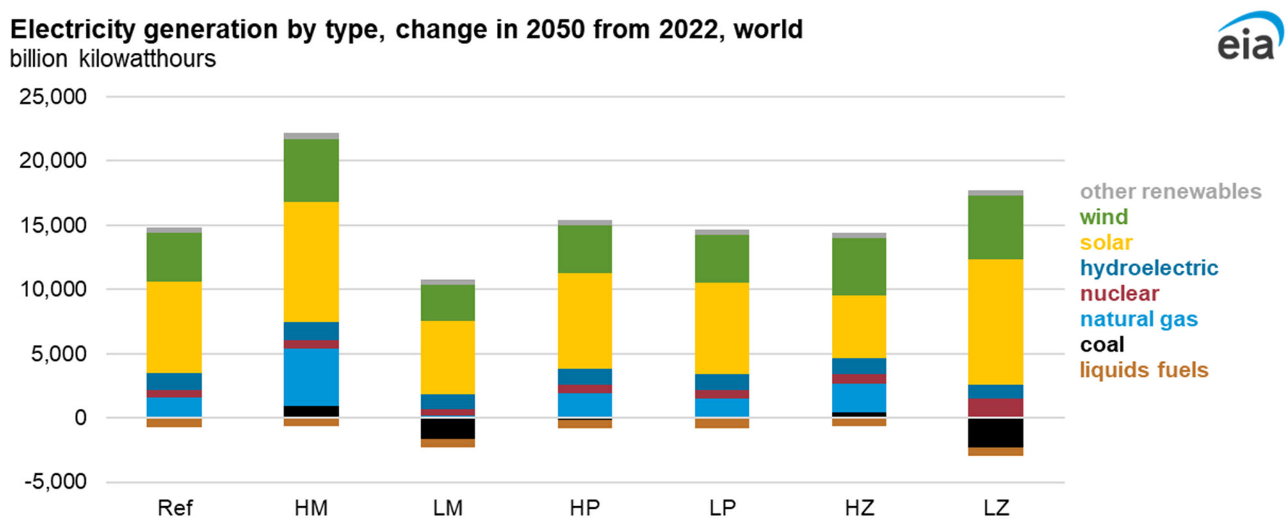
Coal-fired generation varies across cases in 2050, from declining 24% to increasing 10% from 2022 levels. The upper bound for coal occurred in the High Economic Growth case, where the economy is assumed to grow more rapidly compared with the Reference case and more generation is needed from all generating resources. The lower bound for coal generation occurred in the Low Economic Growth case until the mid-2040s and in the Low ZTC case thereafter. In the Low Economic Growth case, where electricity demand is lower, less coal generation is needed to meet demand. In the Low ZTC case, higher generation from zero-carbon technology displaces coal generation.

By 2050, growth in global natural gas-fired generation ranges from 1% to 66% relative to 2022. The upper bound in natural gas-fired generation occurred in the High Oil Price case in the early part of the projection period, but in the High Economic Growth case over the later portion of the projection period. This range indicates the potential effect of high economic growth and the regions' continual use of existing facilities. Multiple cases determine the lower bound of natural gas, depending on the projection period. Natural gas-fired generation is lowest in the Low ZTC case around 2050; in most of the 2030s and 2040s however, natural-gas fired generation is lowest in the Low Economic Growth case.

New global electricity demand is primarily met by non-fossil fuel sources

By 2050, global coal-fired generation and liquid fuel-fired generation decrease in most of the cases we modeled. Generation from zero-carbon technologies—primarily solar, wind, hydroelectric, and nuclear—grows faster than electricity demand in some cases, and accounts for 78% to 120% of the incremental global electricity demand from 2022 across cases, displacing existing fossil generation in some cases (Figure 25). Additional natural gas largely meets the rest of the new electricity demand across cases.

Figure 25.



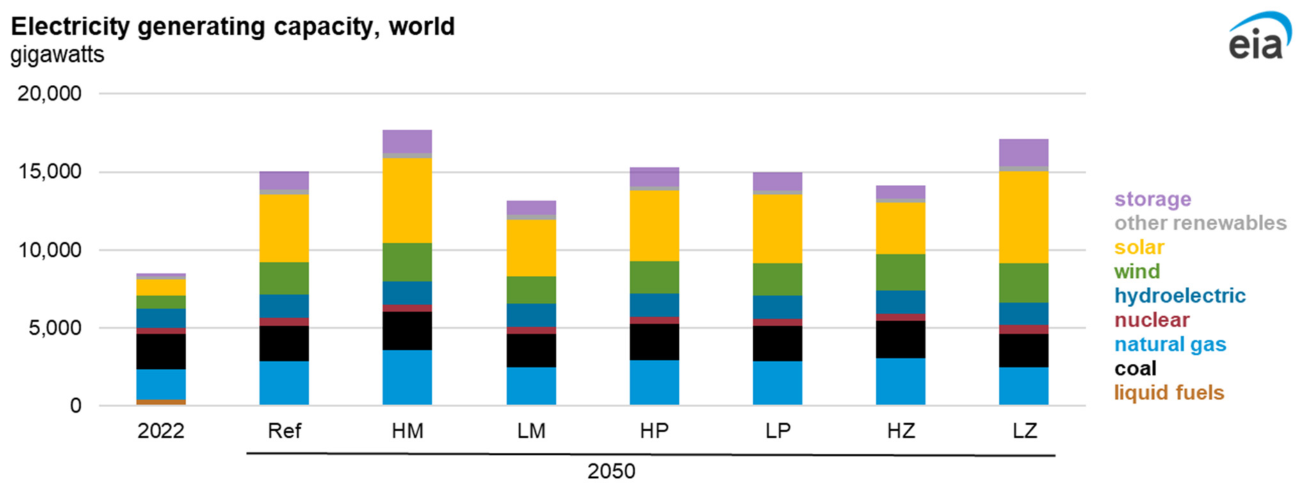
Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Ref=Reference case; HM=High Economic Growth; LM=Low Economic Growth; HP=High Oil Price; LP=Low Oil Price; HZ=High Zero-Carbon Technology Cost; LZ=Low Zero-Carbon Technology Cost.

To meet increased global electricity demand, installed power capacity increases and, by 2050, reaches a total of about one-and-a-half to two times what it was in 2022 (Figure 26). In 2022, coal, natural gas, and liquid fuels combined made up more than one-half of the world electricity generation capacity. Zero-carbon technologies (including storage) make up 81% to 95% of the new global generating capacity installed across cases from 2022 to 2050. In each region, zero-carbon technologies make up most new electric generating capacity installed except Russia and our "Eastern Europe and Eurasia" region. So, by 2050, the combined share of coal, natural gas, and liquid fuels decreases to 27% to 38% of the world's generating capacity across cases.

Among the zero-carbon technologies, solar photovoltaic capacity is projected to grow the most through 2050.

Across cases, the 4,600 gigawatts (GW) to 9,200 GW of generating capacity installed by 2050 is predominantly solar, wind, and storage. Nuclear capacity is stable in most cases except the Low ZTC case, where we eased noneconomic constraints (that is, geopolitical considerations) to explore the economic effects on nuclear builds (Appendix A). In this case, nuclear capacity increases by 194 GW in 2050 relative to the 2022 capacity of 400 GW.

Figure 26.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Ref=Reference case; HM=High Economic Growth; LM=Low Economic Growth; HP=High Oil Price; LP=Low Oil Price; HZ=High Zero-Carbon Technology Cost; LZ=Low Zero-Carbon Technology Cost.

Current policies, demand growth, and energy security considerations in each region determine when zero-carbon technologies grow

In China, zero-carbon technology capacity increases faster early in the projection period but slows closer to 2050 (Figure 27). Western Europe follows a similar trend of a rapid capacity increase early on in all cases and then slower growth rates across most cases toward the end of the projection period. Policy, energy security concerns, and rapid demand growth early in the projection period drive near-term deployment of zero-carbon technology capacity in these two regions. For China, we include 5% annual growth in carbon price because most thermal power plants in the region are currently included in

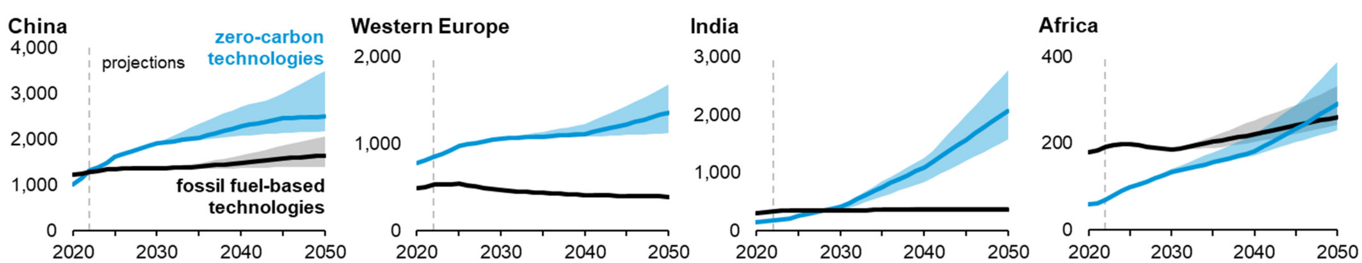
China's emissions trading scheme (ETS). Europe's CO_2 emissions limit is included in the electric power sector projection. Energy security considerations favoring locally available resources—such as wind and solar—further increase installations and planned builds for these technologies as well as batteries in China and Western Europe early in the projection period. We project China will install between 54% and 87% of its 2050 zero-carbon technology capacity across all cases before 2030, and Western Europe will install between 63% and 95% of its 2050 zero-carbon technology capacity over the same period.

Several other regions, including India and Africa, show rapid growth in zero-carbon technology after 2030. In India, this later growth is heavily influenced by assumptions of economic growth, with the growth in these technologies in India across IEO2023 cases bounded by the High and Low Economic growth cases in most years. In Africa, the upper range of zero-carbon technology capacity occurs in the High Economic Growth or Low ZTC case, depending on the projection period, while the lower range occurs in the Low Economic Growth or High ZTC cases. Across all cases, we project India will install between 79% and 84% of its zero-carbon technology capacity after 2030, and Africa will install between 42% and 65% of its zero-carbon technology capacity after 2030. In general, we expect a smaller range of zero-carbon technology capacity growth in more developed countries and regions (for example, in Western Europe) because of the smaller variations in growth rates assumed in our High and Low Economic Growth cases for developed versus developing regions (Appendix A).

IEO2023 cases model policies that are enacted legislation and can be reasonably modeled. Other unmodeled or future policies might affect the timing of zero-carbon technology adoption.

Figure 27.

Electricity-generating capacity, zero-carbon and fossil fuel-based technologies, select regions
gigawatts



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Each line represents IEO2023 Reference case projections. Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases.

Regionally, battery storage installation correlates with high variable renewable capacity—particularly solar

Electricity storage, particularly batteries, is used to store excess power produced by variable generating sources—such as wind and solar—during off-peak hours and to dispatch the stored energy during times when demand is higher. Battery storage grows significantly in all cases. In 2022, battery storage capacity was 52 GW, less than 1% of global power capacity. By 2050, we project that battery storage capacity will increase to between 625 GW and 1,507 GW across cases, making up 4% to 9% of global power capacity.

Use of battery storage differs regionally. In India, the high share of battery storage capacity coupled with low dispatchable capacity results in battery storage dispatch meeting 24% of electricity demand by 2050 in the Reference case.

Technical Note 2: Storage technology representation

IREStore is a complementary module to the International Electricity Market Module (IEMM). IREStore enhances capacity expansion and utilization decisions for variable renewable and electricity storage technologies using higher temporal resolution. IREStore divides the year into 288 representative time slices instead of the 12 time slices per year used in the IEMM.

We model two types of storage technologies in IEMM and IREStore:

- Four-hour diurnal batteries connected to the grid
- Six-hour pumped-storage hydropower

Although electricity storage can play several different roles on the grid, the primary use represented in IREStore and IEMM is for energy arbitrage. That is, the model will store energy when it is cheap, such as when solar energy would otherwise be curtailed, and dispatch from storage technologies when energy is more expensive, such as during periods of peak demand.

In general, our model results indicate that solar, more than wind or other resources, tends to pair well with storage. Solar arbitrage opportunities are very regular and predictable, making it relatively easy to size both the power and energy capacity of a storage system for efficient use, compared with wind energy, which has more irregular generation patterns.

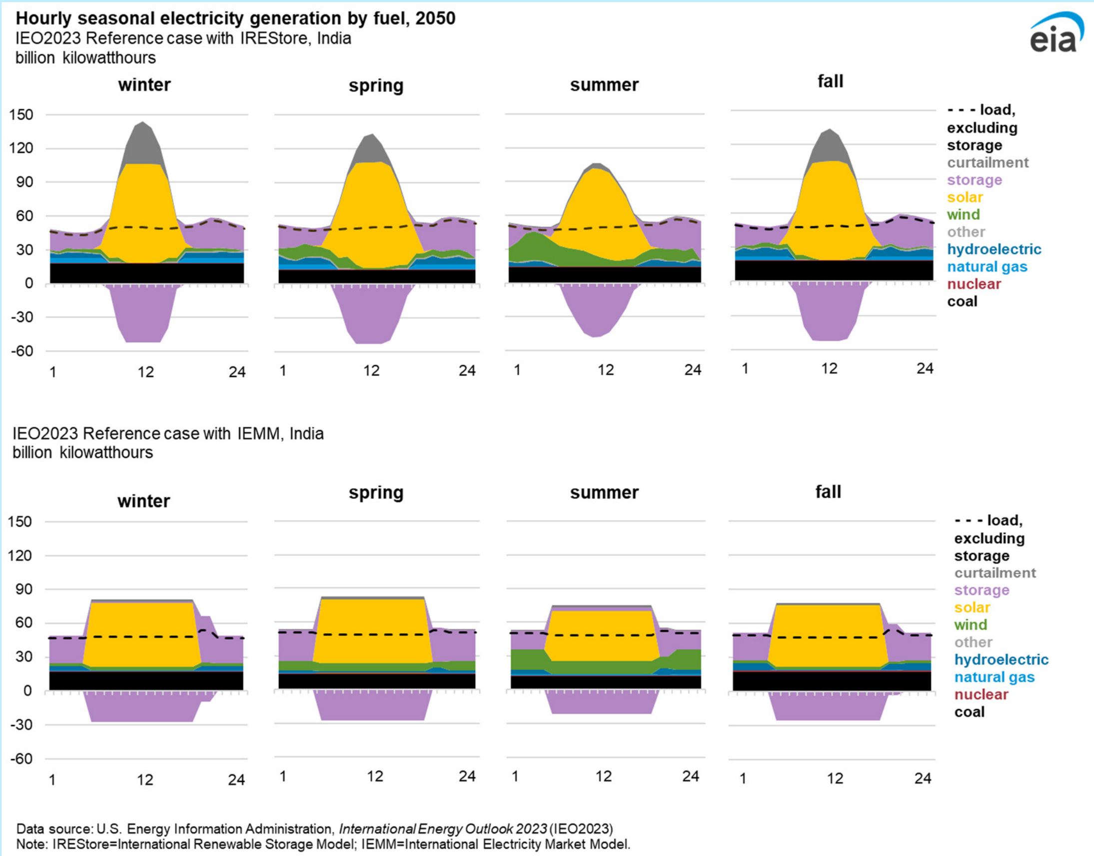
Inside IREStore and IEMM, battery storage has 85% efficiency, meaning that 15% of the energy is lost during the charging and discharging process. At maximum discharging rates, it takes four hours for a battery to fully discharge itself. Pumped-storage hydropower has 80% storage efficiency, meaning that 20% of the energy is lost during charging (pumping water into its reservoir) and discharging (hydropower generation using released water from its reservoir). When the water reservoir is completely full, it can run for six hours before emptying. Either energy-storage type may run longer at a reduced output level. For example, a four-hour battery could operate for eight hours at half of the maximum rated output, or two such batteries could operate at full output for eight hours.

Using the simplified 12 time-slice representation in IEMM, the model tends to underestimate the opportunities for energy arbitrage when solar capacity is just starting to grow and overestimate these opportunities at very high levels of solar penetration. IREStore addresses this shortcoming by allowing energy arbitrage with a much higher temporal resolution.

Figure 28 shows how IREStore models electricity generation and storage in India in 2050 across four seasons.

India's hourly load (demand) in each of the four seasons is similar, although the amount of curtailed energy varies with the seasonal variation in solar output. Curtailed energy is the lowest during the summer due to lower solar energy potential during India's summer monsoon season. The model arbitrages the otherwise-curtailed energy during midday hours to provide energy during hours when more expensive fuels are the marginal dispatch resource. Most of the storage (>99%) in the IREStore model for India is battery storage.

Figure 28.

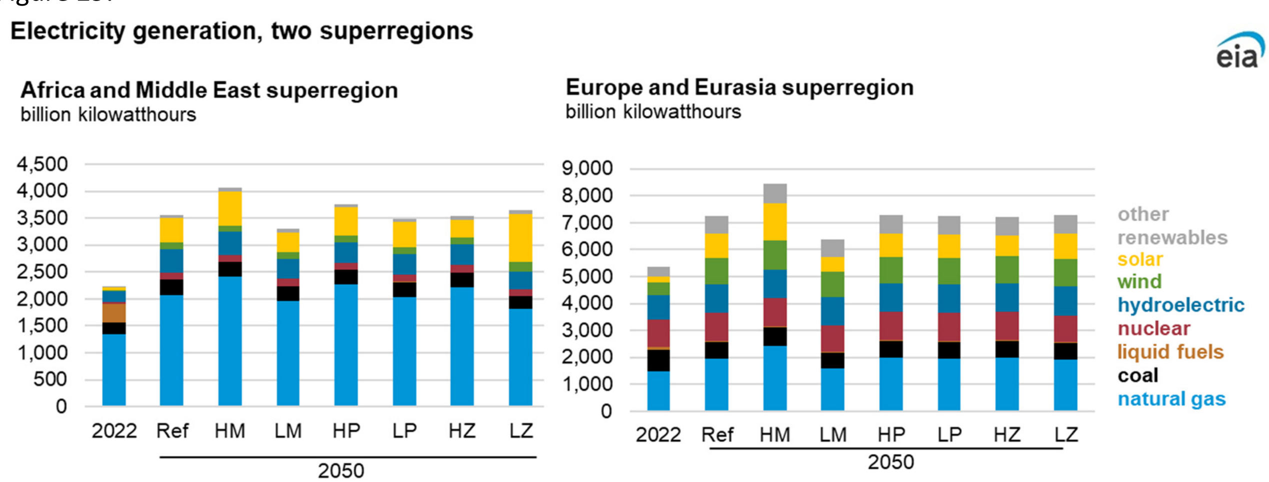


Fossil fuel-fired generation in the Africa and Middle East superregion and Europe and Eurasia superregion remains stable throughout the projection period

Natural gas is an important part of the electricity generation mix in several regions of the world in our projection through 2050. In 2022, natural gas constitutes 61% of the electricity generation share in the Africa and Middle East superregion. By 2050, the natural gas share in this superregion is still close to 60% in almost all cases; it drops to 50% in the Low ZTC case (Figure 29). This result demonstrates the effect of abundant low-cost natural gas in this superregion combined with continued reliance on the existing natural gas generation infrastructure. Other regions, such as Russia and Mexico, also continue to use a significant amount of natural gas for electricity generation.

In the Europe and Eurasia superregion, zero-carbon technology increases by 1,200 billion kilowatthours (BkWh) to 2,300 BkWh across all cases by 2050 to meet new demand. Across all cases, the share of zero-carbon technology in the generation mix increases from 55% in 2022 to between 63% and 65% by 2050. However, the combined generation from natural gas, coal, and liquid fuels of 2,200 BkWh to 2,600 BkWh in 2050 remains stable in all cases (except in the High Economic Growth case, which grows to 3,100 BkWh in 2050) compared with 2,400 BkWh in 2022. Although not as natural gas-dominant as the Africa and Middle East superregion, the Europe and Eurasia superregion continues to have a relatively stable amount of fossil fuel-fired generation, which reflects the continued reliance on the existing capacity mix, the relatively stable demand, and the abundance of natural gas, particularly in Eurasia.

Figure 29.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Ref=Reference; HM=High Economic Growth; LM=Low Economic Growth; HP=High Oil Price; LP=Low Oil Price; HZ=High Zero-Carbon Technology Cost; LZ=Low Zero-Carbon Technology Cost.

Variations in costs of zero-carbon technologies affect the energy mix and emissions most in China and the Other Asia-Pacific region, where coal-fired generation is most prevalent

By 2050, we project worldwide electric-generating capacity for zero-carbon technologies to increase two to three times relative to 2022. The conditions that foster zero-carbon technology capacity installation, however, are not uniform throughout the regions or the projection period.

The assumptions underlying the ZTC cases and the Economic Growth cases particularly affect zero-carbon technology and coal-fired generation within the Asia-Pacific superregion, where electricity demand grows most rapidly and coal is cheap and abundant. China and Other Asia-Pacific, two regions within the Asia-Pacific superregion, show large variations in generation mix and emissions, particularly as it relates to reliance on coal.

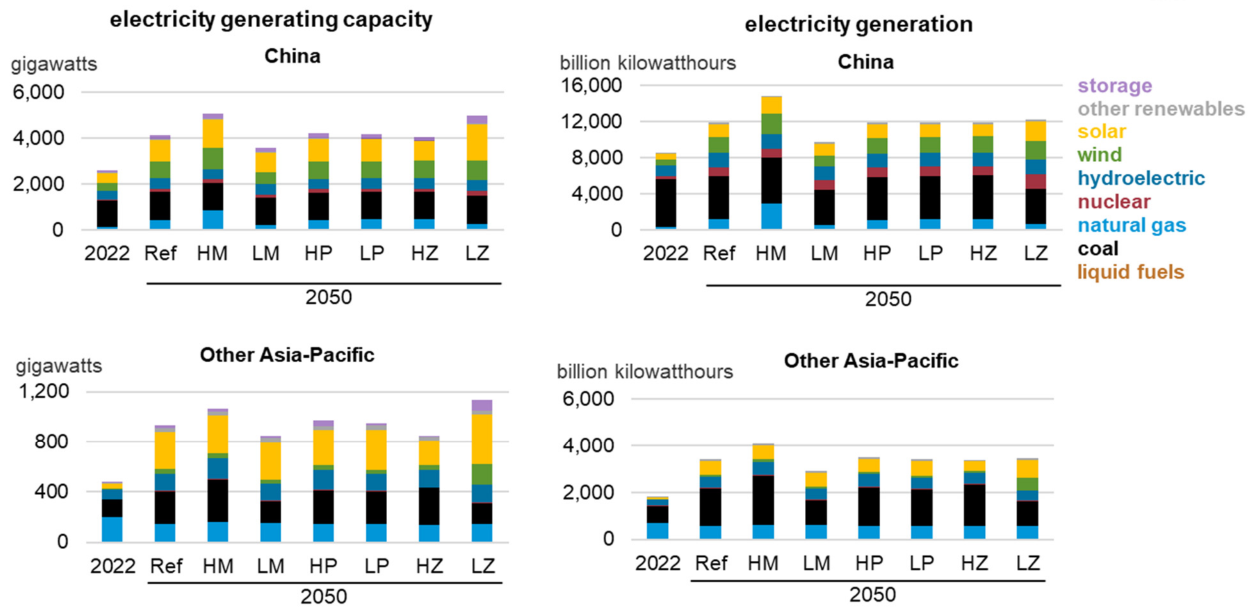
In China, coal-fired generation made up 62% of the electricity generation mix in 2022 and decreases by less than 10% throughout the projection period—from 5,200 BkWh in 2022 to between 4,800 BkWh and 5,100 BkWh in 2050—in all cases except in the Low ZTC and Low Economic Growth cases (Figure 30). In the Low Economic Growth case, coal-fired generation decreases almost 25% to 4,000 BkWh by 2050, but because of the overall decrease in electricity generation due to a decrease in overall demand, coal-fired generation still makes up 41% of the generation mix. In the Low ZTC case, coal-fired generation decreases 27% to 3,800 BkWh, resulting in the lowest share of coal-fired generation (31%) in 2050 among all cases. At the same time, zero-carbon technology generation in China increases from 3,000 BkWh (35% generation share) to 7,700 BkWh (63% generation share) by 2050 in the Low ZTC case. Among the cases modeled, the power generation in China is very sensitive to the cost of zero-carbon technologies, as seen in the Low ZTC case. Impacts of other factors, such as additional policies or potential market disruptions, are not modeled in these cases.

Coal-fired generation in the Other Asia-Pacific region made up 39% of the generation mix in 2022, and we project it to increase from about 700 BkWh in 2022 to between 1,000 BkWh and 2,100 BkWh in 2050 across all cases. In our Reference case, coal-fired generation accounts for 47% of the Other Asia-Pacific region's total generation in 2050 and ranges between 30% and 52% across all cases. By 2050, zero-carbon technology generation in the region accounts for 37% of the generation mix in the Reference case and between 31% to 54% of the generation mix across the other cases. The parameters of the Low ZTC case particularly affect the Other Asia-Pacific region because it is the only case that increases zero-carbon technology generating capacity to over 820 GW (73% of all capacity) and zero-carbon technology generation to over 1,800 BkWh (54% of net generation). In all other cases, in 2050, zero-carbon technology generating capacity does not exceed 570 GW and generation does not exceed 1,400 BkWh. The Low ZTC case is the only IEO case where coal's share of the generation mix decreases to as low as 30% by the end of the projection period.

High coal-fired generation across cases reflects the low cost of coal as a commodity in both China and the Other Asia-Pacific region. With lower zero-carbon technology costs, renewables and nuclear generation become more cost competitive in China and the Other Asia-Pacific region. The sensitivity of China's and the Other Asia-Pacific region's capacity and generation mix to variation in zero-carbon technology cost and economic growth illustrates the impact of cost, existing infrastructure, and demand growth. Policy proposals in China and the Other Asia-Pacific region (where coal is prevalent) could significantly affect the role of coal in the generation mix. The projected variation in the electricity generation mix has a large effect on electric power sector CO_2 emissions in these regions and globally.

Figure 30.

Electricity generating capacity and generation by fuel, China and Other Asia-Pacific

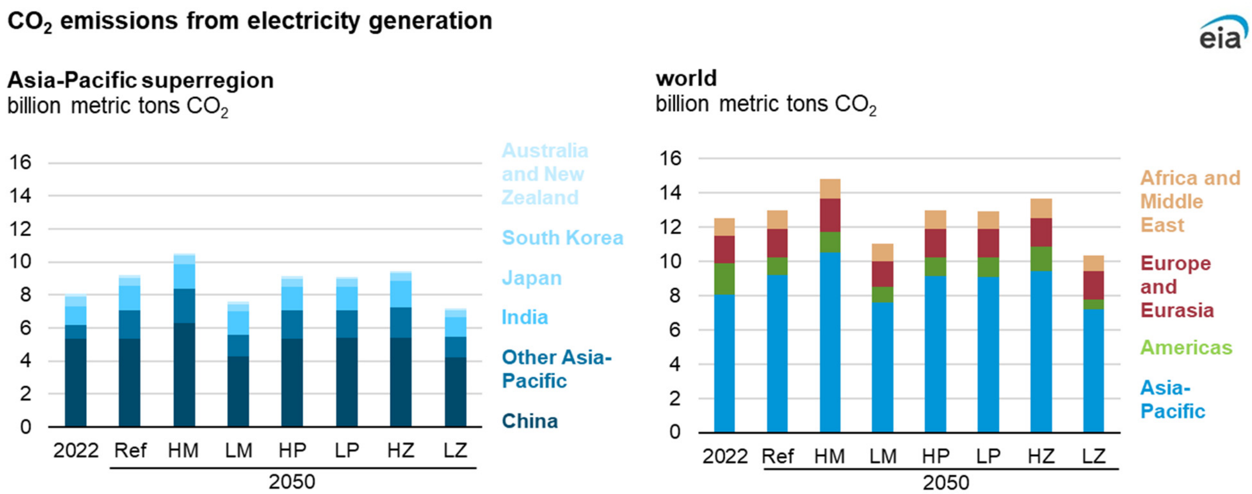


Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Ref=Reference, HM=High Economic Growth, LM=Low Economic Growth, HP=High Oil Price, LP=Low Oil Price, HZ=High Zero-Carbon Technology Cost, LZ=Low Zero-Carbon Technology Cost.

Total CO_2 emissions from fossil fuel-fired generation in China and the Other Asia-Pacific region totaled 6.2 billion metric tons in 2022, accounting for 50% of the world's total CO_2 emissions from fossil fuel-fired generation of 12.5 billion metric tons that year (Figure 31). In 2050, projected CO_2 emissions from fossil fuel-fired generation in China and the Other Asia-Pacific region vary considerably across cases and range between decreasing to 5.5 billion metric tons in the Low ZTC case to increasing to 8.4 billion metric tons in the High Economic Growth case. This range of outcomes still results in the combined electric power sector CO_2 emissions from China and the Other Asia-Pacific region increasing to between a 51% to 57% share of the world's electric power sector emissions, which we project will decrease to 10.4 billion metric tons in the Low ZTC case or increase to 14.8 billion metric tons in the High Economic Growth case.

Of the regions included in the Asia-Pacific superregion, China and the Other Asia-Pacific region combined have the largest coal-fired generation share. Collectively, the two regions contributed to 77% of the Asia-Pacific superregion's coal-fired generation and 61% of the world's coal-fired generation in 2022. The high share of coal-fired generation in China and the Other Asia-Pacific region and the sensitivity of that generation in those two regions to the assumptions made in the Low ZTC and High Economic Growth cases contribute to the large difference in the Asia-Pacific superregion and worldwide electric power sector CO_2 emissions between the two cases.

Figure 31.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Ref=Reference; HM=High Economic Growth; LM=Low Economic Growth; HP=High Oil Price; LP=Low Oil Price; HZ=High Zero-Carbon Technology Cost; LZ=Low Zero-Carbon Technology Cost.

3

Energy security concerns hasten a transition from fossil fuels in some countries, although they drive increased fossil fuel consumption in others.

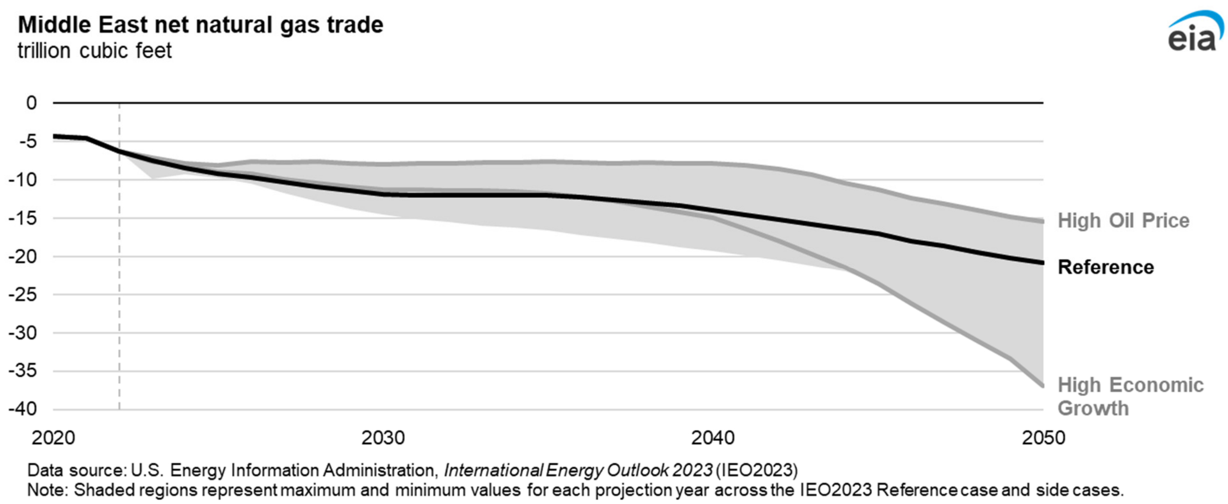
Energy trade is adapting to new realities as Western Europe continues to face challenges in maintaining fossil fuel production as current geopolitical events disrupt traditional trade patterns and as emerging economies continue to grow. Although zero-carbon technologies continue to develop and deploy at scale, our modeled cases suggest major crude oil and natural gas producers will continue producing to keep up with growing demand from consumers such as China, India, Southeast Asia, and Africa under prevailing policy.

The Middle East and North America are the primary regions to increase natural gas production and exports to meet growing international demand, assuming Russia's exports stay flat

Although Russia has 23% of world natural gas reserves, historical net exports peaked at over 8 trillion cubic feet (Tcf) in 2019. Russia's net exports fell to about 6 Tcf in 2022, and in our projection, remain there through 2050. This result assumes that Russia's full-scale invasion of Ukraine will continue to drive Western markets away from importing Russian natural gas. The model assumes that Russia will grow natural gas production to meet future domestic consumption but will not increase its net exports. The model also assumes Nord Stream 1 and 2 will not return to operation during the projection period. In addition, low GDP growth and an outflow of foreign investors in Russia throughout the projection period reduce investment in the country's export-related infrastructure (Figure 4). Russia will require massive infrastructure investment to reroute current natural gas production from Western to Eastern markets. Further, Russia has historically relied on Western companies for liquefied natural gas (LNG) technology. With the departure of these companies, Russia must develop this technology domestically, which will take time and investment to bring it to commercial scale.[7] Because shifting exports from Europe to Asia is limited by technology, trade agreements, and sanctions, Russia's net exports fall across all cases.

Across all cases, the Middle East's natural gas exports grow throughout the projection period as other regions' natural gas consumption—driven by economic growth—outpaces their domestic production (Figure 32). Export growth takes longer to occur in the High Oil Price case, remaining relatively flat until 2040, due to high prices promoting more aggressive production growth in other regions of the world.

Figure 32.

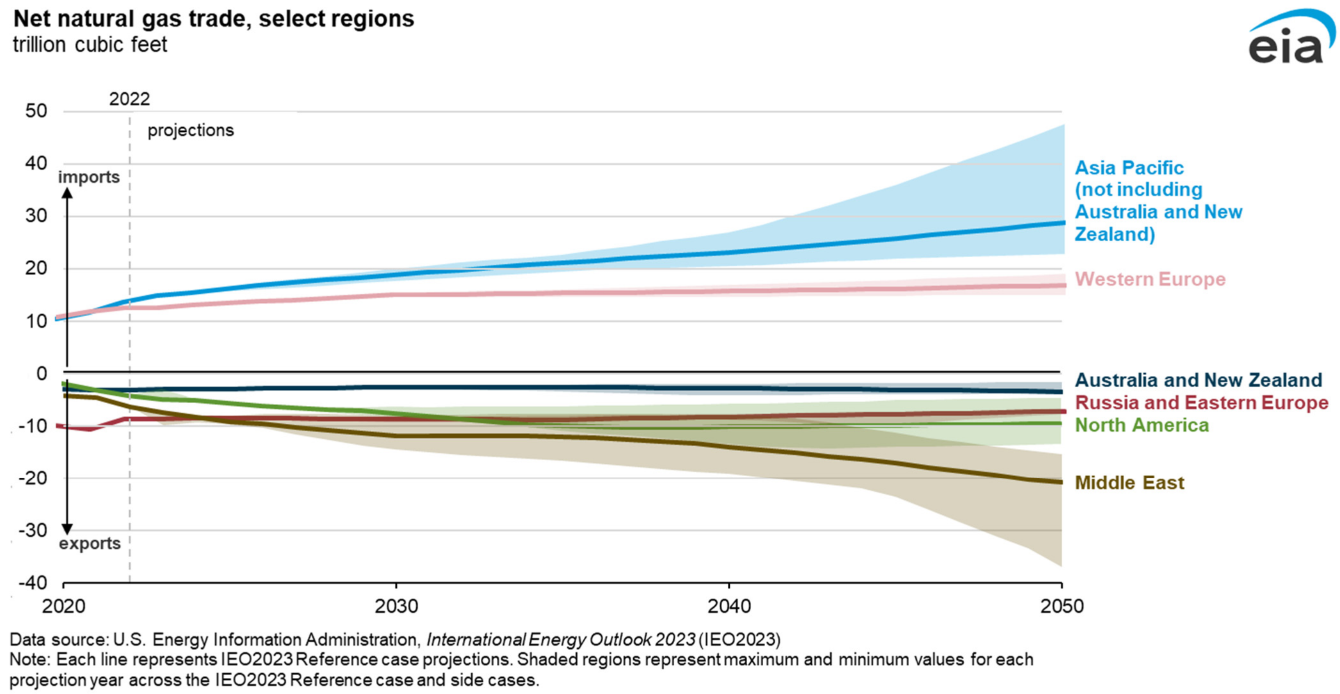


The Middle East holds almost 40% of the world's natural gas reserves[8]. Starting at 6 Tcf in 2022, net exports reach between 15 Tcf and 26 Tcf by 2050 in most cases, but they increase to 37 Tcf by 2050 in the High Economic Growth case. Most of the growth occurs in the latter half of the projection period, especially in the High Economic Growth case. (Figure 33). In the near term, growth of Middle East natural gas exports is consistent with the planned expansions in capacity expected in Qatar. In the latter part of the projection period, the strong growth in global demand for natural gas will require new investment and development of new resources from the significant remaining Middle East reserves. Natural gas production will grow in all regions if domestic resources are available and production is price competitive compared with imports. As a region runs out of cost-efficient resources, it will import natural gas from regions that have access to cheaper resources. As a result, we expect the Middle East will increase exports over the projection period because other regions reach their domestic production limit although their demand continues to grow.

[7] Although we model currently operational capacity by specific line, new natural gas line capacity isn't tied to a specific planned or under construction project.

[8] BP. *Statistical Review of World Energy.* 2021.

Figure 33.



Middle East LNG export volumes depend on assumed U.S. LNG capacity. IEO2023 relies on the Reference case from the *Annual Energy Outlook 2023* (AEO2023), in which almost 10 Tcf of U.S. LNG is exported in 2050. In a supplemental study to AEO2023, we found that U.S. LNG exports reached nearly 18 Tcf if we assumed higher prices and faster LNG export capacity additions. Such a scenario would affect the outlook for Middle East LNG export volumes.

Total global demand for natural gas differs significantly between the Reference case and the High Economic Growth case. By 2050, global natural gas demand reaches 197 Tcf in the Reference case and grows to about 240Tcf in the High Economic Growth case, almost a 22% difference between cases. U.S. supply of natural gas increases 4% from the Reference case to the High Economic Growth case in 2050. Given the lack of significant growth in natural gas production from the United States and the limited growth from Russia, the Middle East's role as a natural gas supplier increases significantly in the High Economic Growth case.

As a result of the anticipated LNG export growth in the United States (as projected in AEO2023), North America becomes the second-highest global natural gas exporter by 2050. Because U.S. LNG exports are fixed to AEO2023 projections, U.S. growth is limited to the early 2030s, and further global LNG demand across the projection period is supplied by other regions. Although Canada increases natural gas production across all cases except the Low Economic Growth case, it struggles to maintain a balance of net exports due to rising domestic natural gas consumption in its electric power sector.

By 2050, U.S. natural gas net exports fall from almost 12 Tcf in the Reference case to 7 Tcf in the Low Oil Price case. Although global natural gas demand in the Low Oil Price case is only marginally higher than in the Reference case, the Middle East increases net exports from 21 Tcf in 2050 in the Reference case to

26 Tcf in the Low Oil Price case, which offsets the decline in U.S. natural gas exports. Because the Middle East is a lower-cost supplier than the United States, the region can supply a larger share of global natural gas demand in a low-price environment.

Asia and Europe continue to import more natural gas

Across cases, the Asia-Pacific superregion—which includes China, India, Japan, South Korea, and the Other Asia-Pacific region—will not be able to meet domestic demand though domestic natural gas production. Due to the lack of natural gas reserves and technically recoverable resources in this superregion, we project it is more economical for these countries and regions to import natural gas, primarily as LNG imports.

Most of this demand growth occurs in China, where natural gas consumption rises across all sectors, particularly the electric power sector in later years. China's net natural gas imports grow by almost 8 Tcf from 2022 to almost 14 Tcf in 2050 across most cases, but its net natural gas imports reach 9 Tcf in the Low Economic Growth case and 29 Tcf in the High Economic Growth case by 2050. Although China has considerable shale gas resources, it has been able to produce only a small fraction of these resources due to difficult geography.[9] We assume that no technological breakthrough occurs to make these difficult-to-access resources more cost effective, resulting in China's growing reliance on natural gas imports throughout the projection period.

The Other Asia-Pacific region also drives the growth of natural gas import markets in Asia. Due to growing domestic demand and declining production, the Other Asia-Pacific region transitions from being a net exporter in 2022 to a net importer, with net imports rising to over 3 Tcf of natural gas by 2050 across all cases except for the High Oil Price case.

India is also a significant source of natural gas import growth in the Asia-Pacific superregion, increasing from 1.3 Tcf of net imports in 2022 to more than 4.0 Tcf in 2050 across all cases. India's natural gas demand grows significantly throughout the projection period because of growth in the industrial sector. In the Reference case, industrial natural gas consumption in India increases from 1.9 Tcf in 2022 to between 5.0 Tcf in the High Economic Growth case and almost 8.5 Tcf in the Low Economic Growth case in 2050. Although India has significant natural gas reserves, most are offshore and expensive to develop. We project India will continue to rely on imports to meet its economic growth.

Both Japan and South Korea remain net natural gas importers, and total net import volumes remain at or just below 2022 levels across all cases. Both countries have strong, established demand markets, particularly in the industrial and electric power sectors. They also have little domestic resources to draw from, resulting in limited to no natural gas production throughout the projection period.

Outside of Asia, we project Western Europe will grow as an import market. Although slowed by energy security considerations and decarbonization policies, Western European natural gas demand across all sectors (including the electric power sector) increases about 12% between 2022 and 2050 across all cases except for the Low and High Economic Growth cases. In the High Economic Growth case, natural

[9] Reuters. *Analysis: Chinese majors to struggle to extend shale gas boom beyond 2025*. 2021.

gas demand grows by 22%, and in the Low Economic Growth case, it grows by less than 4%. We also expect steady natural gas production declines due to depleted North Sea reserves and the closure of the Groningen natural gas field in the Netherlands. The slow but increasing natural gas demand growth, coupled with the region's decreasing natural gas production, increases Western Europe's net natural gas imports by between 2.3 Tcf and 6.2 Tcf by 2050 across all cases. Policy action is ongoing, and any updates or new policies in the future may significantly affect Western Europe's LNG import projections.

OPEC, particularly in the Middle East, acts as a global swing producer

Global crude oil production expands to meet the increase in global demand across all cases. The High and Low Oil Price cases explore the projected range of crude oil production due to the uncertainty around world crude oil prices, a key model assumption. Near- to mid-term production growth (2023–2035) is met by non-OPEC regions, particularly in North and South America, across all cases except the Low Oil Price case**.** Between 2022 and 2035, non-OPEC production rises from 49 million barrels per day (MMb/d) to almost 55 MMb/d—Brazil and the Other Americas region produced over 6 MMb/d in the Reference case. Canada oil sands production continues to grow through most of the 2020s.

> Near-term oil demand growth is met by non-OPEC regions, particularly North and South America in most cases; OPEC regains its relative market share later in the projection period.

In the High Oil Price case, increased oil prices sustain the production of less cost-efficient resources globally, and the share of global production from OPEC declines in the short term. Total non-OPEC production reaches almost 62 MMb/d by 2030, led by increases in U.S. production. Meanwhile, OPEC production continues to decrease through 2030 because OPEC uses its market power to maintain relatively high oil prices by decreasing global supply. As other regions reach peak production, generally between 2030 and 2040, OPEC regains its share of the market in the High Oil Price case. Because OPEC has relatively accessible resources and the ability to shift large volumes of production to meet policy targets, our model assumes that OPEC plays the role of a global swing producer. OPEC Middle East is given the most flexibility of all regions to significantly raise and lower crude oil production from year to year. Non-OPEC regions will produce as much domestic crude oil as economically possible and leave OPEC regions to contract or expand production to meet global demand. In the Low Oil Price case, the OPEC regions maintain stable production in the near term because many OPEC member countries have cheaper access to resources that remain profitable at a lower price.

Technical Note 3: Refinery representation

The World Hydrocarbon Activity Module (WHAM) includes three major components:

- Upstream natural gas and crude oil production
- Oil refining
- A logistics system to handle international trade of these commodities and products

WHAM is a linear program that minimizes the cost of supplying every region in the World Energy Projection System (WEPS) with the natural gas and liquid fuels demanded by the other WEPS modules. Structurally, WHAM has three types of regions—supply, refining, and demand—that are based on geography and economic activity. Each country is assigned to a supply region, a refining region, and a demand region.

WHAM receives petroleum product demand for every WHAM demand region and year, which WHAM must meet with supply from its refineries. These refinery regions import crude oil and natural gas from upstream supply regions. Oil refining is a complex process that is bound by a molecular balance, and WHAM's representation includes many intermediate and finished products.

Petroleum product supply within WEPS must meet demand each year because WHAM does not model refined product storage. Modeling refineries comes with some trade-offs, given their complexity. A more generalized approach that simplifies refineries to a few key components and operations would reduce WHAM's run-time at the expense of flexibility to perfectly balance supply and demand. Alternatively, a complex representation that strictly models every refinery micro-decision would provide greater flexibility to meet WEPS demand precisely and efficiently but add significant run-time. To balance these trade-offs, WHAM represents oil refining regionally.

Countries are aggregated into refining regions based on geography. Countries with large refining sectors—such as the United States—are represented as single-country regions. Within a defined refining region, country-level refinery capacity data are aggregated into a single representative regional refinery—representing that region's total throughput. Each refining region makes its own refining decisions by using WHAM's global logistics representation to export products it makes that exceed domestic demand and to import products required for the region. Because WHAM is formulated as a cost minimization problem, production from the model's refining regions tends to consist of products that are in high demand in close logistical proximity, representing the most cost-efficient outcome.

WHAM allocates capacity utilization across a variety of refinery operation templates. These templates are generated with the third-party Generalized Refining Transportation Marketing Planning System (GRTMPS), which models a sample refinery with varying crude oil slates and refinery configurations. These templates are condensed into refinery yield options and passed into WHAM. Each refinery yield contains information about a particular mode of refinery operations, including:

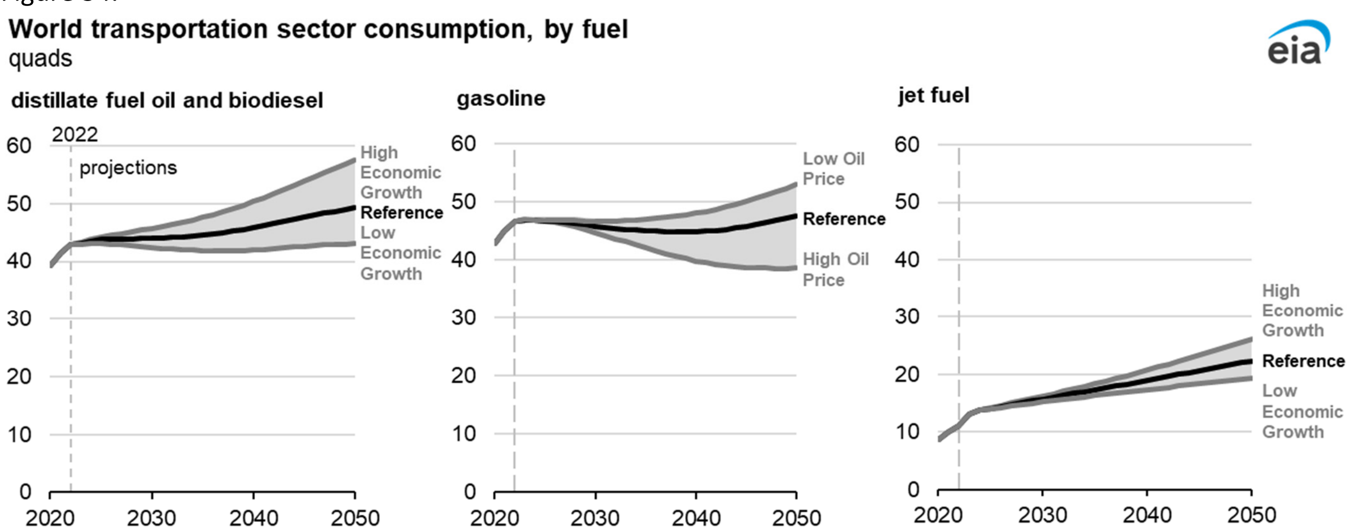
- Crude oil consumption for all crude oil types
- Natural gas and electric power consumption at refineries
- Process unit capacity allocation
- Each finished product's production

By allocating regional capacity across a variety of yields, refineries modeled in WHAM shift global product production over time to meet a changing energy landscape. You can find more information on WHAM and its refining model in our *Component Design Report* and the WHAM fact sheet.

The changing fuel demand mix for petroleum products will drive a shift toward jet fuel production

Refineries are currently configured primarily to meet gasoline and distillate demand and cannot easily change the petroleum ratio of products they produce. In 2050, we project that the transportation sector will account for at least 54% of total global liquid fuels consumption across all cases, despite increased penetration of electric vehicles (EVs) through the projection period. Therefore, this sector remains the main driver behind refinery operations and the crude oil feedstocks needed to produce the volumes and product shares of liquid fuels demanded. The High Economic Growth and Low Oil Price cases are the only cases where motor gasoline demand rises significantly, starting at 47 quads in 2022 and increasing more than 12% by 2050. In the High Oil Price case, motor gasoline demand is lowest, falling more than 17% by 2050 (Figure 34). Motor gasoline demand rises about 2% by 2050 in the Reference case. Compared with gasoline demand, jet fuel demand, rises consistently across all cases through 2050. In the High Economic Growth case, jet fuel demand increases from 11 quadrillion British thermal units (quads) in 2022 to 26 quads in 2050. Because we base projections on current policies, and climate policy is rapidly changing, long-term refinery projections face significant uncertainty.

Figure 34.



Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: Shaded regions represent maximum and minimum values for each projection year across the IEO2023 Reference case and side cases.
Quads=quadrillion British thermal units.

Subject to current policies and technology, we do not assume significant penetration of sustainable aviation fuel in the projection period; therefore, refineries must adjust production over time to meet a changing product slate where gasoline demand falls and jet fuel continues to rise with global economic growth. This shift in focus results in a transition from light crude oil to medium crude oil. Medium crude oil has a higher concentration of distillates compared with lighter varieties (which have a higher concentration of gasoline), allowing for refineries to adjust their jet fuel output via a shift in crude oil consumption patterns. Technological breakthroughs for alternative aviation fuel production could significantly affect the long-term preference of refineries for each crude oil type.

Appendix A.
Case descriptions

Reference case

The Reference case models projections under assumptions that reflect current energy trends and relationships, existing laws and regulations, and select economic and technological changes.

The Reference case includes existing non-U.S. laws and regulations as of spring 2023, and it reflects legislated energy sector policies that can be reasonably quantified in the World Energy Projection System (WEPS). More information on our general approach to modeling climate policies is available in our companion article, *Climate Considerations in the International Energy Outlook (IEO2023)*.

U.S. projections in IEO2023 reflect the published projections in the *Annual Energy Outlook 2023* (AEO2023), which assumes that U.S. laws and regulations, current as of November 2022, remain unchanged.

In the Reference case, we assume the world oil price in 2050 is $102 per barrel (2022 USD). Macroeconomic growth rate assumptions in our Reference case are listed by region in Table 1.

Table 1. IEO2023 Reference case GDP growth rates by region

Region	**Reference case** Average annual GDP (purchasing power parity) percentage change, 2022–2050
Americas	
United States	1.9%
Canada	1.8%
Mexico	1.7%
Brazil	1.1%
Other Americas	2.6%
Europe and Eurasia	
Western Europe	1.3%
Russia	1.0%
Eastern Europe and Eurasia	4.2%
Asia Pacific	
Japan	0.3%
South Korea	1.0%
Australia and New Zealand	2.1%
China	3.0%
India	5.0%
Other Asia-Pacific	3.7%

Region	
Africa and Middle East	
Africa	2.7%
Middle East	1.7%
World	2.6%

Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)

High and Low Economic Growth cases

The High Economic Growth and Low Economic Growth cases reflect the uncertainty in projections of global economic growth. These cases show the effects of alternative assumptions about economic growth that result in higher or lower growth relative to the Reference case projection for different regions.

In the economic growth cases, we alter GDP growth rates of each region based on its GDP per capita—measured in real 2015 purchasing power parity (PPP) adjusted U.S. dollars (USD) per person. In IEO2023, we divide countries into two categories:

- Low GDP per capita: less than or equal to $30,000 (2015 PPP USD) per person
- High GDP per capita: greater than US $30,000 (2015 PPP USD) per person

In general, countries with lower GDP per capita exhibit more volatile business cycles and vary more in long-term-trend growth rates.[10] As a result, more uncertainty surrounds the economic projections of low-income economies compared with high-income economies.

To reflect this uncertainty, the growth rate of countries classified as low GDP per capita varies between approximately -1.0% in the Low Economic Growth case and +1.0% in the High Economic Growth case, relative to the Reference case. The annual GDP growth rate of countries classified as high GDP per capita varies less—between approximately -0.5% in the Low Economic Growth case and +0.5% in the High Economic Growth case, relative to the Reference case (Table 2).

Table 2. Macroeconomic growth rates in the IEO2023 Low Economic Growth, Reference, and High Economic Growth cases, average annual GDP (measured in 2015 PPP USD) percentage change, 2022–2050

Region	Low Economic Growth case	Reference case	High Economic Growth case
Americas			
United States	1.4%	1.9%	2.3%
Canada	1.3%	1.8%	2.3%
Mexico	0.8%	1.7%	2.7%
Brazil	0.5%	1.1%	2.1%
Other Americas	1.9%	2.6%	3.4%

[10] Aguiar, Mark, and Gita Gopinath. "Emerging Market Business Cycles: The Cycle Is the Trend." *Journal of Political Economy*, vol. 115, no. 1, 2007, pp. 69–102. *JSTOR*, https://doi.org/10.1086/511283. Accessed 17 Aug. 2023.

Region	Low Economic Growth case	Reference case	High Economic Growth case
Europe and Eurasia			
Western Europe	0.6%	1.3%	1.9%
Russia	-0.1%	1.0%	2.1%
Eastern Europe and Eurasia	3.1%	4.2%	5.2%
Asia Pacific			
Japan	-0.2%	0.3%	0.8%
South Korea	0.5%	1.0%	1.4%
Australia and New Zealand	1.7%	2.1%	2.6%
China	2.0%	3.0%	4.1%
India	4.0%	5.0%	6.0%
Other Asia-Pacific	2.9%	3.7%	4.6%
Africa and Middle East			
Africa	2.0%	2.7%	3.6%
Middle East	1.4%	1.7%	2.3%
World	1.8%	2.6%	3.4%

Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023).
PPP=purchasing power parity.

High and Low Oil Price cases

Different expectations about long-term future oil prices can significantly affect our energy system projections. IEO2023 considers three cases (Reference, Low Oil Price, and High Oil Price) to assess the impacts of alternative future paths of oil prices. We draw the initial assumptions for the world crude oil price in IEO2023 from AEO2023, which projects spot prices for North Sea Brent crude oil, an international standard for light, sweet crude oil prices. In the Low Oil Price and High Oil Price cases, the high and low prices of a wide range of potential price paths occur, illustrating uncertain and potentially varied global demand for and supply of petroleum and other liquid fuels.

The Low Oil Price case assumes that all crude oil resources are extracted with more cost-efficient methods due to technology or policy drivers, thereby lowering the price. The High Oil Price case assumes the opposite, in which higher extraction costs and policy result in higher prices for all crude oil resources. U.S. crude oil consumption and production match the respective Low and High Oil Price and Reference cases in AEO2023, where U.S. liquid fuels production and consumption respond only to changes in prices.

Input prices to WEPS are listed in Table 3, and the full input price paths are in our data tables.

Table 3. IEO2023 Brent oil prices in selected years in the High Oil Price, Reference, and Low Oil Price cases (2022 USD per barrel)

Case	2022	2050
High Oil Price case	$102	$187
Reference case	$102	$102
Low Oil Price case	$102	$48

Data source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)

High and Low Zero-Carbon Technology Cost cases

The share of electricity generation from renewable sources has been increasing significantly in many parts of the world in recent years, due in part to rapid cost declines. Capital costs of renewables over the past 20 years suggest significant uncertainty and variability in the rate of decline. For example, between 2000 and 2010, wind technology costs in the United States increased; in the following decade, they decreased by a similar amount before increasing again in recent years. Although the decline in solar technology cost has been more directionally consistent, the rate of decline has varied significantly during this period. Uncertainty in nuclear technology costs also plays a role in the future development of nuclear as a zero-carbon technology.

The International Electricity Market Module (IEMM) in the WEPS assumes capital costs for each technology in the Reference case decline annually through the projection period. This decline is the result of experience-based cost reductions from factors such as learning-by-doing and manufacturing scale, government-funded research and development (R&D), and changes in the cost of commodities.

To address this uncertainty, we examine the impact of the capital cost assumptions that, in turn, determine relative economic competitiveness among generating technologies. The High Zero-Carbon Technology Cost case assumes no cost reduction from learning-by-doing and holds capital costs constant at the 2022 level throughout the projection period for zero-carbon electric-power generating technologies, which include solar, wind, battery storage, and nuclear. The Low Zero-Carbon Technology Cost case assumes a more rapid capital cost decline compared with the Reference case, achieving capital costs that are 40% lower by 2050 for these zero-carbon technologies. In the Reference case, potential nuclear additions and retirements are largely constrained based on noneconomic factors—geopolitical considerations such as nonproliferation agreements, energy security, and government regulations, among others. For the Low Zero-Carbon Technology Cost case, in addition to the lower costs described above, we eased these noneconomic constraints to explore the economic effects on nuclear builds.

Appendix B.

Modeling assumptions related to Russia's full-scale invasion of Ukraine

In February 2022, Russia's full-scale invasion of Ukraine introduced significant geopolitical upheaval that had immediate and future impacts. Although some impacts have already occurred, significant uncertainty surrounding long-term effects remains. In our detailed energy system model (the World Energy Projection System [WEPS]), we make assumptions about these events. In the section below, we discuss the assumptions that we made for IEO2023, which are held constant across all cases. By making fixed parameter assumptions rather than examining a range, our modeling assumptions understate the uncertainty in the range of potential outcomes.

Russia's full-scale invasion of Ukraine has affected energy markets worldwide. For example, Russia was a significant natural gas supplier to markets throughout the world, particularly to Europe. In response to the invasion, some of Russia's trade partners placed sanctions on Russia's exports, and other market participants have changed their trade preferences. These changes will continue to have impacts, but their duration and extent are uncertain. For IEO2023, we make consistent assumptions on the length and extent of these impacts on energy markets. Regardless of when the conflict ends, we assume the geopolitical ramifications, to the degree described below, will persist through 2050, the IEO2023 projection period. Implicitly, this assumes the end of the invasion will not reset relationships within energy markets.

This appendix is a comprehensive list of all relevant modeling assumptions specific to each WEPS module, but it may not include all global responses to the invasion. Although we did not vary these assumptions across cases, changing these assumptions would yield different projections. For example, assuming a more restricted natural gas supply might lead to higher natural gas prices and, consequently, lower natural gas consumption (or vice versa)—underscoring the importance of our modeling assumptions.

We will continue to monitor the ongoing events in Ukraine and incorporate new information in future IEOs. You can also review our *Short-Term Energy Outlook*, country analysis briefs, *Today in Energy* articles, and the International Energy Statistics database for our latest assumptions.

Macroeconomic activity

The macroeconomic projections we used came from the Oxford Economics Global Economic Model and Global Industry Model as of February 1, 2023. These projections include a post-invasion recovery (around 2030) that captures impacts in Russia, Ukraine, and Europe, as well as related effects on the rest of the world, including:

- Changes in demand for goods and services in Europe and elsewhere

- Changes in non-energy trade flows to reflect Oxford Economics economic data and analysis
- Legislated subsidies in various countries, including assumptions on availability of subsidies into the future as reflected in Oxford Economics' economic data and analysis
- Legislated sanctions targeting Russia implemented in 2022 that remain in place as of February 1, 2023, assuming sanctions remain in place without end dates and no new sanctions are implemented
- Russia's efforts to lessen the economic impact of sanctions and policies, including concealing crude oil trade flows, using multiple trade partners to avoid sanctions, and identifying new purchasers for its exports

We also assume Nord Stream will remain offline through 2050, as further discussed in the oil and natural gas section, and the Zaporizhzhya nuclear plant will resume operations beginning in 2030, as further discussed in the electricity section.

These bullets are broad categorizations of the analysis included inside the Oxford Economics models and databases. Additional detail is available to subscribers of their services or by requesting more information from us.

Buildings

We made assumptions based on REPowerEU, which is a European Commission proposal to end reliance on Russia's fossil fuels before 2030. Russia's full-scale invasion of Ukraine has prompted the EU to move forward with more urgency on the existing energy and climate policy goals in place. In May 2022, under the REPowerEU plan, the European Commission proposed an increase to the binding EU energy efficiency target from 9% to 13% by 2023 (relative to 2020). In July 2022, EU member states agreed to reduce their natural gas consumption by 15% through March 2023.

We account for demand-side measures that EU countries implemented to curb natural gas consumption and reduce natural gas imports from Russia. We modeled Western Europe's attempts to curb demand for natural gas in homes and commercial buildings throughout the winter of 2022 by applying higher sensitivity to price increases than in previous years. We considered policies and public calls to reduce natural gas consumption in buildings—such as new rules in Germany affecting energy consumption in public buildings and similar measures in France. We assume that non-price considerations will reduce consumers' willingness to pay for natural gas. We also expect homeowners and commercial building operators will generally be more sensitive to increases in the natural gas price than they have been historically. As a result, growth in natural gas demand slows in buildings, and we project electricity consumption to grow faster than historical rates.

WEPS modules do not explicitly account for national- or sub-national subsidies for purchasing energy or heat across the end-use sectors.

Industrial

As with the buildings sector, we made assumptions based on REPowerEU in the industrial sector. Energy-efficiency goals were part of Europe's pre-invasion climate goals, and we assume the invasion of

Ukraine will spur structural shifts that will lower Europe's long-term natural gas demand. To model this, we increased industrial natural gas demand elasticities for several European industries that have the technical potential to increase energy efficiency with respect to natural gas consumption. We adjusted food, paper, non-metallic minerals, and many non-energy intensive industries that use boilers and low-temperature process heat, such as other metal-based durables, motor vehicles, and *industrial other*, the catch-all for small manufacturing.

District heat

The RePowerEU plan revises the target for the share of renewables used to generate heat in centralized district energy plants to 45% of heat generation by 2030. Centralized district energy plants distribute heat and steam to meet demand for space heating, water heating, and process heat in the buildings and industrial sectors. Increasing the use of renewables for heat generation in Western Europe displaces some natural gas and coal as a heat generation source.

Transportation

We made no additional assumptions in the transportation sector.

Electricity

We made assumptions in the Eastern Europe and Eurasia modeling region (including Ukraine and 10 other countries)[11] regarding when and how quickly the two Ukrainian nuclear power plants located in military conflict zones—Zaporizhzhya Nuclear Power Plant and South Ukraine—resume operations.

- Zaporizhzhya Nuclear Power Plant: ramp up from cold shutdown, beginning in 2030 to 100% by 2034
- South Ukraine: generation remains at 70% of total plant capacity over 2022–2029 and increases to 100% by 2030

Crude oil and natural gas production and trade

We made assumptions specific to oil and natural gas production and trade for IEO2023, which include:

- Russia's crude oil and petroleum liquids exports directly to the United States and Western Europe are suspended, beginning in 2023 and lasting through 2050
- The Nord Stream natural gas pipelines remain offline through 2050

We assume zero net export growth of Russia's natural gas. EU sanctions prohibit supplying Russia with the goods and technology suited for liquefying natural gas. Without access to Western company technology and replacement equipment, Russia's current liquefied natural gas (LNG) projects may struggle to be completed on time, and future projects will face significant barriers. Our model does not currently model LNG at the project level and does determine the expected completion of projects under development.

[11] WEPS regionality is outlined in Appendix C.

Coal production and trade

We made two sets of time period-specific assumptions for coal production and trade. Across both periods, Ukraine no longer imports coal from Russia.

From 2023 to 2028:

- We decreased trade between Japan and Russia. During this period, total trade of steam and metallurgical coal will decrease to nearly zero, but Japan will continue purchasing a small amount under previous contracts.
- We decreased trade between Western Europe and Russia, not including Türkiye. During this period, we assume that coal trade will occur between only Russia and Türkiye.

For 2029 and later:

- Japan and Türkiye return to pre-invasion coal trade activity with Russia.
- Western Europe, excluding Türkiye, seeks to reduce coal imports from Russia relative to imports before the invasion. Within the model, we allow Western Europe, excluding Türkiye, to import up to about two-thirds of pre-2022 imports.

Appendix C.

New Regions in IEO2023

Regions have changed in IEO2023

For the *International Energy Outlook 2023* (IEO2023), we are introducing new regional groupings for countries in the World Energy Projection System (WEPS). Previously, our publication regions were defined primarily by Organisation for Economic Cooperation and Development (OECD) designation and secondarily by geography. We based the new regional groupings solely on geography. A map of our new 16 regions and a table of the countries assigned to each region are in this appendix.

The previous regions were partially based on organizational membership

We have used OECD membership as a partial basis for WEPS publication regions since 2006, when we determined that OECD membership was a reasonable proxy for economic development, and economic development was a reasonable grouping for modeling regions. In IEO2021 we used 16 regions based on geography and OECD membership, and we combined these regions into two larger groupings: OECD and non-OECD.

Many WEPS modules use higher geographic resolution internally but aggregate to 16 regions for communication with the greater WEPS system and for the IEO publication. You can find more details on module regionality in the model documentation.

Dividing the world economically is complicated

In recent years, OECD and non-OECD are no longer simple proxies for economic development. For example, China does not belong to the OECD but had the second-largest economy in the world in 2022. Several countries—with smaller economies than China—have joined the OECD in the past decade, such as Latvia (in 2016); Colombia (in 2020); and most recently, Costa Rica (in 2021). Using the OECD designation led to geographically noncontiguous regions, such as the WEPS region that combined Mexico and Chile.

In peer publications, many organizations use regions largely based on geographies in their models, although they may use economic indicators for reporting.

The new regions are largely based on proximity

IEO2023 uses four superregions—larger regional groupings:

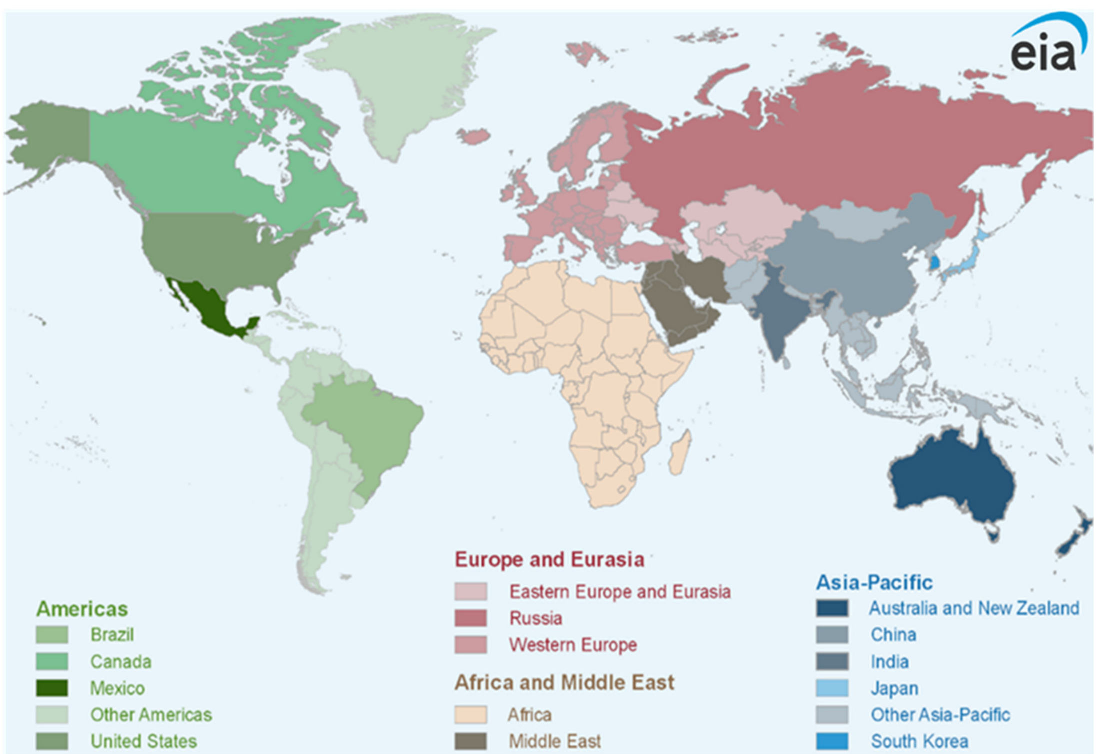
- Americas
- Europe and Eurasia
- Africa and the Middle East
- Asia-Pacific

Within those superregions, the new IEO publication regionality breaks out certain countries into independent regions. The United States, Canada, Brazil, Mexico, Russia, China, India, Japan, and South Korea make up 9 of the 16 WEPS regions. The remaining seven regions are aggregate regions with two or more component countries in each (Figure 35 and Table 4).

Next steps

We plan to continue to evaluate and take comments on additional publication regions, particularly in Africa and the Asia-Pacific.

Figure 35.
Map of *International Energy Outlook 2023* regions



Data source: U.S. Energy Information Administration

Table 4. IEO2023 country-region assignments

IEO2023 WEPS region	Country
Africa	Algeria
Africa	Angola
Africa	Benin
Africa	Botswana
Africa	Burkina Faso
Africa	Burundi
Africa	Cameroon
Africa	Cape Verde
Africa	Central African Republic
Africa	Chad
Africa	Comoros
Africa	Congo-Brazzaville
Africa	Congo-Kinshasa
Africa	Côte d’Ivoire
Africa	Djibouti
Africa	Egypt
Africa	Equatorial Guinea
Africa	Eritrea
Africa	Ethiopia
Africa	Gabon
Africa	Gambia, The
Africa	Ghana
Africa	Guinea
Africa	Guinea-Bissau
Africa	Kenya
Africa	Lesotho
Africa	Liberia
Africa	Libya
Africa	Madagascar
Africa	Malawi
Africa	Mali
Africa	Mauritania
Africa	Mauritius
Africa	Morocco
Africa	Mozambique
Africa	Namibia
Africa	Niger
Africa	Nigeria

IEO2023 WEPS region	Country
Africa	Réunion
Africa	Rwanda
Africa	Saint Helena, Ascension and Tristan da Cunha
Africa	Sao Tome and Principe
Africa	Senegal
Africa	Seychelles
Africa	Sierra Leone
Africa	Somalia
Africa	South Africa
Africa	South Sudan
Africa	Sudan
Africa	Swaziland
Africa	Tanzania, United Republic of
Africa	Togo
Africa	Tunisia
Africa	Uganda
Africa	Western Sahara
Africa	Zambia
Africa	Zimbabwe
Australia and New Zealand	Australia
Australia and New Zealand	New Zealand
Brazil	Brazil
Canada	Canada
China	China
Eastern Europe and Eurasia	Armenia
Eastern Europe and Eurasia	Azerbaijan
Eastern Europe and Eurasia	Belarus
Eastern Europe and Eurasia	Georgia
Eastern Europe and Eurasia	Kazakhstan
Eastern Europe and Eurasia	Kyrgyzstan
Eastern Europe and Eurasia	Moldova, Republic of
Eastern Europe and Eurasia	Tajikistan
Eastern Europe and Eurasia	Turkmenistan
Eastern Europe and Eurasia	Ukraine
Eastern Europe and Eurasia	Uzbekistan
India	India
Japan	Japan
Mexico	Mexico
Middle East	Bahrain

IEO2023 WEPS region	Country
Middle East	Iran
Middle East	Iraq
Middle East	Israel
Middle East	Jordan
Middle East	Kuwait
Middle East	Lebanon
Middle East	Oman
Middle East	Palestine, State of
Middle East	Qatar
Middle East	Saudi Arabia
Middle East	Syrian Arab Republic
Middle East	United Arab Emirates
Middle East	Yemen
Other Americas	Antarctica
Other Americas	Antigua and Barbuda
Other Americas	Argentina
Other Americas	Aruba
Other Americas	Bahamas
Other Americas	Barbados
Other Americas	Belize
Other Americas	Bermuda
Other Americas	Bolivia
Other Americas	Cayman Islands
Other Americas	Chile
Other Americas	Colombia
Other Americas	Costa Rica
Other Americas	Cuba
Other Americas	Dominica
Other Americas	Dominican Republic
Other Americas	Ecuador
Other Americas	El Salvador
Other Americas	Falkland Islands
Other Americas	French Guiana
Other Americas	Greenland
Other Americas	Grenada
Other Americas	Guadeloupe
Other Americas	Guatemala
Other Americas	Guyana
Other Americas	Haiti

IEO2023 WEPS region	Country
Other Americas	Honduras
Other Americas	Jamaica
Other Americas	Martinique
Other Americas	Montserrat
Other Americas	Netherlands Antilles
Other Americas	Nicaragua
Other Americas	Panama
Other Americas	Paraguay
Other Americas	Peru
Other Americas	Puerto Rico
Other Americas	Saint Kitts and Nevis
Other Americas	Saint Lucia
Other Americas	Saint Pierre and Miquelon
Other Americas	Saint Vincent and the Grenadines
Other Americas	St. Kitts and Nevis
Other Americas	St. Lucia
Other Americas	St. Vincent and the Grenadines
Other Americas	Suriname
Other Americas	Trinidad and Tobago
Other Americas	Turks and Caicos Islands
Other Americas	Uruguay
Other Americas	Venezuela, Bolivarian Republic of
Other Americas	Virgin Islands, British
Other Americas	Virgin Islands, U.S.
Other Asia-Pacific	Afghanistan
Other Asia-Pacific	American Samoa
Other Asia-Pacific	Bangladesh
Other Asia-Pacific	Bhutan
Other Asia-Pacific	Brunei
Other Asia-Pacific	Cambodia
Other Asia-Pacific	Cook Islands
Other Asia-Pacific	Fiji
Other Asia-Pacific	French Polynesia
Other Asia-Pacific	Guam
Other Asia-Pacific	Hong Kong
Other Asia-Pacific	Indonesia
Other Asia-Pacific	Kiribati
Other Asia-Pacific	Korea, Democratic People's Republic of
Other Asia-Pacific	Laos

IEO2023 WEPS region	Country
Other Asia-Pacific	Macao
Other Asia-Pacific	Malaysia
Other Asia-Pacific	Maldives
Other Asia-Pacific	Micronesia, Federated States of
Other Asia-Pacific	Mongolia
Other Asia-Pacific	Myanmar
Other Asia-Pacific	Nauru
Other Asia-Pacific	Nepal
Other Asia-Pacific	New Caledonia
Other Asia-Pacific	Niue
Other Asia-Pacific	Northern Mariana Islands
Other Asia-Pacific	Pakistan
Other Asia-Pacific	Papua New Guinea
Other Asia-Pacific	Philippines
Other Asia-Pacific	Samoa
Other Asia-Pacific	Singapore
Other Asia-Pacific	Solomon Islands
Other Asia-Pacific	Sri Lanka
Other Asia-Pacific	Taiwan, Province of China
Other Asia-Pacific	Thailand
Other Asia-Pacific	Timor-Leste
Other Asia-Pacific	Tonga
Other Asia-Pacific	Tuvalu
Other Asia-Pacific	Vanuatu
Other Asia-Pacific	Viet Nam
Other Asia-Pacific	Wake Island
Russia	Russian Federation
South Korea	Korea, Republic of
United States	United States of America
Western Europe	Albania
Western Europe	Austria
Western Europe	Belgium
Western Europe	Bosnia and Herzegovina
Western Europe	Bulgaria
Western Europe	Croatia
Western Europe	Cyprus
Western Europe	Czech Republic
Western Europe	Denmark
Western Europe	Estonia

IEO2023 WEPS region	Country
Western Europe	Faroe Islands
Western Europe	Finland
Western Europe	France
Western Europe	Germany
Western Europe	Gibraltar
Western Europe	Greece
Western Europe	Hungary
Western Europe	Iceland
Western Europe	Ireland
Western Europe	Italy
Western Europe	Kosovo
Western Europe	Latvia
Western Europe	Lithuania
Western Europe	Luxembourg
Western Europe	Macedonia, the former Yugoslav Republic of
Western Europe	Malta
Western Europe	Montenegro
Western Europe	Netherlands
Western Europe	Norway
Western Europe	Poland
Western Europe	Portugal
Western Europe	Romania
Western Europe	Serbia
Western Europe	Slovakia
Western Europe	Slovenia
Western Europe	Spain
Western Europe	Sweden
Western Europe	Switzerland
Western Europe	Türkiye
Western Europe	United Kingdom

Source: U.S. Energy Information Administration, *International Energy Outlook 2023* (IEO2023)
Note: WEPS=World Energy Projection System.