McKinsey & Company

Global Energy Perspective 2024

September 2024

About this report

The Global Energy Perspective is produced by Energy Solutions, part of McKinsey's Global Energy & Materials Practice, in close collaboration with McKinsey's Sustainability and Advanced Industries practices. McKinsey is committed to our position that the world requires a major course correction to reach climate goals aligned with the Paris Agreement, and our research is focused on helping global stakeholders meet those targets.

The Global Energy Perspective 2024 offers a detailed demand outlook for 68 sectors and 78 fuels across a 1.5° pathway, as set out in the Paris Agreement, as well as three bottom-up energy transition scenarios. The scenarios have been redesigned this year to better reflect changing global conditions, including geopolitical challenges, increasingly complex supply chains, and higher inflation. Together, they explore potential outcomes, ranging from a sustainable transformation—a plausible scenario where sustainability becomes a global priority and nations coordinate toward decarbonization, despite the challenges—through a continuation of the current energy transition momentum, to a slower evolution characterized by a fragmented response to decarbonization. Data for these scenarios come from a variety of sources, including the International Energy Agency (IEA), the Energy Institute, Eurostat, the Intergovernmental Panel on Climate Change (IPCC), Oxford Economics, the United Nations, the US Department of Agriculture (USDA), and the US Energy Information Administration, among others.

This broad range of scenarios is intended to show the implications of different pathways and to provide a fact base to inform decision makers. However, these scenarios are not exhaustive in the realm of all possible outcomes, nor will any individual scenario unfold exactly as we describe it. In certain cases in this report, we may highlight a particular scenario that best illustrates a trend, but this does not mean that we believe this scenario is more or less likely to reflect the actual outcome. The insights in this report are based on currently available data, but multiple factors could influence real-world outcomes as the energy transition continues to advance.

About Energy Solutions: Energy Solutions is McKinsey's global market intelligence and analytics group focused on the energy sector. The group enables organizations to make well-informed strategic, tactical, and operational decisions by using an integrated suite of market models, proprietary industry data, leading industry benchmarks, advanced analytical tools, and a global network of industry experts. It works with leading companies across the entire energy value chain to help them manage risk, optimize their organizations, and improve performance.

About the Global Energy & Materials Practice: McKinsey's Global Energy & Materials Practice deploys its deep insights, functional capabilities, and proprietary benchmark and data solutions across the converging energy, materials, and natural resources supply chains to help create substantial and long-lasting value for stakeholders. Guided by advanced analytics and the power of a global team, it brings distinctive industry perspectives across sectors that support today's critical infrastructure ecosystems. The practice is proud to have partnered with hundreds of major industry players as the leading and most integrated advisor on strategic and functional transformations, enabling clients to accelerate decarbonization and realize the energy, materials, and food transitions.

About McKinsey & Company: McKinsey is a global management consulting firm committed to helping organizations accelerate sustainable and inclusive growth. The firm works with clients across the private, public, and social sectors to solve complex problems and create positive change for all their stakeholders. It combines bold strategies and transformative technologies to help organizations innovate more sustainably, achieve lasting gains in performance, and build workforces that will thrive for this generation and those to come.

Global Energy Perspective 2024: Foreword

While significant progress has been made in the nine years since the landmark Paris Agreement, the global energy transition is entering a new phase, marked by rising costs, complexity, and increased technology challenges. To successfully navigate this next phase and meet the Paris Agreement goals, urgent action will be required and the pace of change must accelerate.[1] The clean energy transition will also need to be balanced with affordability, energy system resiliency, and energy security in an increasingly uncertain macroeconomic environment.

Despite significant global public and private sector momentum grounded in increasingly ambitious policies, overcoming major physical challenges is crucial to transform today's large and complex energy system. New low-carbon technologies will have to be developed and deployed, along with entirely new supply chains and infrastructure to support them. While the cost of low-carbon technologies has continued to decline in most regions, in McKinsey Global Institute's recent report, "*The hard stuff: Navigating the physical realities of the energy transition*," it is estimated that only 10 percent of the technologies required globally by 2050 have been deployed. Most of these in promising use cases or "low-hanging fruit" where policy and funding have been most plentiful.[2] For example, renewable energy sources (RES) have seen significant success. In Europe, solar photovoltaic (PV) deployment is on track to meet 2030 targets and solar PV build-out in Spain sits at around 30 gigawatts (GW) of installed capacity, which could double by 2030 at the current growth trajectory.[3] China has also reported notable achievements in low-carbon technology deployment, with more solar capacity and electric vehicles (EVs) added last year than by the rest of the world combined.[4]

By contrast, a new wave of less mature technologies faces costs that may inhibit large-scale deployment. As highlighted in McKinsey's recent article, "The energy transition: Where are we, really?," there is a persistent and growing gap between low-carbon technology project commitments and realization, with a significant proportion of announced projects not reaching final investment decision (FID).[5] Corporate, public, and private investors are hesitant about deploying capital due to softening business cases, technology cost-competitiveness, and project-enabling and market-forming policy support. Value chains remain constrained across all low-carbon technologies, impacting the availability of everything from basic materials to equipment. Consequently, fossil fuels will continue to supply growing energy demand across all our bottom-up scenarios.

Successfully navigating the transition away from fossil fuels will require focusing beyond a single solution or technology. There are no silver bullets—the future calls for a holistic transformation of the global energy system by incorporating a range of proven and emerging levers. To do this, considerations beyond technological feasibility will need to be addressed, spanning capital deployment, improving business cases, ensuring economic returns, adjusting regulation, and establishing continued political and public support in the face of competing economic and societal priorities.

This report presents a view of the road ahead to serve as a fact base for stakeholders to navigate the opportunities and challenges of this new phase. It does not constitute McKinsey's view on what should happen, but rather presents a range of scenarios that could plausibly play out, based on the best data currently available—recognizing that the energy transition is an extremely complex undertaking influenced by multiple factors. The critical question this research aims to address is how the world can achieve a step change in its efforts toward meeting net-zero goals and avoid the worst impacts of climate change.

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[1] For more on the trade-offs associated with the energy transition, see Mekala Krishnan, Daniel Pacthod, and Sven Smit, "Affordability, reliability, and industrial competitiveness will make or break the net-zero transition. Here's how," McKinsey, March 14, 2024.

[2] *The hard stuff: Navigating the physical realities of the energy transition*," McKinsey Global Institute, August 14, 2024.

[3] "The Iberian green industrial opportunity: Electrification and renewables," McKinsey, July 31, 2024.

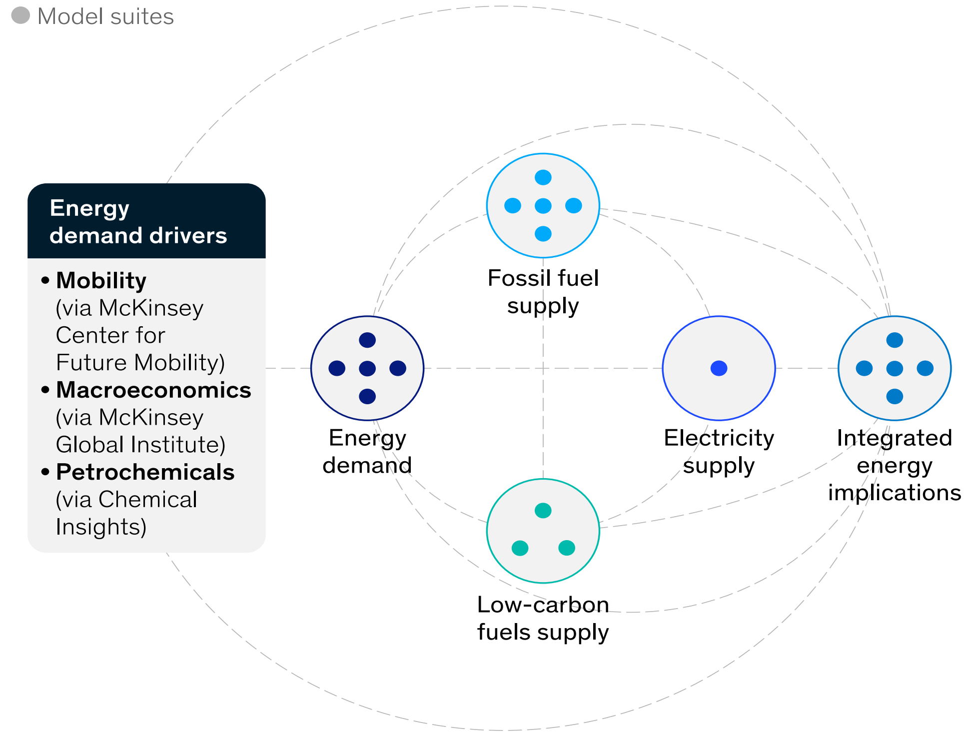
[4] *Global EV outlook 2024*, IEA, April 2024; "Electricity 2024,"IEA, January 2024.

[5] "The energy transition: Where are we, really?," McKinsey, August 27, 2024.

Global Energy Perspective 2024: Our perspective redesigned

Global Energy Perspective intelligence network

Our fully integrated supply and demand perspective incorporates energy demand drivers from McKinsey's broader research teams with the Energy & Materials Practice's suites of market intelligence models



[1]Non-exhaustive; only major model suites with linkage to Global Energy Perspective are shown.
[2]Carbon capture, utilization, and storage.

Model suite categories[1]

Energy demand
- Chemicals
- Industry and buildings
- Maritime and aviation
- Power
- Road transport

Fossil fuel supply
- Gas and LNG
- Midstream and services
- North America oil and gas
- Oil and liquids
- Refining activity and margins

Electricity supply
- Power generation and pricing

Low-carbon fuels supply
- CCUS[2]
- Hydrogen
- Sustainable fuels

Integrated energy implications
- Energy asset decarbonization
- Energy value pools
- Green power procurement optimization
- Industrial electrification
- Metals supply and demand

Globally, net-zero targets have proliferated, and commitments and enthusiasm for reaching net zero are on the rise. However, the crucial transition technologies needed to achieve these targets are still not being deployed at the required speed. In the next phase of the global energy transition, low-carbon technologies need to scale up in an environment where capital availability is decreasing in light of elevated interest rates and geopolitical developments. To consider this evolving global environment, we have redesigned our energy transition scenarios[6] to:

- present a range of plausible futures, anchored on credible input assumptions and the extrapolation of current trends
- better reflect the complexity of the energy transition, which is driven by multiple factors
- be used as a baseline to model additional shocks to the system in future, such as geopolitical changes

Our updated scenarios are primarily differentiated over nine dimensions across three broad areas that could determine the evolution of the energy transition:

- **Policy:** Policy ambition, energy security, and implied CO_2 price
- **Technology development:** Efficiency gains, technology cost learning curves, and novel technology
- **Potential constraints for renewables deployment:** Technology bottlenecks, grid build-out, and nuclear build-out

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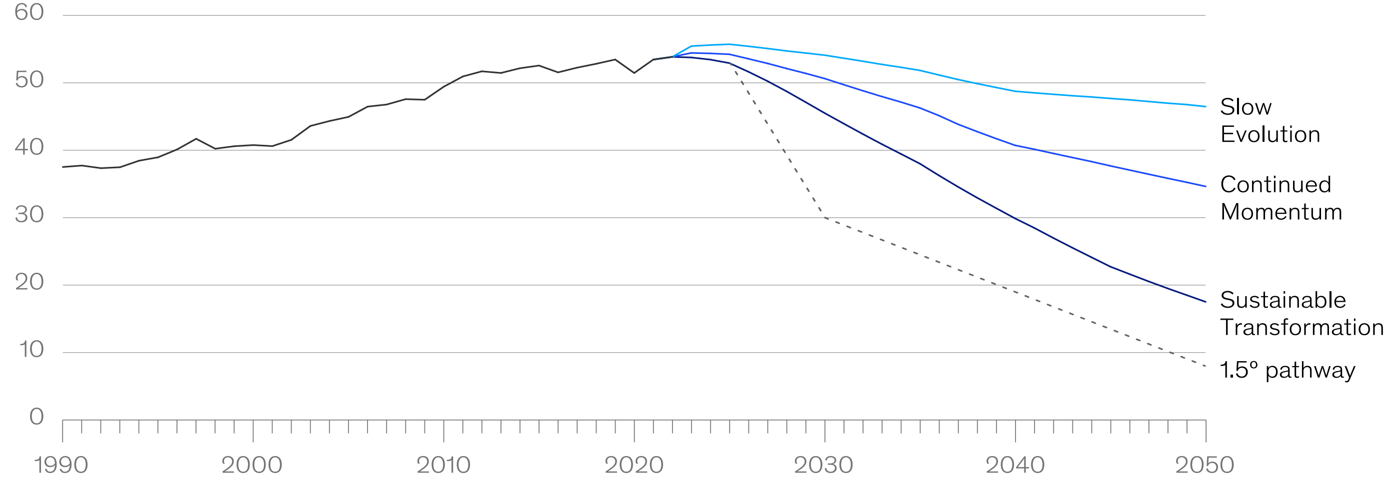
[6] All scenarios assume a consensus view of around 2.3 percent global GDP growth per year between 2023 and 2050; (Oxford Economics; McKinsey analysis).

McKinsey’s Global Energy Perspective 2024 explores a 1.5° pathway and three bottom-up energy transition scenarios

Scenarios reflect the pace of technological progress, level of policy enforcement, and potential constraints for renewables deployment

Global greenhouse gas emissions,[1] $GtCO_2$ equivalent per annum



Projected global temperature increase by 2050, °C

<1.5	~1.8	~2.2	~2.6
1.5° pathway	Sustainable Transformation	Continued Momentum	Slow Evolution

Faster **Speed of energy transition** *Slower*

Note: 1.5° pathway modeled as part of McKinsey’s Climate Math effort; other scenarios modeled bottom-up as part of McKinsey’s *Global Energy Perspective 2024.*

[1] Includes process emissions from cement production, chemicals production and refining, and negative emissions from applying carbon capture, utilization, and storage (CCUS).

Source: McKinsey, September, 2024

1.5° pathway

Under this scenario, a 1.5° pathway is adopted globally. International cooperation is mobilized to rapidly scale decarbonization technologies, release large-scale investments (including in emerging economies), and shift behavior. Limiting warming to 1.5°C is key to avoiding the worst impacts of climate change and doing so would require staying within a 570 gigaton (Gt) carbon budget, reducing CO_2 emissions by 50 percent by 2030 compared to current levels—and reaching net-zero emissions by 2050. Other greenhouse gases, especially methane and nitrous oxide, would also need to be steeply reduced. Achieving a 1.5° pathway requires a substantial departure from current trends and significant changes to the energy demand mix, pace of decarbonization, and investment into nascent technologies, but is still possible with rapid global action across all economic sectors.

Projected global temperature increase by 2050[7]: < 1.5°C

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[7] The warming estimate is an indication of the global rise in temperature by 2100 versus pre-industrial levels, based on MAGICCv7.5.3 as used in IPCC AR6, given the respective energy and nonenergy (for example, agriculture and deforestation) emission levels and assuming the continuation of trends after 2050 but no net-negative emissions. The remaining emissions in 2050 (approximately 4 gigatons [Gt]) are compensated by negative emissions from direct air carbon capture and sequestration (DACCS), bioenergy with carbon capture and storage (BECCS), and reforestation.

McKinsey's Global Energy Perspective 2024 explores a 1.5° pathway and three bottom-up energy transition scenarios

Scenarios reflect the pace of technological progress, level of policy enforcement, and potential constraints for renewables deployment

Sustainable Transformation

The Sustainable Transformation scenario charts a pathway to decarbonization based on current global economic conditions and technology maturity and viability. Here, nations intensify their commitment to sustainability, with increasing global coordination to alleviate bottlenecks, unlock investment pledges for low-carbon technologies, and improve energy efficiency above recent historical levels. Global cooperation to decarbonize is underscored by the creation of cross-regional financing, with nations adopting cost-efficient policies to reduce emissions. However, despite this momentum, practical constraints impose certain limits on the pace of clean technology adoption. For this scenario to materialize, several economic and technological issues would need to be resolved, and interim targets might not be met if not plausible under these assumptions.

Projected global temperature increase by 2050: ~1.8°C

Continued Momentum

In the Continued Momentum scenario, nations' focus on sustainability is balanced by other factors, including affordability and security of energy supply, with some emerging economies mostly prioritizing affordability and security of supply over sustainability. Technology and efficiency improvements largely follow current trends, driven by economics where practical constraints persist in the widespread adoption of low-carbon technologies. This scenario largely mirrors current trends and assumes they will continue, resulting in uneven deployment of low-carbon technologies across technology type and regions. This scenario would fail to meet the key goals of the Paris Agreement, creating a range of negative social, environmental, and economic effects.

Projected global temperature increase by 2050: ~2.2°C

Slow Evolution

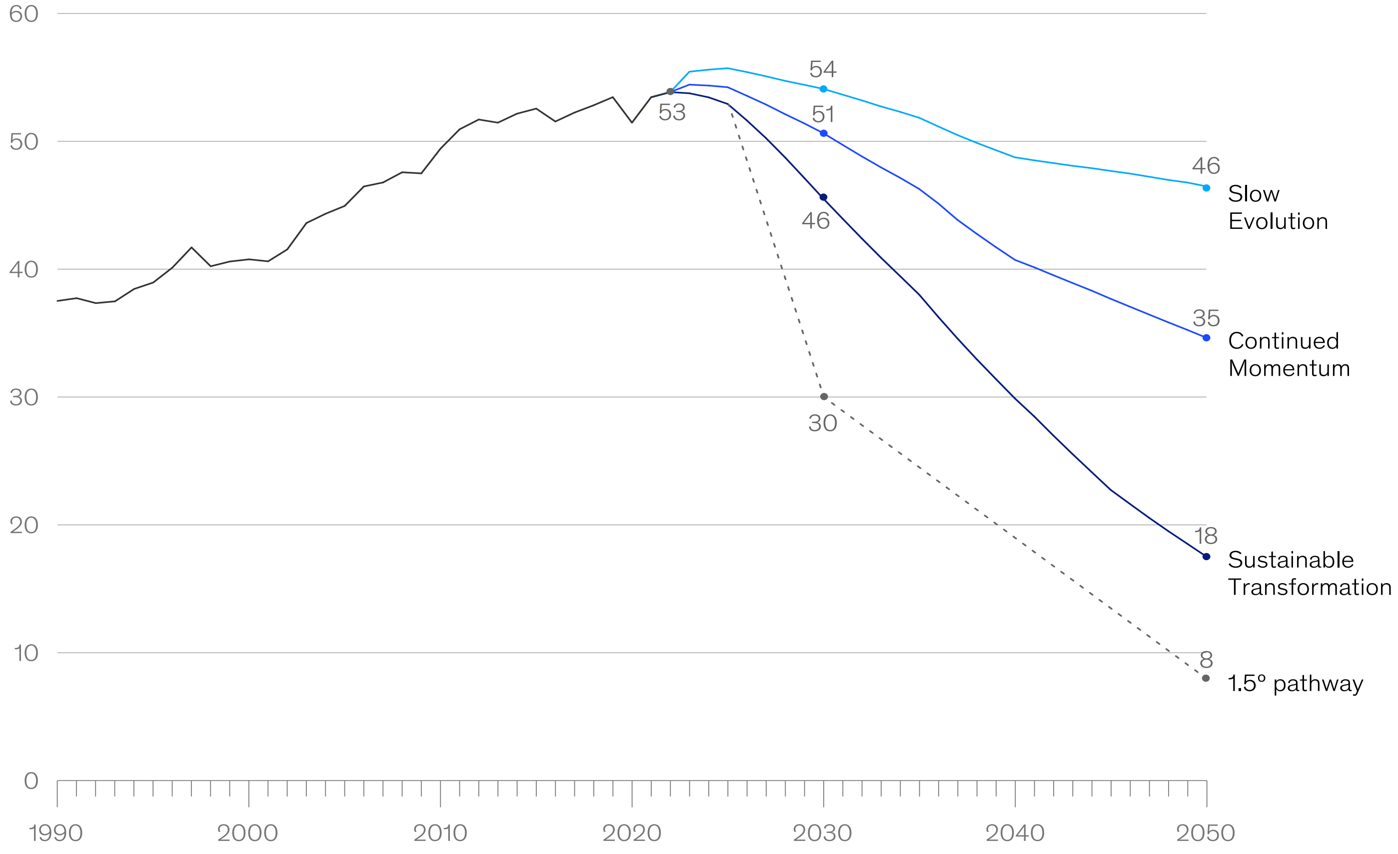
The Slow Evolution scenario sees local decision making focused on (domestic) energy affordability and supply security, relegating sustainability to a secondary priority. This fragmented response to decarbonization leads to a decrease in prior low-carbon investments, resulting in reduced investments into low-carbon technology and lower CO_2 prices, which, in turn, leads to significant environmental, economic, and social impacts. Stark geographic differences emerge in this scenario, with some countries and regions making good progress toward decarbonization targets, while others lag behind significantly. To an even greater extent than the Continued Momentum scenario, if this scenario materializes, the key goals of the Paris Agreement will not be met, creating a range of severe social, environmental, and economic effects.

Projected global temperature increase by 2050: ~2.6 °C

Our analysis of the data shows global emissions to 2050 remaining above a 1.5° pathway—even if all countries deliver on current commitments

Knock-on effects and regional differences could drive significantly higher temperature increases

Global greenhouse gas emissions,[1] GtCO_2 equivalent per annum



Note: Warming estimate is an indication of global rise in temperature by 2100 versus pre-industrial levels, based on MAGICCv7.5.3 as used in IPCC AR6 given the respective energy and non-energy (eg, agriculture, deforestation) emission levels and assuming continuation of trends after 2050 but no net-negative emissions. The remaining emissions in 2050 (ie, ~4Gt) are compensated by negative emissions from direct air carbon capture and sequestration (DACCS), bioenergy with carbon capture and storage (BECCS), and reforestation.

[1] Includes process emissions from cement production, chemical production and refining, and negative emissions from applying carbon capture, utilization, and storage (CCUS).

Source: IEA Global Energy Review 2022; IEA World Energy Balances

Increased energy demand and the continued role of fossil fuels in the energy system mean emissions could continue rising through 2025 to 2035. Emissions have not yet peaked, and global CO_2 emissions from combustion and industrial processes are projected to increase until around 2025 under all our bottom-up scenarios. The scenarios begin to diverge toward 2030, with all showing a decline in emissions by 2050. Despite this projected decline, 2050 emissions are still meaningfully above net-zero targets across all scenarios.

The emissions decline is driven primarily by economic factors, particularly the increasing cost-effectiveness of low-carbon technology in sectors such as power and road transport. For example, solar photovoltaic (PV) deployment in Europe is on track to reach 2030 targets, while China is making strides in both solar and electric vehicle (EV) adoption. Policy and regulations will also continue to contribute to the adoption of low-carbon technology and support a decline in emissions.

In all our bottom-up scenarios, rising emissions would lead to global temperature increases above 1.5°C by 2050, from around 1.8°C in the Sustainable Transformation scenario, through around 2.2°C in Continued Momentum, to around 2.6°C in Slow Evolution.

Key insights from our analysis

Eight important insights flow from our analysis in this year's Global Energy Perspective

1

Despite policy innovations, increasing global consensus, and growing private-sector commitments, emissions are not declining at the rate required

Globally, emissions are rising and are projected to peak between 2025 and 2035 before beginning to decline, but would stay well above the carbon budget for a 1.5°C trajectory. This is despite the implementation of numerous carbon-mitigating policies that have translated net-zero commitments into legislation since the Paris Agreement, alongside increasing global consensus around decarbonization—with countries accounting for more than 90 percent of global GDP now having net-zero commitments in place—as well as growing private-sector commitments. While enacting effective policy to overcome a complex and multifaceted issue such as curbing emissions is challenging, policy and other government action is a crucial component of enabling the energy transition. In many cases, macrolevel climate targets are ambitious (such as EU and US net-zero commitments by 2050) but these may not be sufficiently translated at lower-level regions and jurisdictions. Local internal combustion engine (ICE) bans or RES targets, for example, can meet opposition on the ground due to consumer affordability, grid congestion, and manufacturing capacity. Additionally, rising energy demand in emerging economies, particularly in the Association of Southeast Asian (ASEAN) countries, India, and the Middle East, means carbon-mitigating policy in these regions will be important in curbing emissions. That said, net-zero goals in these regions tend to stretch further into the future than in more mature economies. Other differences between mature and emerging economies are also still prominent, such as in the financing of low-carbon technologies. Taking all of this into account, existing policy and legislation may need to be reexamined to enable the energy transition at speed and at scale.

2

Energy demand is projected to grow by up to 18 percent through 2050

Over the next two decades, our analysis shows that global energy demand composition will shift, mainly driven by growth in energy consumption from emerging economies. This demand growth is primarily due to increasing populations, rising GDP (and energy consumption) per capita, and the growth and relocation of manufacturing industries to emerging economies. Nevertheless, per capita consumption in these regions is projected to remain below that of mature economies, driven by increasing energy efficiency, such as switching from fossils to low-carbon energy sources in ASEAN countries and electrification in China. In mature economies, as well as in China, overall demand is projected to flatten in the short to medium term. However, there are several forces at work that could affect the demand trajectory in different regions. In the United States, industrial resurgence would drive demand growth through electrification, while in Europe, by contrast, continued deindustrialization would lead to declining demand in the region. Globally, new demand sources, such as data centers (driven by the rise of AI), are also projected to contribute to increased demand.

Key insights from our analysis

Eight important insights flow from our analysis in this year's Global Energy Perspective

3

Fossil fuel demand continues, with a previously anticipated peak in the late 2020s now turning into a decade-spanning plateau

The build-out of clean energy technologies has not been fast enough to supply growing global energy demand. Consequently, fossil fuels will continue to be used across all our bottom-up scenarios, meeting 40 to 60 percent of global energy demand by 2050. Continued oil demand is projected to be driven primarily by a slowdown in EV adoption relative to historical numbers in some geographies, due to high costs and rollout challenges. Gas will continue to be used for power generation to provide firmness for an energy system with increased penetration of intermittent renewables, and gas distribution for heating will be migrated to electric load over the medium to long term. Overall, fossil fuel demand is expected to plateau between 2025 and 2035 before declining, with the timing and rate of the decline differing by scenario. This demand picture means fossil fuel investments will continue across scenarios and remain a critical part of the energy landscape to support an orderly energy transition that is affordable, reliable, and competitive.

4

Low-carbon energy sources are set to grow, but not currently fast enough to meet net-zero goals due to business case viability and other challenges

Low-carbon energy sources are projected to grow, accounting for 65 to 80 percent of global power generation by 2050. However, this growth is not fast enough under current conditions to meet short-term deployment targets. Growth rates are also projected to differ by technology. Those technologies for which the levelized cost of energy (LCOE) is already low at the point of production, such as solar, wind, and energy storage systems, are projected to continue to grow, while those with higher cost—including hydrogen and other sustainable fuels, and carbon capture, utilization, and storage (CCUS)—lack sufficient demand and policy support for strong growth. Solar stands out with particularly strong growth projections, while hydrogen growth to 2050 has been revised downward by 10 to 25 percent compared to previous estimates due to higher cost projections. Overall, low-carbon energy sources face several challenges that could threaten net-zero goals, and which are particularly pronounced for those with higher LCOE. Weak business cases for new installations where future revenues and technology costs are uncertain put the project pipeline at risk. Other challenges include rising capital costs, longer project timelines, and the need for grid build-out. For instance, in the European Union and the United States, all operational, under-construction, and announced on- and off-shore wind capacity may still be 200 GW short of 2030 targets. Overcoming these hurdles could require the support of durable and flexible policy to facilitate continued deployment. Our analysis suggests that all elements—including renewable energy, other low-carbon energy sources, energy efficiency gains, and carbon capture—will be required to achieve the goals of the transition while providing energy security.

Key insights from our analysis

Eight important insights flow from our analysis in this year's Global Energy Perspective

5

Nuclear could play a significant role in the transition, but faces headwinds in policy and public sentiment

Nuclear power could be a key driver of decarbonization—it is virtually carbon free and, given the same level of investment, generates more power than most other low-carbon energy sources. In addition, nuclear power is firm, and next-generation nuclear power projects, such as small modular reactors and molten salt reactors, show efficiency gains and lower waste generation. However, unless several policy bottlenecks are overcome and public sentiment shifts, nuclear build-out will come too late to make a meaningful difference in the energy transition. Growth in nuclear power is projected to be almost flat to 2050 due to more stringent regulatory requirements than for other low-carbon energy sources, negative public perception, perceived safety issues, supply chain constraints, and uncertainty around waste disposal. In Europe, for example, nuclear build-out has been slow and expensive, as a scarcity of projects has resulted in execution gaps across all stakeholders. While the outlook for nuclear could improve in the longer term (2050 to 2100), overcoming current hurdles could help to advance the energy transition more quickly.

6

The global cost of carbon is too low to be compatible with faster transition scenarios

Current mechanisms in place to create a global carbon market are largely ineffective in driving emissions reductions. The global carbon price is at present too low for our faster decarbonization pathways to materialize and is not compatible with a 1.5° pathway. The market is also constrained by a lack of liquidity, particularly on the demand side. Unless the current carbon price is reexamined, the global carbon market will not be effective in driving the decarbonization required for the conditions of faster scenarios to be met, particularly the at-scale uptake of CCUS. Our analysis suggests that the carbon price would need to rise to \$150 to \$225 per ton of CO_2, varying by region depending on local costs for low-carbon technology and clean energy prices.

Key insights from our analysis

Eight important insights flow from our analysis in this year's Global Energy Perspective

7

The transition cannot proceed at speed and at scale without addressing raw materials supply chains, manufacturing, and geopolitical developments

A set of interconnected challenges needs to be overcome to unlock a pathway to net zero. Supply chains are becoming increasingly interconnected, and energy security is a pressing issue for many countries. As a result, multiple parallel supply chains for crucial materials are forming, reinforced by domestic demand. Original equipment manufacturers (OEMs) are experiencing high demand for new low-carbon energy installation components but are also facing substantial backlogs. Demand may therefore be challenged both in terms of speed and scale by the availability of critical components that enable low-carbon energy build-out. Geopolitical challenges could further impact global supply chains and shift focus to energy security.

8

The scale-up of critical materials faces constraints, including lack of viable business cases

Low-carbon technologies often require different materials than those embedded in conventional technologies, such as battery materials (primarily lithium, nickel, and cobalt) and magnet materials (mainly rare earth), with these materials accounting for less than 20 percent of global metals and mining revenue, which is led by steel and thermal coal. The scale-up of some raw materials is constrained by the long development timelines of greenfield assets. And for cases where supply is likely to be sufficient, prices may have to increase to make business cases viable. A major challenge for the extraction and processing of critical materials is the uncertainty around long-term demand profiles, which creates hesitation among investors and weakens business cases for new mining and refining assets. This unclear demand picture is impacted by the rapid development of downstream technology, geopolitical uncertainties, and local political instability in some geographies. For the energy transition to succeed, business cases would need to be robust enough to enable sufficient materials to be extracted and processed at the scale required to enable the build-out of low-carbon energy sources. For more, read our companion report, *Global Materials Perspective 2024*.

Energy demand

Global energy demand is growing faster than expected, and a more challenging geopolitical landscape—combined with the emergence of new sources of demand and smaller-than-expected efficiency gains—means that the evolution of demand growth could see rapid changes in unexpected directions.

Global energy demand is projected to grow by up to 18 percent through 2050. Most of this growth will come from emerging economies, where growing populations and a strengthening middle class will result in higher energy demand. The relocation of manufacturing industries from mature to emerging economies will further shift demand to these economies, too. The rise of artificial intelligence (AI) and its future trajectory could also significantly influence demand, with uncertainty still surrounding its future impact. How this new demand is met will set the trajectory of the energy transition.

Developments in emerging economies, particularly ASEAN countries, India, and the Middle East, are critical, given that these regions are projected to drive between 66 and 95 percent of energy demand growth to 2050, depending on the scenario. A substantial part of this growth is projected to come from ASEAN countries, cementing the region as a key energy demand center—further reshaping global energy trade flows and increasing the region's geopolitical importance.

In Europe, on the other hand, overall energy demand has been flat or declining for some time. If energy prices remain high, the expected demand trajectory may not materialize. While the European Union has seen significant decarbonization, energy prices are still around two to three times higher than historical averages and could grow to more than double those in the United States in the long run, contributing to a potential lack of industrial competitiveness in the region. This raises important questions around how to achieve decarbonization while supporting economic growth.

Uncertainty in the global energy demand outlook is also impacted by the emergence of new demand centers, the most striking of which is the rise of AI and the associated boom in data centers. The effect that AI could have on future energy demand could vary substantially depending on the growth trajectories of its many applications, as well as those of other technologies. Our research estimates that the rise of cloud solutions, cryptocurrency, and AI could see data centers accounting for 2,500 to 4,500 terawatt hours (TWh) of global electricity demand by 2050 (5 to 9 percent of total electricity demand). New demand centers such as these can have unpredictable effects on the energy system—for example, data centers are mostly powered by electricity (with backup generators) and have constant demand, creating greater need for gas or other firming sources of energy to balance out the intermittency of RES.

AI could create between $10 trillion and $15 trillion of economic value annually across the global economy, while generative AI (gen AI) alone could create between $2.5 trillion and $4.5 trillion annually.[8] However, realizing even a quarter of this potential by the end of the decade would require an additional 50 to 75 GW of data center infrastructure worldwide. Unleashing the full economic potential of AI will require sufficient supply of clean electricity to meet burgeoning demand from data centers, as well as the associated grid infrastructure.

Electrification is accelerating—our analysis suggests that between 2023 and 2050, electricity consumption could more than double in slower energy transition scenarios and nearly triple in faster scenarios. This is in comparison to total energy consumption growth of 12 to 21 percent over the same period, depending on the scenario. Electrification is a key lever for increasing energy efficiency, but the uptake of electrification technologies, including heat pumps and EVs, has slowed despite ongoing investment (energy efficiency investments in 2022 increased by 16 percent to $600 billion).[9]

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[8] "AI at scale: Propelling your organization into the next normal," McKinsey, February 25, 2021; "Notes from the AI frontier: Applications and value of deep learning," McKinsey, April 17, 2018; "The economic potential of generative AI: The next productivity frontier," McKinsey, June 14, 2023.

[9] "Energy efficiency," IEA.

Energy demand

Although the drivers of global energy demand are multifaceted and liable to change, governments will play an important role in shaping future demand. While regulatory certainty is critical for unlocking investment, governments also need to respond to the ever-evolving reality of the energy transition and adapt in a predictable and well-defined way to evolving variables in the system, such as interest rates and capture prices. The right balance will need to be struck between policy stability and regulatory responsiveness.

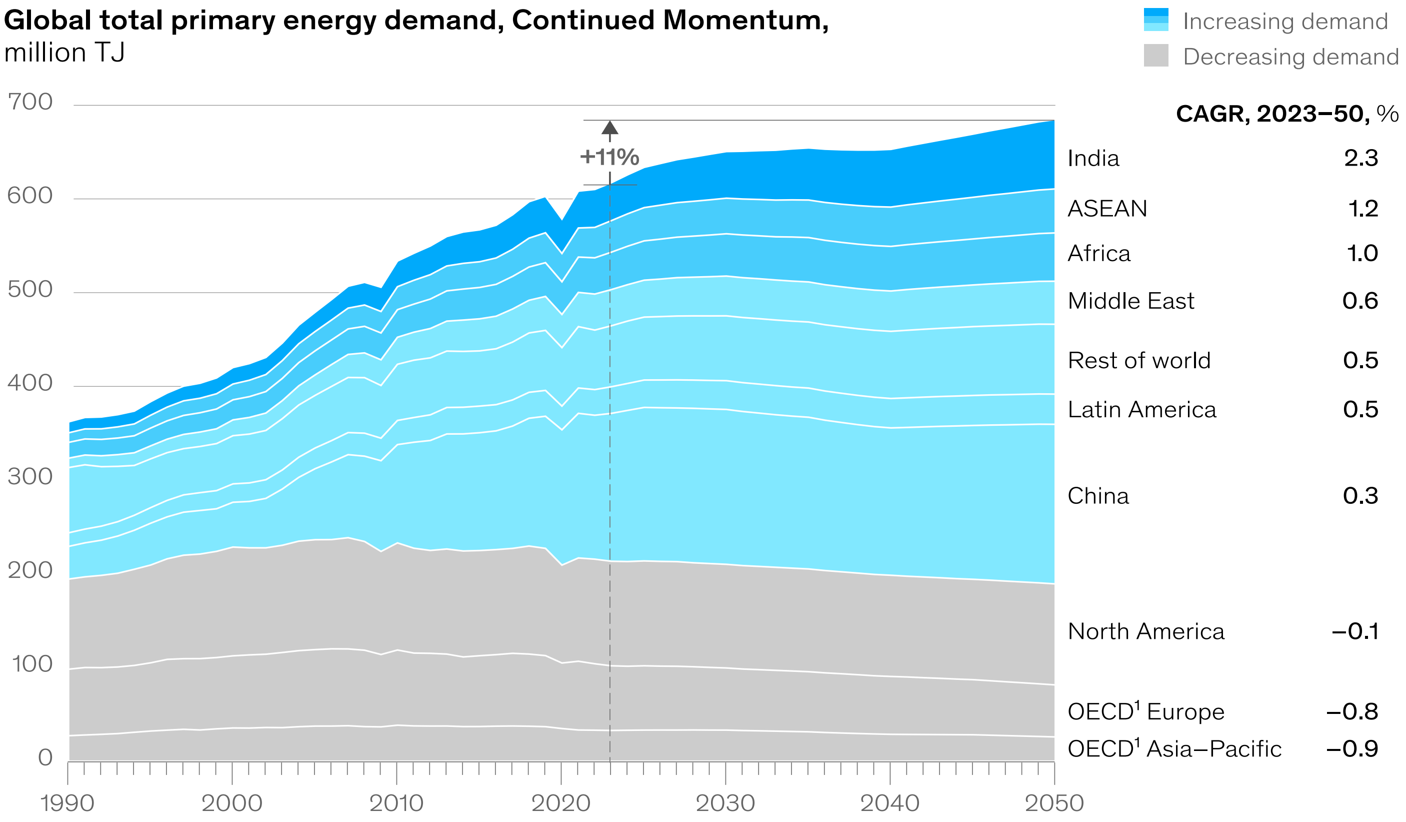
How the world will meet the projected increase in energy demand is one of the key questions of the energy transition. Both RES and new fossil fuels build-out will be required to ensure demand is met by supply, and nuclear power could play a bigger role in the years beyond 2050. However, for all these energy sources, lengthy project timelines and higher interest rates could add costs and put project execution at risk.

All of this has important implications for emissions. As a result of rising energy demand, slower-than-expected efficiency gains and the continued role of fossil fuels in the energy mix, emissions have not yet peaked. By 2050, emissions remain substantially above a level compatible with a 1.5° pathway in all our bottom-up scenarios, emphasizing the ongoing need for a major course correction in the energy transition.

Energy demand is projected to increase

Emerging economies in the ASEAN region, India, and the Middle East will account for the majority of demand growth

Global total primary energy demand, Continued Momentum, million TJ



¹The Organization for Economic Cooperation and Development.

Global energy demand[10] is projected to grow by between 11 percent (in the Continued Momentum scenario) and 18 percent (in the Slow Evolution scenario) by 2050. This is driven by increased demand in emerging economies, especially in the ASEAN region, India, and the Middle East, among others. Africa is also projected to see significant growth in energy demand, but still accounts for a small fraction of global energy demand since it is growing from a current low base. In contrast to recent decades, demand growth in China is projected to be largely flat and more in line with demand growth in Europe and North America.

Historically, emerging economies have had low energy demand compared to more mature economies but are now seeing an increase linked to population growth (1.5 billion by 2050) and economic development contributing to increased affluence and higher living standards. In Africa, ASEAN countries, India, and the Middle East, GDP per capita is projected to increase by between 1.0 and 4.5 percent per annum over the same period. Together, these factors are projected to result in higher total energy demand globally by 2050, despite energy efficiency gains.

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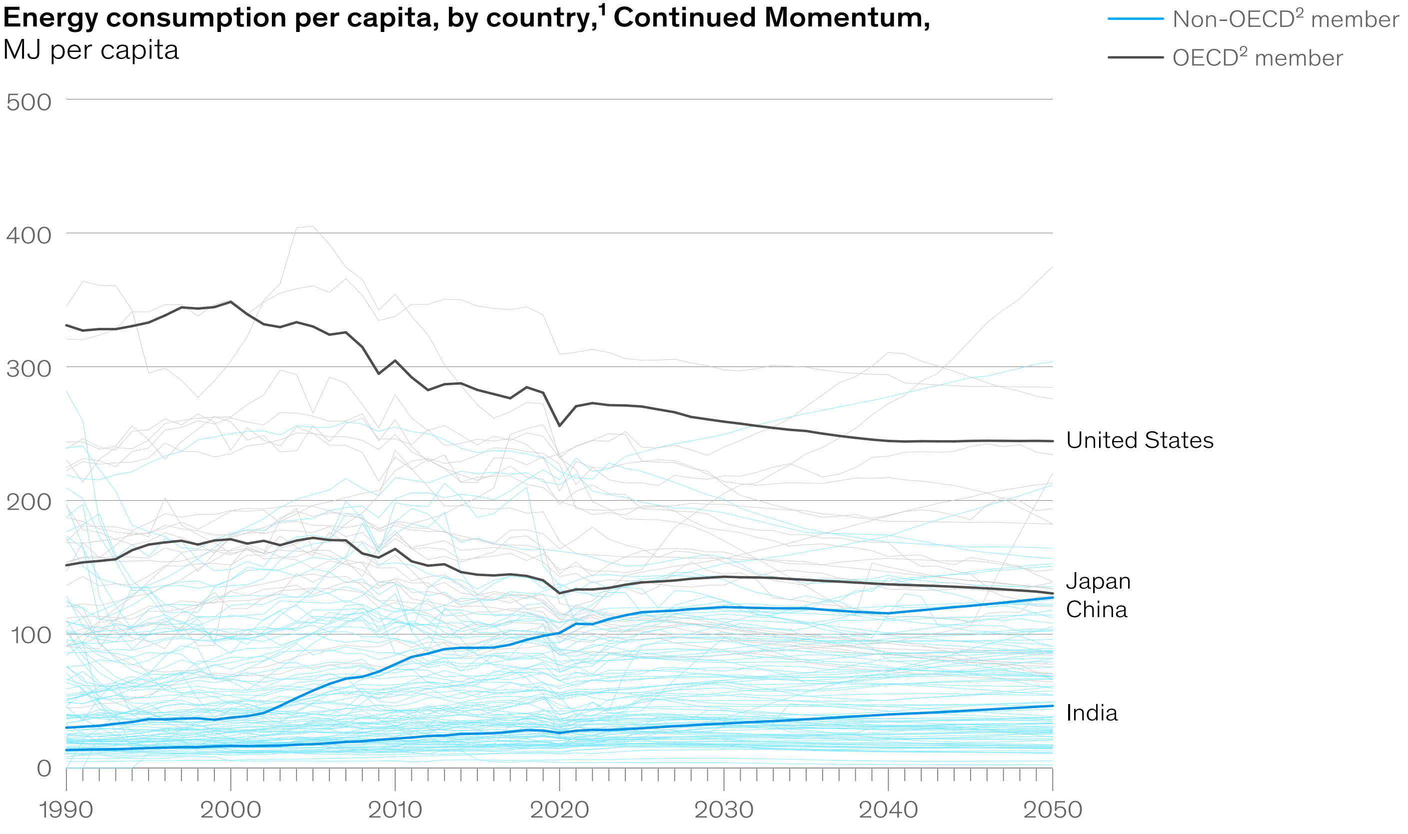
[10] Demand refers to the total primary energy demand that is required to fulfil total final energy consumption, including losses (for example, final gas-powered electricity consumed requires more natural gas demand to account for losses in electricity generation).

Per capita demand is projected to increase in non-OECD countries

Nevertheless, per capita demand will still be lower in non-OECD countries than OECD

Energy consumption per capita, by country,[1] Continued Momentum, MJ per capita



[1] Some countries are removed for readability.

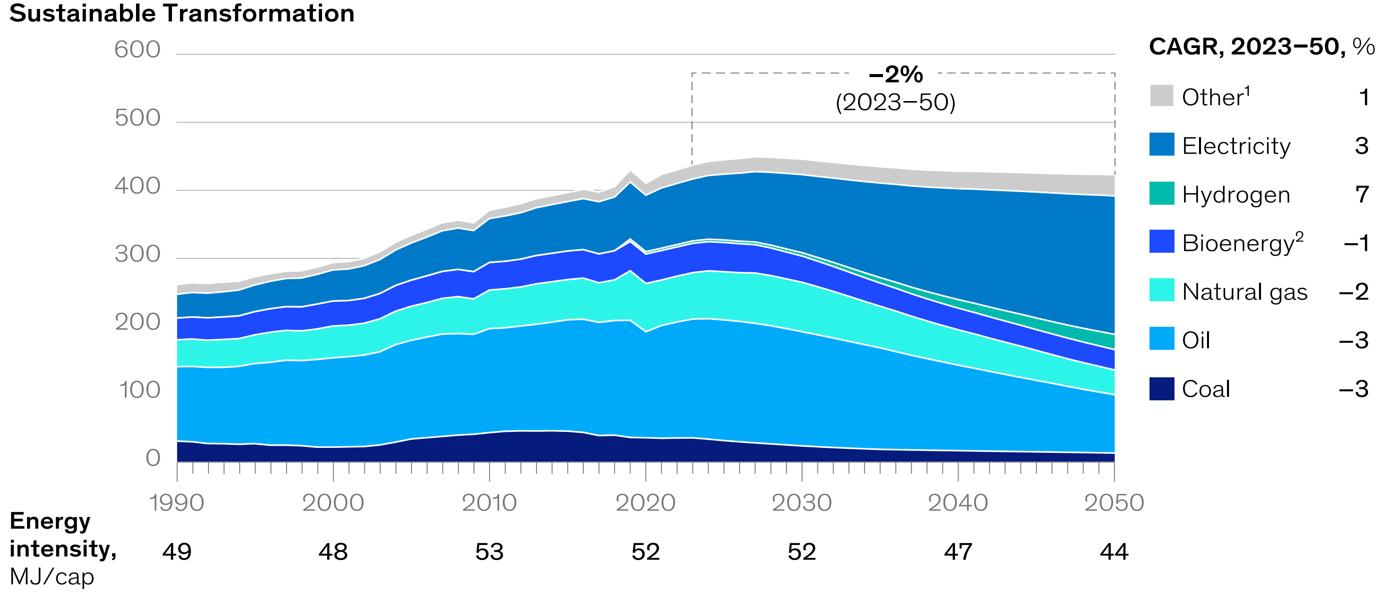
[2] The Organization for Economic Cooperation and Development.

At the same time, energy demand per capita is projected to decrease, partially offsetting the growth in absolute energy demand, but will remain highly variable between countries and regions. Despite their role in driving energy demand, emerging economies will likely continue to have lower energy demand per capita than mature economies.

Our Sustainable Transformation scenario exhibits stronger gains in energy efficiency compared to demand growth

The share of electricity in final consumption is projected to be 32 to 48 percent by 2050 across scenarios

Global final energy consumption by fuel, million TJ



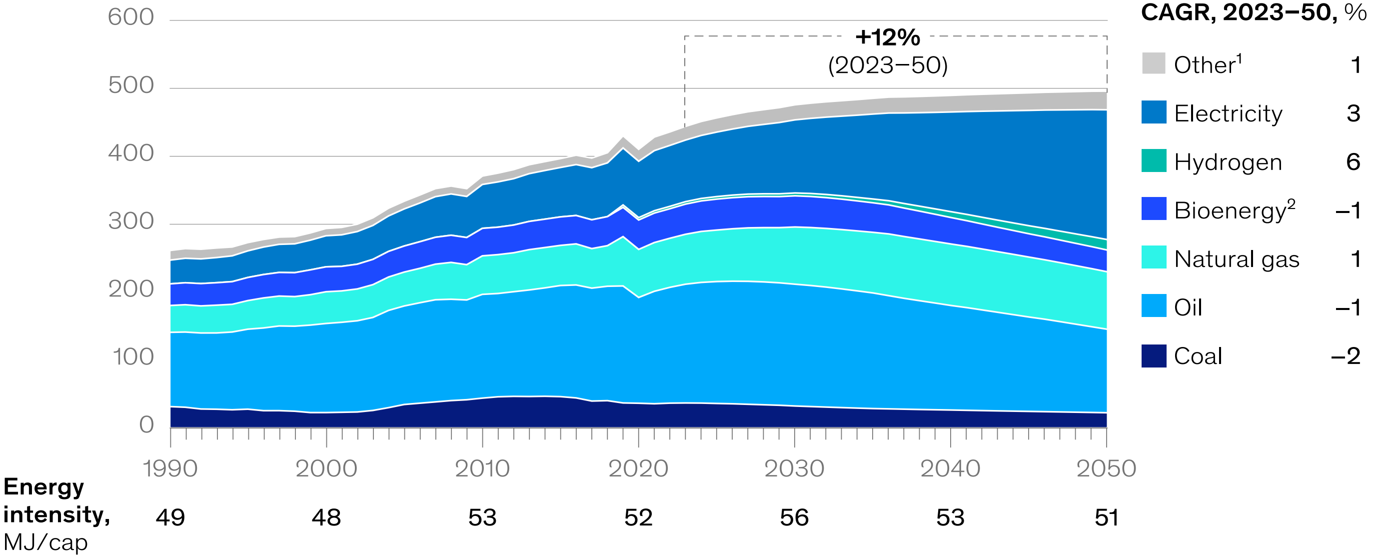
Despite expected improvements in energy efficiency, global energy consumption to 2050 is projected to decrease by 2 percent in the Sustainable Transformation scenario, while increasing by between 12 and 21 percent in the Continued Momentum and Slow Evolution scenarios, respectively.

[1] Includes heat, geothermal, and solar thermal.
[2] Includes synthetic fuels, biofuels, and other biomass.

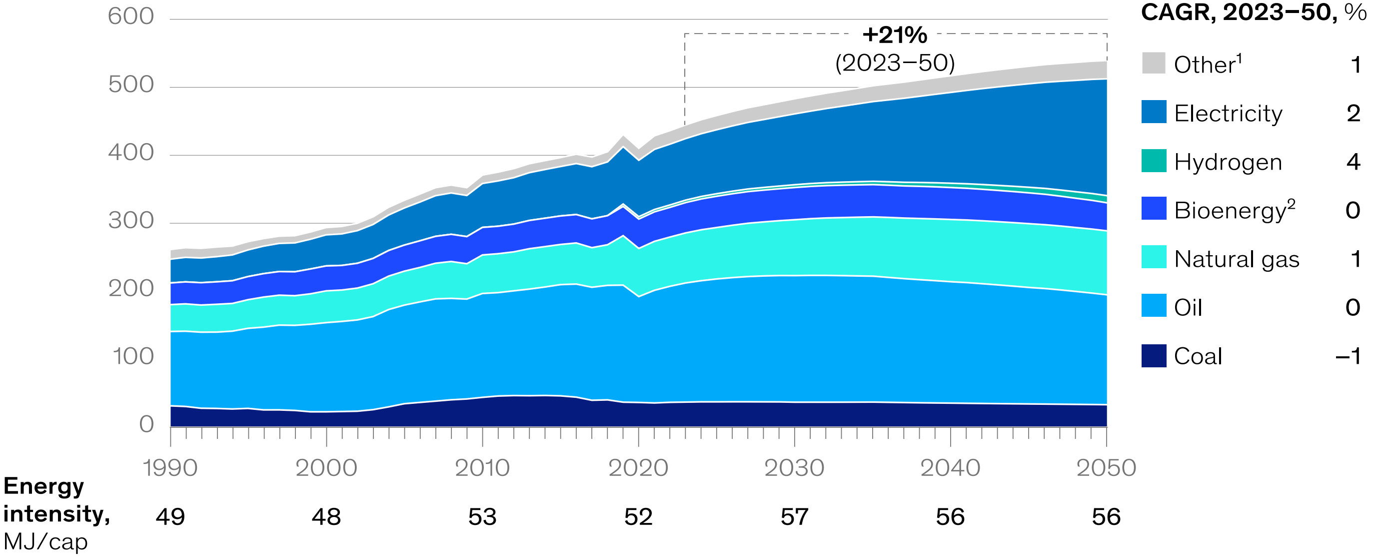
Energy consumption is projected to increase in most scenarios

The share of electricity in final consumption is projected to be 32 to 48 percent by 2050 across scenarios

Continued Momentum



Slow Evolution



The increase in consumption is largely due to the same fundamentals underlying global energy demand: population growth and increasing GDP per capita. The extent of this growth in consumption varies significantly by scenario due to differences in energy efficiency and electrification.

Electrification of the energy system results in a reduction in final energy consumption due to the more efficient use of energy. Electricity is projected to become the largest source of energy by 2050 across scenarios, with consumption coming from traditional sectors (for example, electrification of buildings) as well as newer sectors (such as data centers, EVs, and green hydrogen).

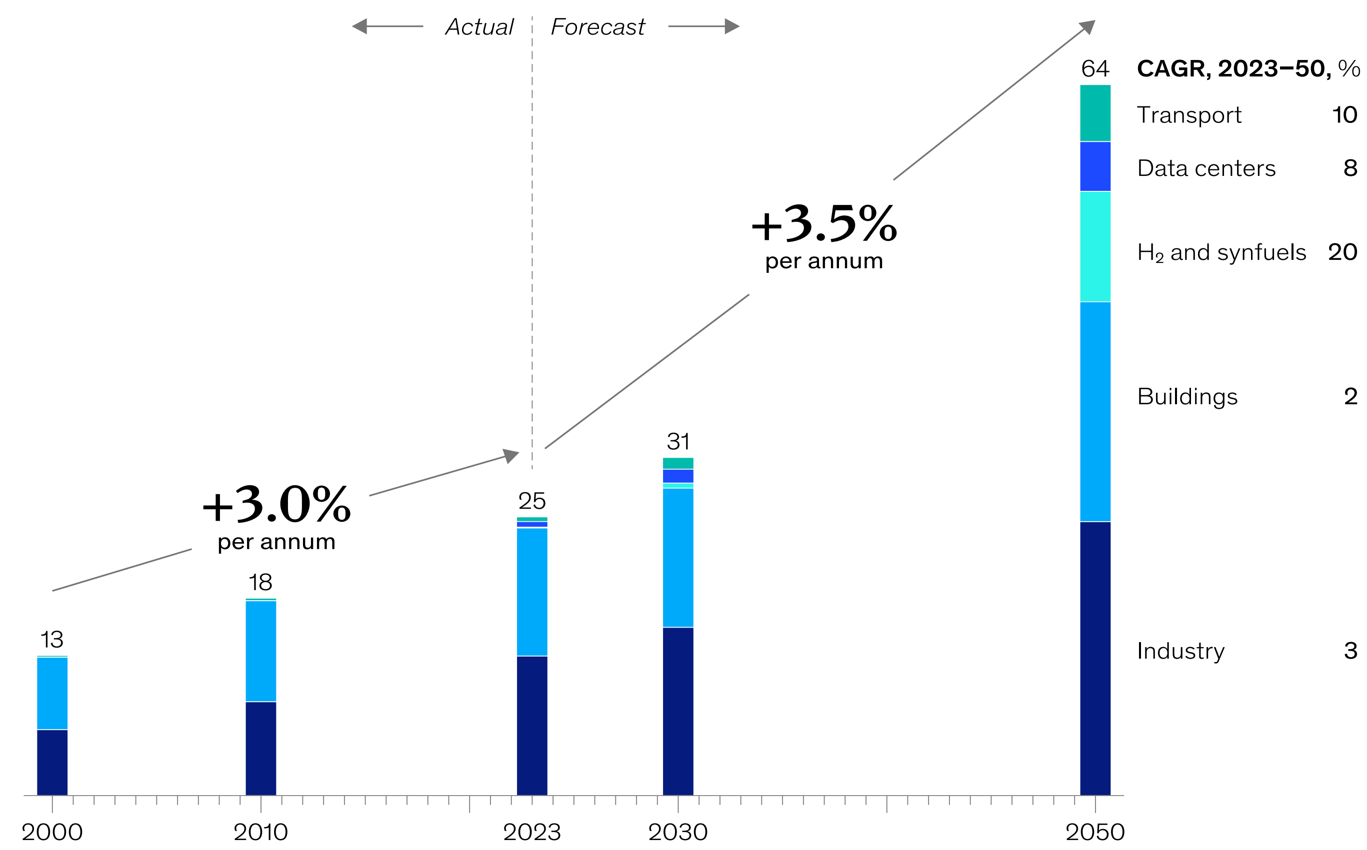
Despite the uptake of electrification, fossil fuels are projected to continue to account for a significant share of the energy mix to 2050.

[1] Includes heat, geothermal, and solar thermal.
[2] Includes synthetic fuels, biofuels, and other biomass.

Growth in electricity consumption is expected to accelerate as new demand centers emerge

Data centers, hydrogen production, and EVs are projected to account for a growing share of electricity consumption by 2050

Global power consumption by sector, Continued Momentum, thousand TWh



Source: IEA; IRENA

The rapid rise of cloud solutions, cryptocurrency, and AI is set to lead to significant growth for data centers globally. By 2030, there is projected to be a 150 GW capacity of graphic processing units (GPUs) for data centers globally, and data centers could account for up to 4,500 TWh of electricity consumption by 2050 (5 to 9 percent of total electricity consumption).

Data centers could be a significant driver of power demand growth in several regions. In Europe, for instance, data centers are projected to be the primary near-term growth driver for power demand—with most of this for clean electricity. Meeting this clean power demand will be crucial to enable the full economic potential of AI and will require the build-out of sufficient clean power sources and associated grid infrastructure.

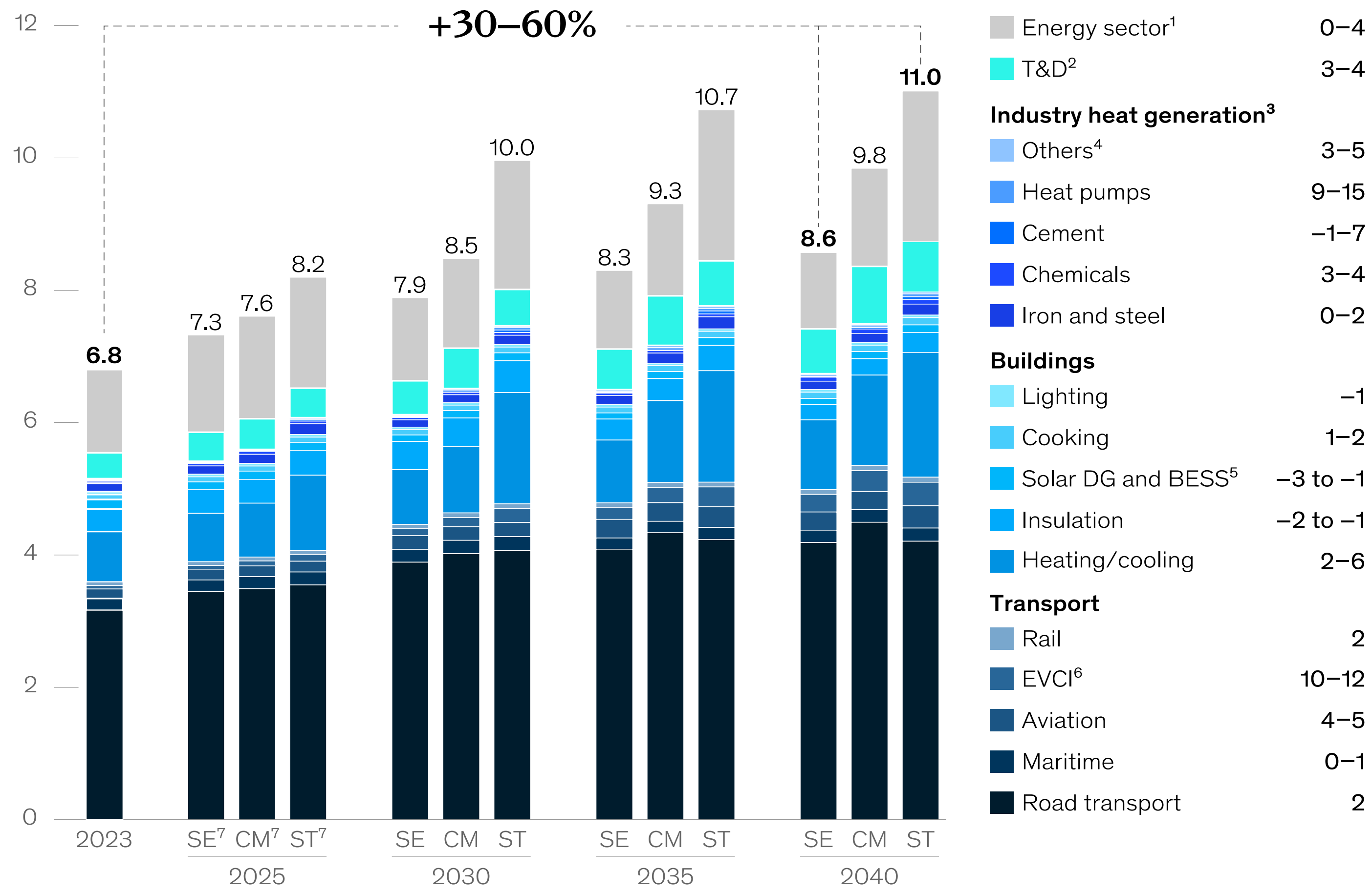
Under the Continued Momentum scenario, global green hydrogen consumption is projected to increase to 179 megatons per annum (Mtpa) by 2050, up from less than 1 Mtpa today and 5 Mtpa in 2030. This could lead to a growth in power consumption of 20 percent per year for the sector.

Electricity consumption in transport could grow by around 10 percent annually in the Continued Momentum scenario, driven by increased penetration of EVs. Battery electric vehicles (BEVs) are projected to account for most global passenger car sales by 2050, up from 13 percent today.

Annual capital spending on physical assets is projected to grow by 40 to 80 percent until 2040

Faster scenarios would require additional spending in all sectors

Global annual capital spending on physical assets, $ trillion



Under all scenarios, more capital is needed to enable the energy transition—particularly in the Sustainable Transformation scenario. A large portion of this capital will need to be deployed in the infrastructure required for a transforming energy system, particularly transmission and distribution (T&D) infrastructure. Investment is expected to grow at 3 to 4 percent CAGR.

Capital spend for fossil fuels is projected to continue under all scenarios in the short to medium term. This will help to ensure that there is sufficient capacity to meet demand and to balance intermittency as renewables make up a bigger share of the global energy system.

Note: Numbers are also available in the 2041–50 period, but outputs are less accurate.

[1] Includes upstream and selected parts of midstream and downstream (ie, power, carbon capture, utilization, and storage [CCUS], compression, transport, and storage). [2] Transmission and distribution. [3] For industry, only energy intensive or heavy emissions assets were considered. [4] Includes mining and direct air capture (DAC). [5] Solar distributed generation and battery energy storage system. [6] Electric vehicle charging infrastructure. [7] SE = Slow Evolution; CM = Continued Momentum; ST = Sustainable Transformation.

Low-carbon energy sources

Meeting the growing global demand for energy will require a significant build-out of RES along with other low-carbon energy sources. However, a set of new and existing challenges to RES build-out will need to be overcome to ensure the energy transition continues at pace. While RES are now cheaper and make up a larger part of the energy mix than ever before, more work is needed around the economic viability of some RES business cases.

To better understand the complex economics of RES build-out, this year's iteration of the Global Energy Perspective includes an analysis of grid costs, alongside generation costs. In many cases, the build-out of a supporting grid, rather than RES installation itself, may be the limiting factor for new RES. Renewables projects require extensive grid build-out, often in areas away from centers of demand, with important implications for costs and project timelines (for more detail on grid costs, see Bottlenecks section).

Power pricing is another emerging challenge affecting energy systems with a high penetration of renewables. The comparatively lower marginal costs of RES mean that the price of electricity tends toward zero—or even negative pricing—at certain times of day. For new RES installations, this could potentially impact the business case, requiring electricity providers to derisk their positions. In some scenarios, including those with the most cost-effective decarbonization pathways, our analysis shows that new RES build-out would not have a positive business case without regulatory intervention. The macroeconomic landscape for RES build-out has also changed. Capital has become more expensive in recent years, further affecting new RES build-out, which tends to be more capital expenditure (capex) intensive than traditional energy sources, particularly for off- and onshore wind. Despite these challenges, renewables growth remains strong, supported by governments' decarbonization targets and boosted by new demand for clean power, though the pace and extent of growth remains uncertain.

To supply projected energy demand and increase the viability of RES-based power systems, stakeholders now need to consider how to build a fully running and reliable energy system based on renewables. Here, emerging economies have an opportunity to build a renewables-based system from the ground up to meet their burgeoning energy needs, potentially leapfrogging some of the constraints imposed by adapting a preexisting energy system to run on renewables. Doing so would require conscious planning; purposeful, pragmatic action; and a supportive policy environment to ensure that a renewables-based energy system could meet rapidly growing demand.

Considerable progress has been made on the policy front. In many mature economies, industrial policy is now anchoring climate technologies as a core pillar and substantial public funds are being earmarked for their development. In Europe, for instance, the European Green Deal, introduced in 2019, aims to make the European Union climate-neutral by 2050, with intermediate Fit for 55 targets to reduce greenhouse gas (GHG) emissions by at least 55 percent by 2030 compared to 1990 levels.[11] In the United States, the Inflation Reduction Act (IRA) of 2022 provided total climate-related spending of almost $370 billion over ten years, with the aim of cutting emissions by 40 percent by 2030 from 2005 levels.[12] In addition, the Infrastructure Investment and Jobs Act has allocated billions toward modernizing the energy grid, expanding EV infrastructure and enhancing energy efficiency across sectors.[13] Together with continued cost improvement, including through innovation, these and other policy initiatives are leading to progress in the deployment of low-carbon power.[14]

Achieving firmness in a renewables-based system introduces another complex challenge. The business case for firming capacity, such as from gas or battery electric storage systems (BESS), needs to make sense and be supported by government and correct market design. Even though a renewables-based system may be cheaper than a fossil-based one, the need

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[11] "European green deal," Council of the European Union, June 17, 2024.
[12] *Building a clean energy economy: A guidebook to the Inflation Reduction Act's investments in clean energy and climate action*, The White House, January 2023.
[13] "A guidebook to the bipartisan infrastructure law," The White House, January 2024.
[14] For further information on how state leaders in the United States can support the energy transition while creating inclusive economic growth, see Adam Barth, Karina Gerstenschlager, Ksenia Kaladiouk, and Adi Kumar, "How US states can advance a successful clean-energy transition," McKinsey, January 29, 2024.

Low-carbon energy sources

for firmness is nontrivial—and this, in combination with the required grid investment, could make the final cost of power for the consumer higher than previously anticipated. Policy and regulation can play a role in ensuring the build-out of low-carbon firm energy sources is feasible, with robust business cases that result in affordable power for end users. Additionally, BESS and other long-duration energy storage (LDES) technologies could play an important role in meeting demand located far from the grid and in balancing a renewables-based system.

Despite the many challenges facing them, low-carbon energy sources are still projected to experience significant growth, accounting for the majority of the global power mix by 2050. However, this growth will not be evenly distributed among the various low-carbon energy sources:

- Solar is projected to make up the bulk of the global renewable power mix in 2050, at 16,000 to 30,000 TWh, due to decreasing equipment costs, increased flow of private equity capital into solar, coupling to BESS, and the easing of permitting processes. The penetration of solar varies by region—China stands out from an absolute volume perspective, with far more solar installed than other regions. However, solar still makes up a relatively lower share of the Chinese power mix than in regions that have less absolute capacity, such as the European Union and the United States.
- Hydrogen demand growth is projected to be slower than previously anticipated—10 to 25 percent lower in 2050, depending on the scenario—driven by reductions in projected demand across sectors, particularly road transport and buildings. Increased capital costs, lower learning rates, more expensive electrolyzer capex, and higher RES costs have driven up the cost of green hydrogen by 20 to 40 percent. Some lingering uncertainty around regulations also remains. While future hydrogen demand will be greater than it is now, our analysis shows that this slower growth would mean the associated demand for power for hydrogen production would be lower than previously anticipated, too, though also still greater than today.
- Other sustainable fuels are projected to see significant growth, particularly in hard-to-abate transportation segments such as aviation, maritime, and heavy-duty road transport. Growth to 2030 is mainly driven by policy already in place or proposed, while long-term growth will depend on future regulations and technological advancements. Most of the growth is projected to come from new technologies and advanced or waste feedstocks, requiring a fundamental change in how clean fuels are produced today. Feedstock for sustainable fuels is likely to continue to be the major bottleneck to deployment, and governments are set to play a critical role in the evolution of sustainable fuel demand.

Renewables are projected to make up the bulk of the power mix into the future

The share of renewables could more than double in the next 20 years, while clean firm and gas power generation increases across most scenarios

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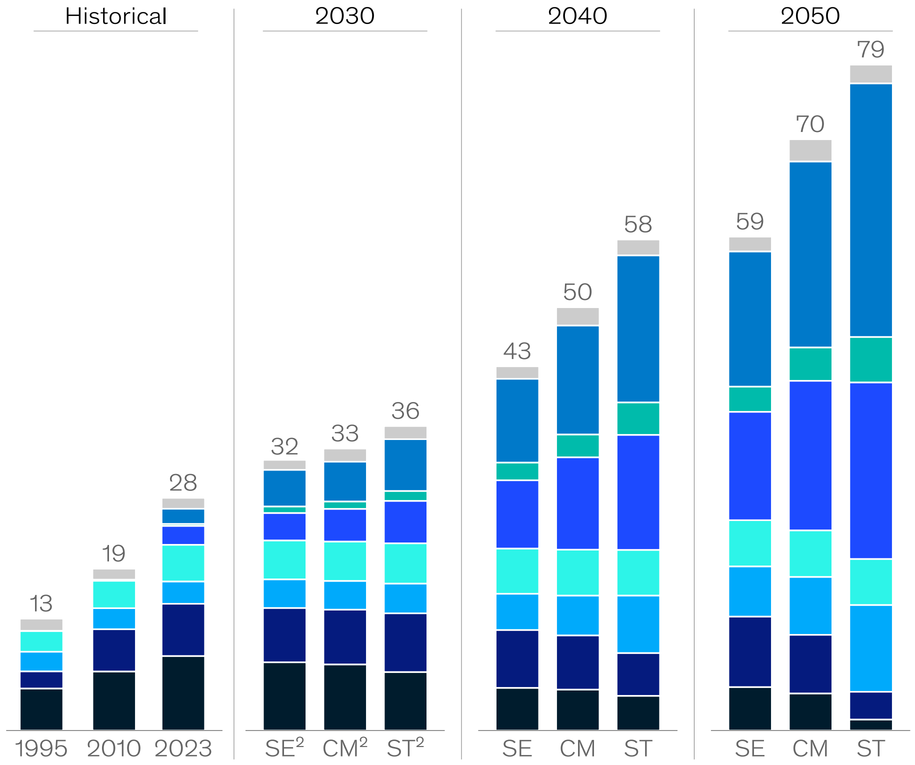
Global power generation,[1] thousand TWh



CAGR, CM,[2] 2023–40, %	
Other[3]	3
Solar	12
Wind offshore	15
Wind onshore	10
Hydro	1
Clean firm[4]	3
Gas	0
Coal	–3

	1995	2010	2023	SE[2]	CM[2]	ST[2]	SE	CM	ST	SE	CM	ST
Share of renewables,[5] %	19	18	32	~45	~45	~50	~60	~70	~75	~65	~75	~80
CO$_2$ emissions, Gt		~11	13	~13	~13	~12	~11	~10	~8	~11	~9	~4

Renewables currently account for 32 percent of global power generation and are projected to grow to between 65 and 80 percent by 2050, depending on the scenario. This growth is primarily driven by the lower cost of RES, though policy and incentives also play a role. Clean firm power generation—which includes gas and coal plants with CCUS, nuclear, and hydrogen—is also projected to make up a relatively larger share of the energy system in 2050, with a projected growth rate of 4 percent per annum.

Installed capacity will need to be sufficient to cover peak demand, given it does not correspond one-to-one with generation for any power supply. This is particularly marked for renewables, as the intermittency of RES means there can be a large difference between capacity and generation. RES (without time-shift battery systems) can only cover peak demand during RES operating hours, which might not correspond with the demand peak in any given day. And, to enable new-generation projects to come online, significant grid build-out will also be required.

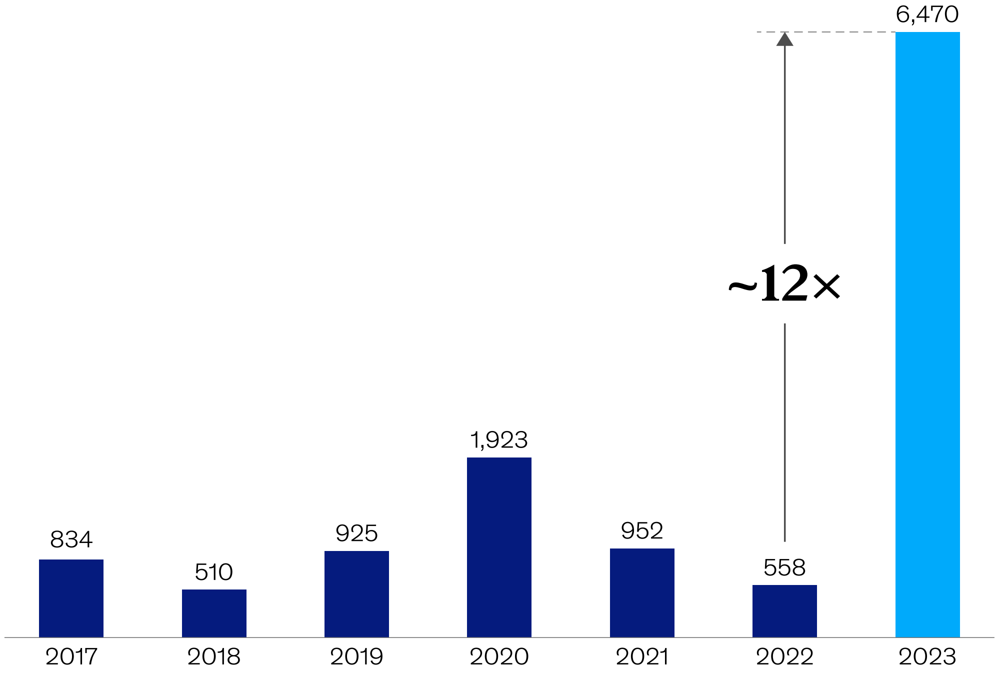
Ensuring firmness is another key consideration for a renewables-based system. Gas is likely to play a key role in providing firmness to the system as it can be deployed quickly, allowing the system to respond rapidly to supply shortages. However, the business case for installing gas capacity with low utilization may not be viable in some situations, potentially requiring government intervention to ensure that RES systems (with their characteristic intermittency) are enabled by the necessary firming capacity.

[1] Excludes generation from storage (pumped hydro, batteries, LDES). [2] SE = Slow Evolution; CM = Continued Momentum; ST = Sustainable Transformation. [3] Other includes bioenergy (with and without carbon capture utilization and storage [CCUS], geothermal, and oil. [4] Includes gas and coal plants with CCUS, nuclear, and hydrogen. [5] Includes solar, wind, hydro, biomass, bioenergy with carbon capture and storage (BECCS), geothermal, and hydrogen-fired gas turbines.

Hourly prices are becoming more volatile in regions such as Europe

Price volatility will be driven by an increase in hours with zero or negative prices

Yearly occurrences[1] of day-ahead negative electricity prices in the EU[2]



[1] One occurrence corresponds to one hour during which prices are negative.
[2] EU + Norway and Switzerland.
Source: European Union Agency for the Cooperation of Energy Regulators (ACER)

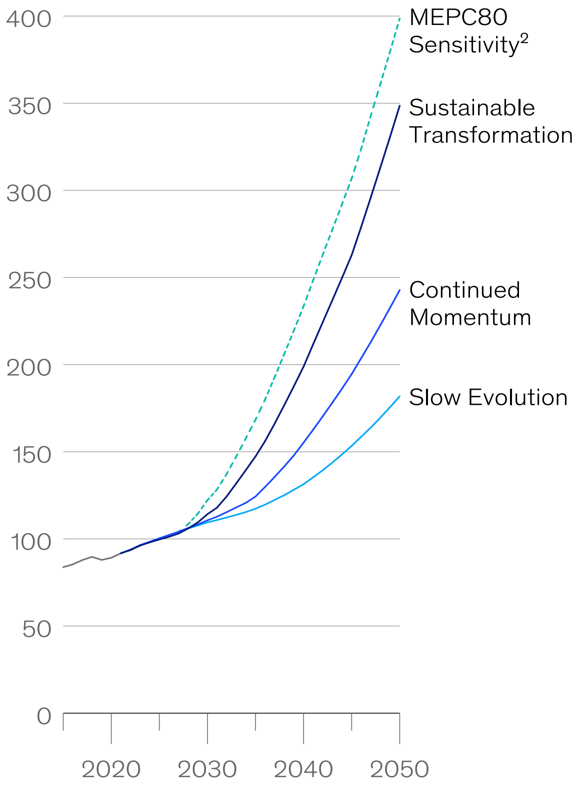
As renewable penetration increases over time, the distribution of hourly prices is projected to be impacted in two different ways. First, an increasing number of hours is expected when RES set the price, driving the spot price toward zero or even into the negative in Europe; and second, a decreasing number of hours when combined cycle gas turbines (CCGTs) are operating. This trend creates uncertainty over the future business case for renewables technologies (including future revenues and technology costs) and could put renewables projects in the pipeline at risk. High solar penetration in California has led to significant periods of negative pricing, particularly in the colder months during mild weather when demand is muted but irradiation is strong.

For example, in 2025, RES are projected to set the price 5 percent of the time, with CCGTs setting the price between 60 and 70 percent of the time. By 2035, RES are projected to set the price 20 percent of the time, with CCGTs only setting the price 35 percent of the time.

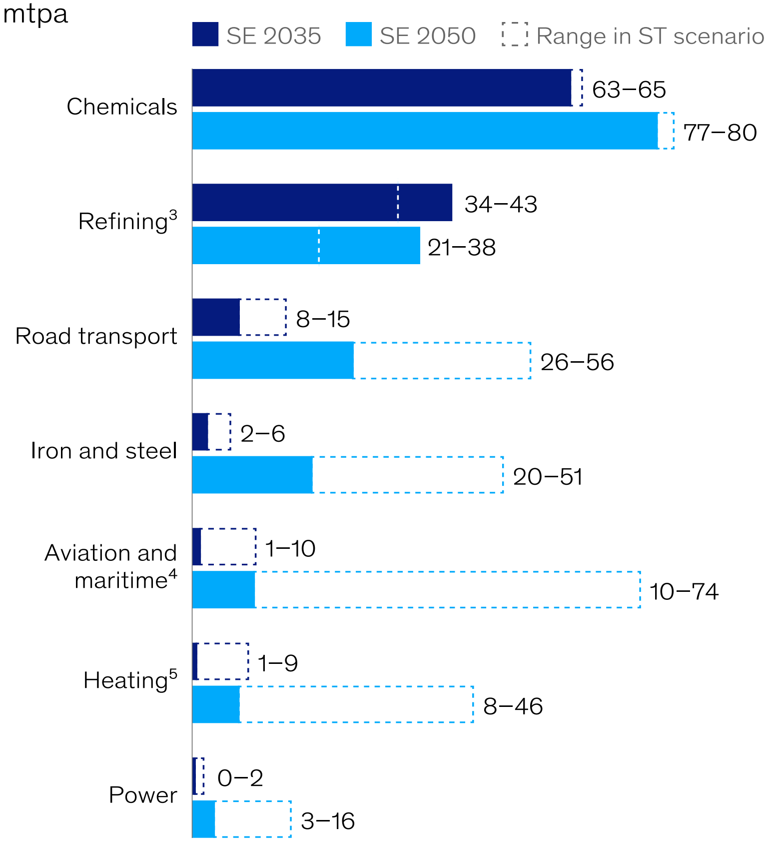
For providers, this could mean that business cases for new RES installation may not be viable, particularly where build-out is done on a merchant (rather than derisked) basis. Developers could even lose revenue through noncompensated energy curtailments where there is a mismatch between supply and demand.

Across scenarios, hydrogen demand is projected to be lower than previously anticipated but still calls for significant expansion

Demand for clean hydrogen is projected to grow two to four times by 2050[15]



Global hydrogen demand outlook by scenario, mpta



Global hydrogen demand by sector, SE to ST scenarios,[1] mtpa

[1]SE = Slow Evolution; ST = Sustainable Transformation. [2]MEPC80 Sensitivity includes the implications of the 2023 adoption of IMO Greenhouse Gas Strategy. [3]Refining is the only sector where demand in 2035 and 2050 in the ST scenario is lower than in the SE scenario. Includes conventional fuels refining and biofuels hydrogenation and refining. [4]Aviation and maritime include the direct use of hydrogen and hydrogen-derived synfuels including kerosene, diesel, methanol, gasoline, and ammonia. The category also includes some hydrogen-derived synfuels in road transport. Maritime in Sustainable Transformation includes MEPC72. [5]Includes hydrogen demand for heating in other industry and buildings.

Hydrogen demand is projected to grow two- to fourfold by 2050, driven by increasing demand in existing sectors and emerging demand from new sectors where clean hydrogen will be necessary for decarbonization. The large majority of this future demand is projected to be for green hydrogen, accounting for 50 to 70 percent of total demand, depending on the scenario.

Although this growth is significant, it is 10 to 25 percent lower than previously anticipated. Projected growth has been revised downward due to fundamental cost increases that have disproportionally affected hydrogen, as well as some continued uncertainty around regulation. Demand is projected to be lower than expected across sectors, but particularly in road transport and buildings.

By sector, road transport could drive around 15 percent of hydrogen demand growth until 2050, driven by the uptake of fuel cell EVs.

Aviation is expected to account for around 5 to 15 percent of hydrogen-based energy demand by 2050 due to demand for hydrogen for synthetic kerosene production.

Iron and steel are projected to account for around 10 to 15 percent of total hydrogen demand growth, driven by uptake of clean direct reduced iron (DRI) steel production.

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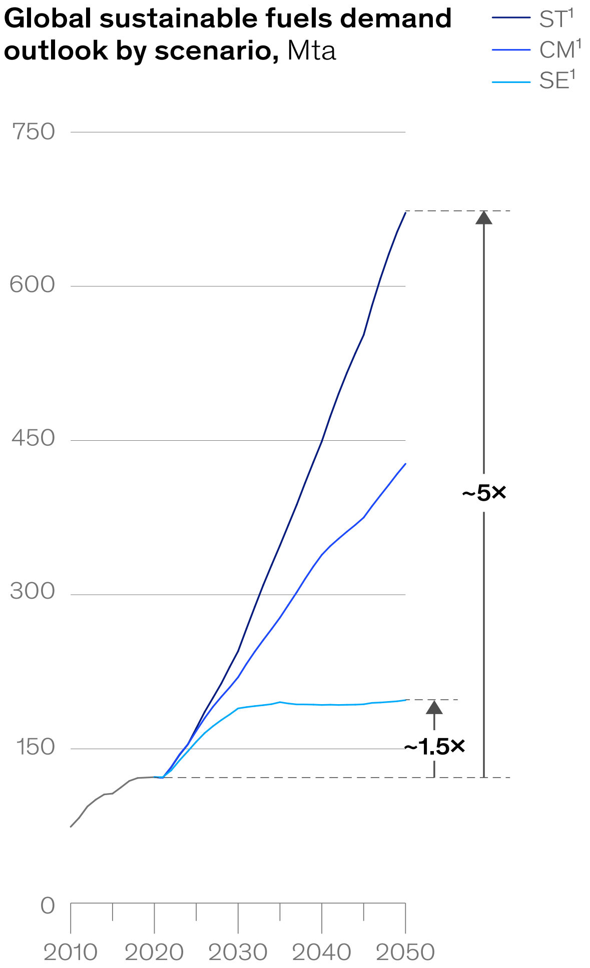
[15] Including green hydrogen (hydrogen produced by the electrolysis of water using RES) and blue hydrogen (hydrogen produced from natural gas with carbon capture and storage).

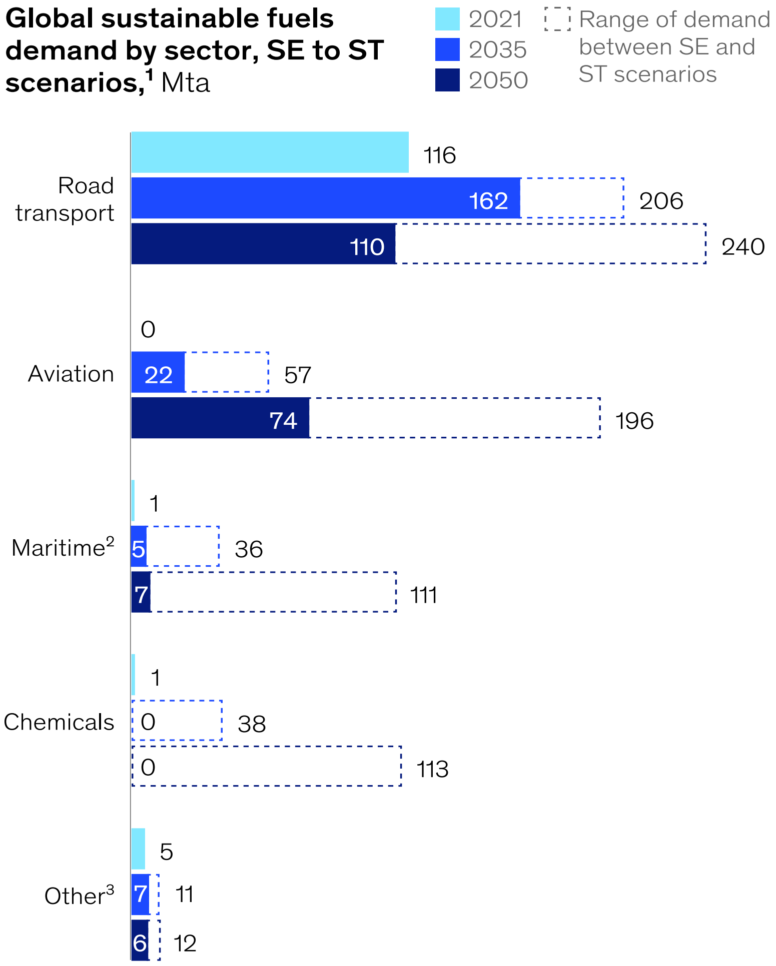
Demand for sustainable fuels is expected to grow significantly, quadrupling by 2050 in some scenarios

The main differentiation in growth rates occurs in 2030–50

Global sustainable fuels demand outlook by scenario, Mta



Global sustainable fuels demand by sector, SE to ST scenarios,[1] Mta



Note: Liquids only.
[1]SE = Slow Evolution; CM = Continued Momentum; ST = Sustainable Transformation.
[2]Maritime in Sustainable Transformation includes MEPC72.
[3]Other includes iron and steel, other industry, buildings, and electricity generation.

Across scenarios, sustainable fuels (excluding clean hydrogen) are expected to play an increasingly important role in transportation, including in hard-to-abate sectors, such as aviation, maritime, and heavy duty road transport. The share of gasoline has already started to decline in Europe, potentially leading to lower demand for conventional biofuels, too (however, new applications could prolong their market contribution).

The most resilient outlook for sustainable fuels is projected to be in road transport. The variability between scenarios is largely driven by less mature markets like aviation, maritime, and chemicals. To 2030, the uptake of sustainable fuels will mainly be driven by regulation already proposed. The long-term contribution of sustainable fuels to decarbonization is expected to be shaped by future regulations (including subsidies, mandates, and tax credits) as well as technological advancement.

The sustainable fuels picture varies by geography. In Brazil, India, Indonesia, and the United States, strong support of the local agricultural industry is projected to result in a 30 to 40 percent growth in demand by 2030, driven by use cases such as the introduction of ethanol flex cars in Brazil and India, and pushing the fatty acid methyl esters (FAME) blend-wall limits in Indonesia.[16]

Feedstock availability is a key bottleneck for sustainable fuels. In faster scenarios, unlocking new feedstocks would be necessary as soon as 2030 to meet growing demand. With limited waste oil availability, the role of edible oils, synthetic fuels, and new pathways (including gasification-Fischer Tropsch or ethanol-to-jet) will be substantial after 2040. Declines in production costs could enable decarbonization through the uptake of sustainable fuels.

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[16] Indonesia is pushing the maximum blending rate of bioliquids from 35 to 40 percent (mainly FAME in diesel).

Fossil fuels

Despite progress in RES build-out, the energy transition has been slower than expected in certain areas, and key transition levers are not yet mature, scalable, or cost-effective. This, combined with the constraints facing renewables build-out and growing energy demand, means renewables alone are not currently projected to be sufficient to meet the world's future energy needs in all our bottom-up scenarios. Fossil fuels are therefore projected to continue to play a role, albeit a moderating one, in the global energy system to 2050. Analysis of the data shows that investment and capital flow into fossil fuels are projected to continue for at least the next ten years to ensure the global energy system can keep up with demand.

This means that future fossil fuel demand in 2030 is best characterized as a decade-spanning plateau rather than a peak, with the duration of this plateau varying by scenario. Reducing the duration of this plateau will depend on several levers, including accelerated electrification of the economy, particularly in transport (EV adoption) and faster industrial heat pump deployment, enhanced adoption of bio and synfuels in difficult-to-abate sectors such as heavy transport and other industrial segments, and accelerated build-out of RES in the power sector.

In this context, underinvestment in fossil fuels could result in energy demand challenges and lead to concerns around energy security and achieving an orderly energy transition that is affordable, reliable, and competitive. It is increasingly clear from our analysis that the energy system is not a zero-sum game—our analysis shows that both fossil fuels and RES will form part of the energy mix for the foreseeable future, with fossil fuels projected to meet the demand unable to be met by RES due to slow build-out, and to provide firming capacity for renewables-based energy systems.

This continued role of fossil fuels will vary by region. While mature economies may be able to absorb the growing costs of the energy transition, current data indicate that for some developing economies fossil fuels are the most viable option to ensure affordability and support economic growth and development—particularly under the Slow Evolution scenario, where the cost of low-carbon technologies is expected to be the highest, but also to a lesser extent in the faster scenarios. This could lead to increased emissions in these regions, potentially jeopardizing their Paris Agreement goals.

Further, in the current context, geopolitical factors have brought increasing attention to fossil fuels. Countries are now working on balancing their sustainability goals with the considerations of energy independence, affordability, reliability, and security. In this context, many will consider all available energy sources.

Nevertheless, the costs of continued dependence on unabated fossil fuels cannot be measured in monetary terms alone. The climate consequences and subsequent negative social impact associated with the continued use of unabated fossil fuels must be considered, too. If fossil fuel growth follows a trajectory similar to the projections in the slower energy transition scenarios, investment into CCUS and energy efficiency would become more important to mitigate the potential climate impacts of continued fossil fuel demand. However, even with CCUS and energy-efficiency gains, key goals of the Paris Agreement would not be met if a slower scenario materializes—and this would create a range of negative social, environmental, and economic effects. The world now needs to chart a careful path to ensure that the continued use of fossil fuels can remain compatible with climate goals that aim to drastically reduce CO_2 and methane emissions to limit global warming.

Fossil fuels

The demand trajectory for fossil fuels varies substantially by fuel:

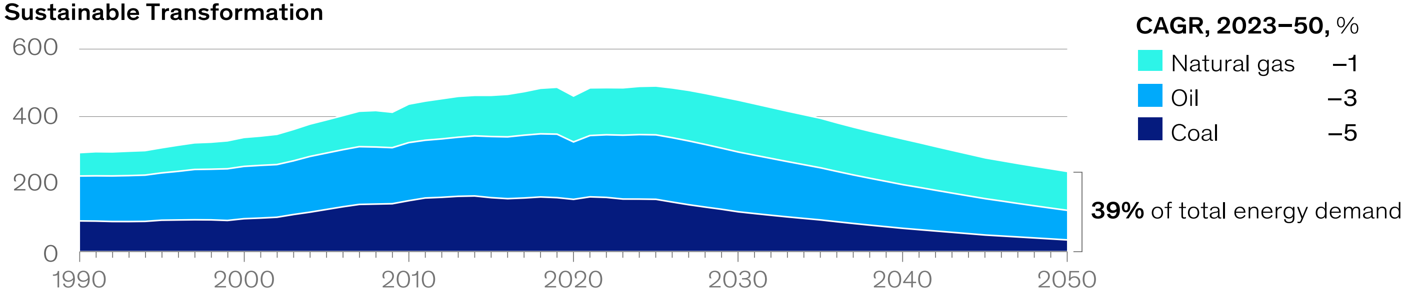
- Oil demand has seen record high growth in recent years due to the global economic recovery following the COVID-19 pandemic. Oil demand is projected to continue to grow in the short term, albeit at a more moderate rate, before plateauing at around 102 million barrels per day (MMb/d)—similar to current levels—or up to 108 MMb/d (6 percent higher than current levels). This difference in oil demand projections is largely driven by the rate of EV penetration, with lower oil demand scenarios having a faster penetration of EVs. For example, 40 percent of new cars sold by 2030 in the Slow Evolution scenario will be EVs, compared to 68 percent of new cars in the Sustainable Transformation scenario. The plateau in oil demand lasts until the mid-2030s, with the plateau happening later in slower scenarios, after which oil demand is projected to begin its decline across all modeled scenarios. Although light vehicles and power are expected to drive an overall decline in oil demand, the chemicals and heavy transport sectors could see continued growth in demand to 2050. New supply would be needed to meet this continuing oil demand, at least in the short to medium term, even in faster energy transition scenarios.
- Gas demand continues to grow into the 2030s across scenarios, as long-term price competitiveness and lower-than-expected hydrogen demand keeps gas in the energy mix—especially in power generation and for heat in industry and in buildings, where heat pump installation is experiencing bottlenecks. Gas is also projected to play a key role in providing firming capacity for renewables-based systems, as it can be deployed much more quickly than alternatives. On the supply side, the demand for gas will result in increasing liquefied natural gas (LNG) needs as supply and demand regions diverge geographically. Future gas supply could be significantly affected by geopolitical developments. For example, the Russian invasion of Ukraine has affected gas supply and prices, and future developments could further affect global gas trade flows. Tightness in the LNG market is projected to emerge in the early 2030s.
- Coal demand is projected to remain at close to current levels for the next two to three years, driven largely by the refiring of coal plants in the past few years in response to higher prices for alternative fuels, partially as the result of geopolitical challenges. However, coal demand is expected to decline during this decade under all scenarios. In many regions, coal will remain cost-competitive unless regulations such as carbon taxes are put into place.

Fossil demand is projected to plateau before declining, but still accounts for 40 to 60 percent of total energy demand in 2050

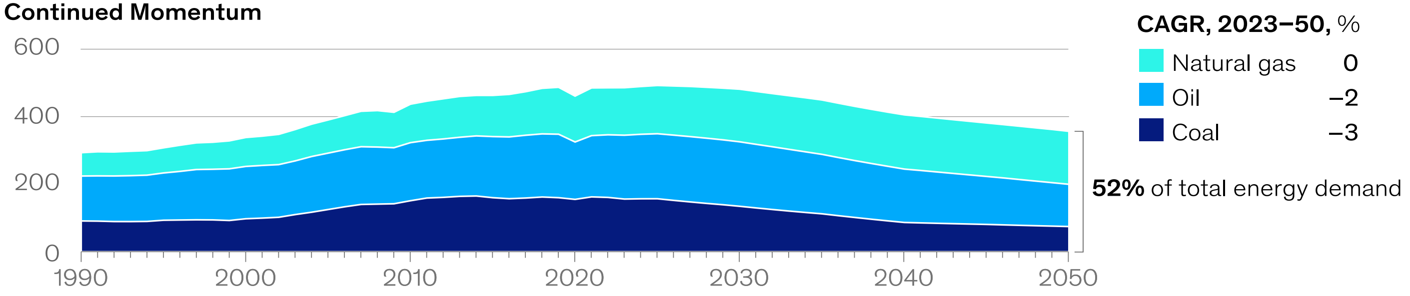
Fossil fuels are expected to continue supplying growing energy demand across all scenarios

Global primary energy demand by fuel, million TJ

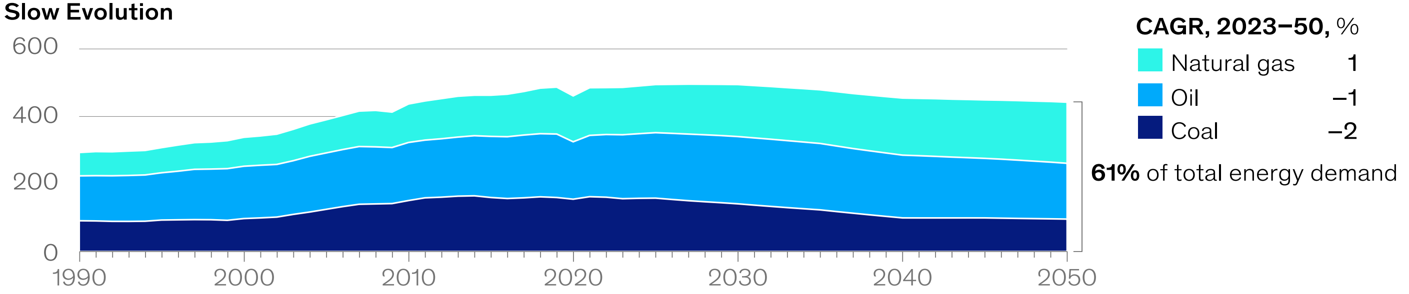
Sustainable Transformation



Continued Momentum



Slow Evolution



While RES are projected to make up a significant and increasing share of the energy mix, under all modeled scenarios RES remain insufficient to meet growing energy demand while also displacing the current energy system.

Consequently, fossil fuels, including oil, natural gas, and coal, will likely still be needed to meet between 40 to 60 percent of global energy demand in 2050, depending on the scenario, down from 78 percent in 2023.

Fossil fuel demand is expected to plateau between 2025 and 2035 before declining, with the timing and rate of the decline differing by scenario.

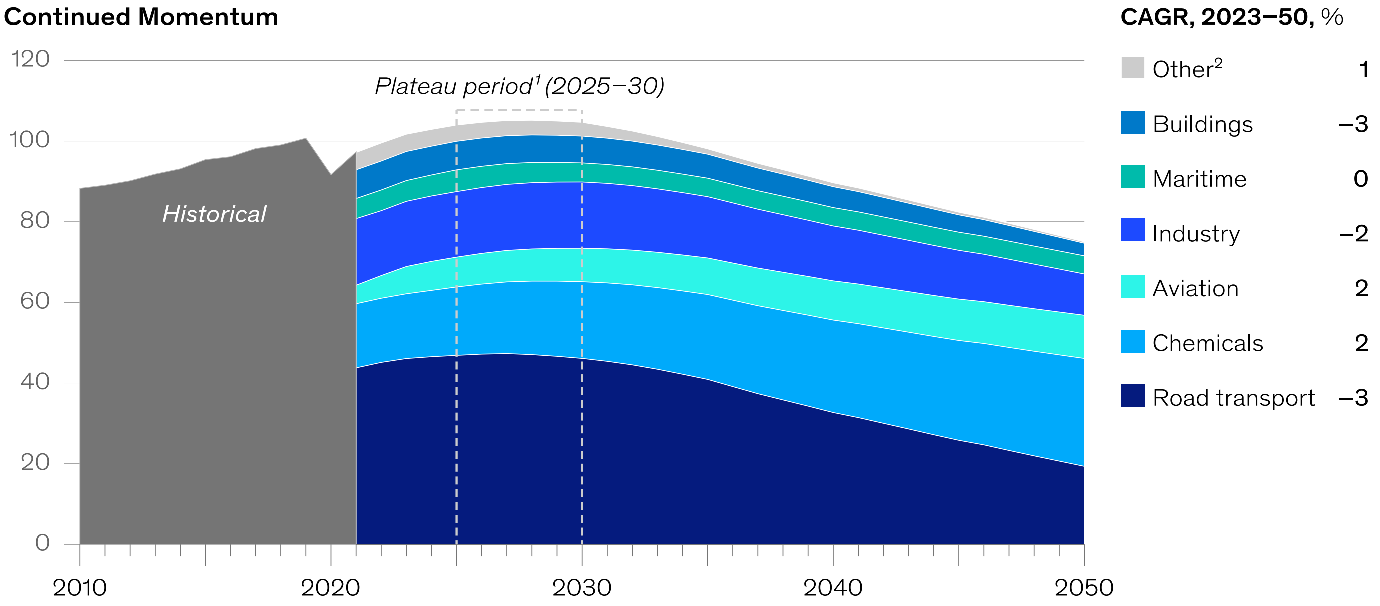
Oil demand is projected to continue to grow in the short term, albeit at a more moderate rate, before plateauing between 2025 and 2030 in the Continued Momentum or Sustainable Transformation scenarios, and later in the slower scenario.

Gas demand continues to grow into the 2030s across scenarios, and coal demand is projected to remain at close to current levels for the next two to three years, but begins to decline during this decade under all scenarios.

Long-term trends in road transport, aviation, and chemicals are projected to drive oil demand

These sectors account for more than 60 percent of the range in oil demand in 2050 across scenarios

Global oil demand (including biofuels and synfuel), MMb/d



[1] Plateau defined as ~1 MMb/d range around peak.
[2] Includes power, rail, oil and gas own use, etc.

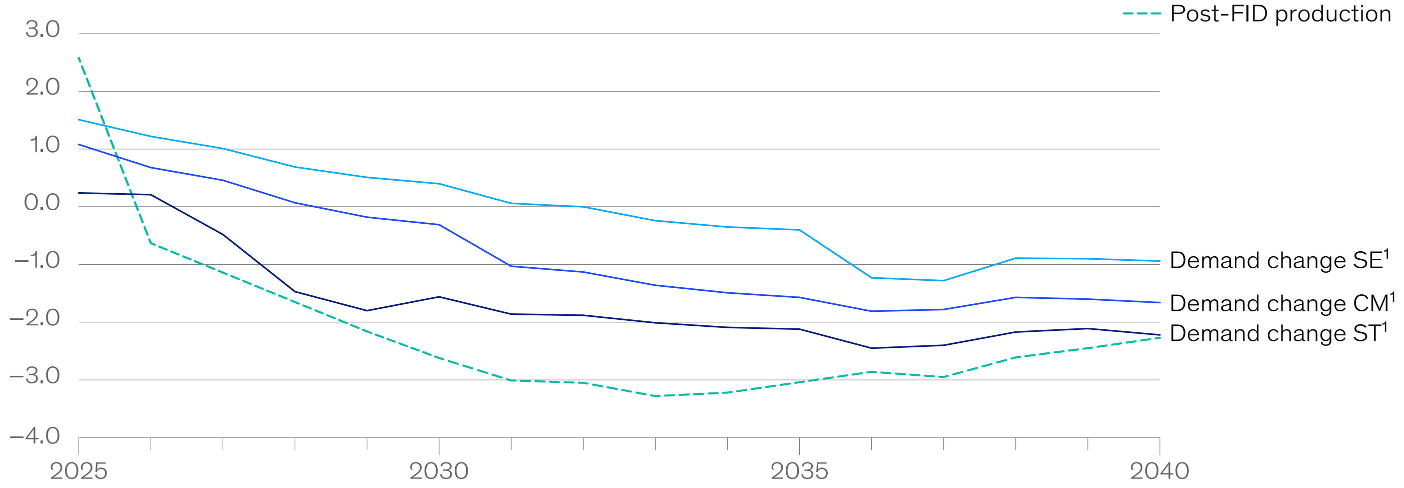
After a plateau between around 2025 and 2035, oil demand is expected to decline by 2050 across all scenarios. Key drivers of oil demand decline include EV uptake, continued plastic recycling, and an increase in demand for sustainable fuels.

By 2050, BEVs are projected to account for 99 percent of global passenger vehicle sales in the Continued Momentum scenario, up from 13 percent today and 71 percent in 2030. The share of plastics recycled globally is projected to remain at roughly the same level as today, at 16 percent, in the same scenario. However, alternative fuels are projected to see significant growth—in aviation, the share of alternative fuels is projected to increase to 14 percent in the Continued Momentum scenario, up from 0 percent today and 5 percent in 2030.

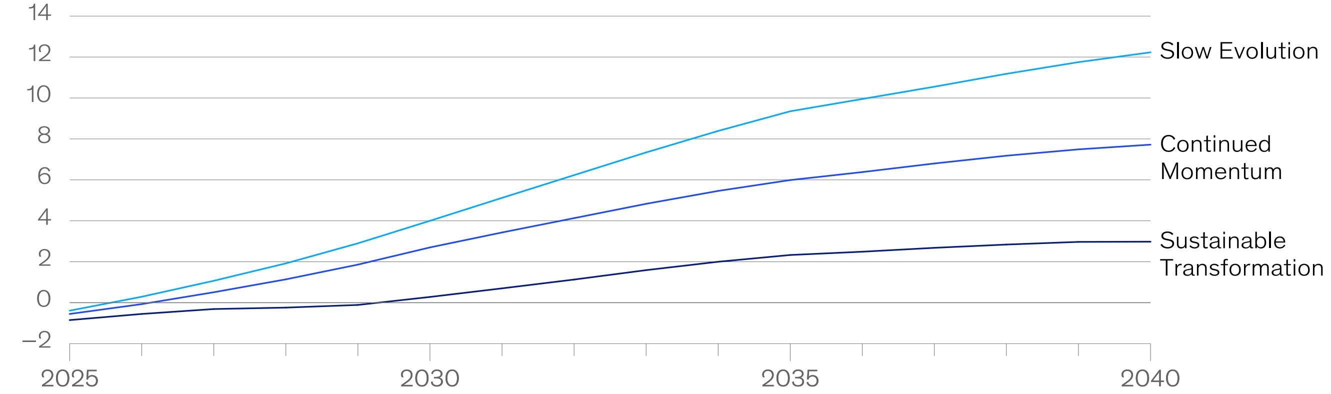
Even in faster scenarios, additional oil demand is projected—and not met by current supply

Faster scenarios would require additional spending in all sectors

Annual change in global oil demand, %



Cumulative global supply gap if no new supply of oil supply is introduced, billion barrels



Our analysis shows that new, additional supply will likely be needed to meet oil demand in all our bottom-up scenarios. This is because the decline in existing oil fields would exceed the decline in oil demand across the scenarios, at least until 2040.

In the Sustainable Transformation scenario, this could mean an additional 11 MMb/d of new supply in 2040, coming mainly from the Middle East and North America. In scenarios where more supply is needed, it would likely come from deepwater reservoirs in, among other places, South America and West Africa.

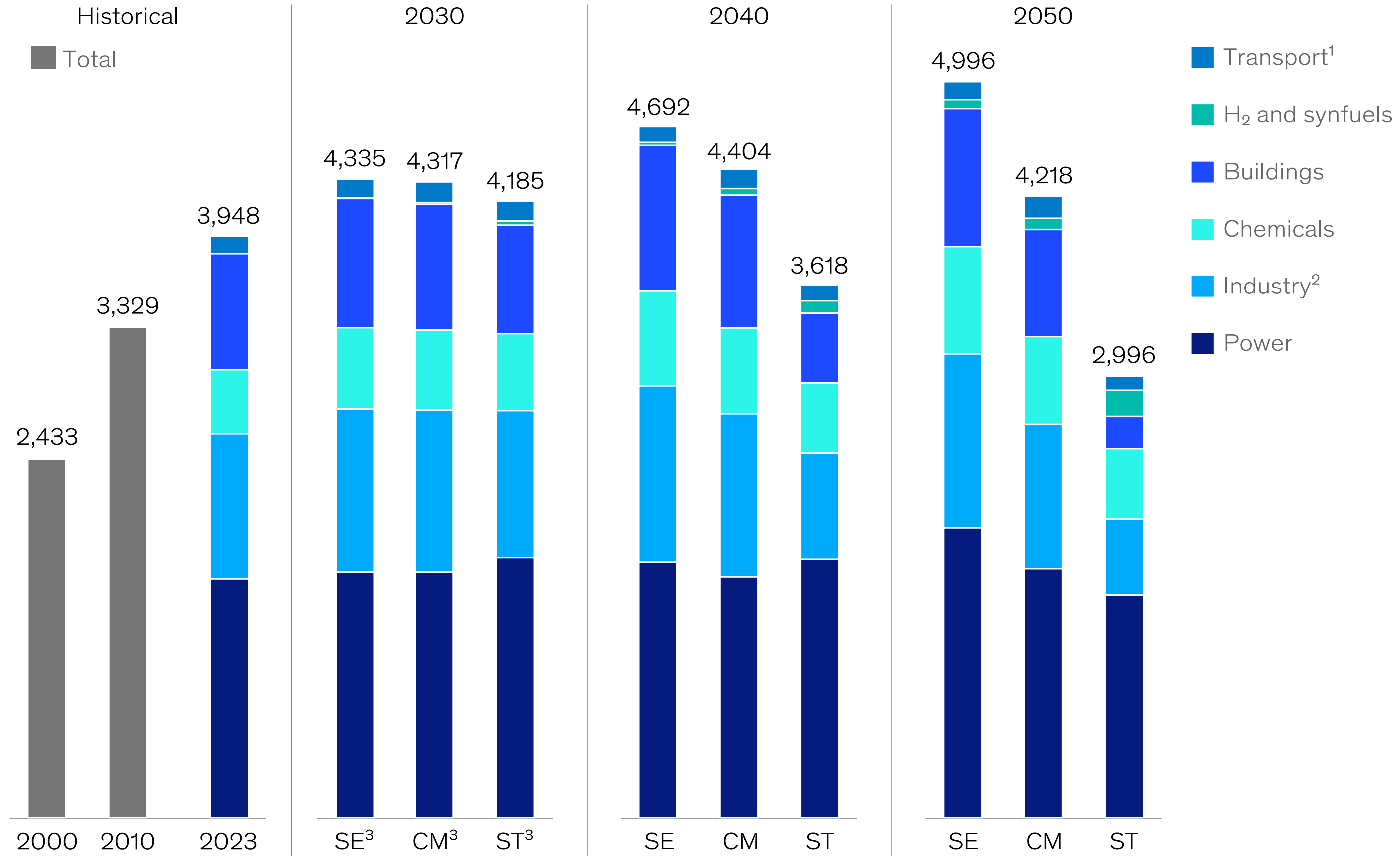
Analysis of the data shows that ending investment in oil would not reduce energy demand but likely lead to energy shortages as demand outstrips supply. If this supply were not to materialize, it could result in higher oil prices and even a lack of energy access in some regions.

[1] SE = Slow Evolution; CM = Continued Momentum; ST = Sustainable Transformation.

Gas demand is expected to continue to grow beyond 2030

Power will be the main driver of gas demand across scenarios

Global natural gas demand by sector, bcm



[1] Aviation, maritime, rail, and road transport.
[2] Iron and steel, heat generation, refining, and primary industries.
[3] SE = Slow Evolution; CM = Continued Momentum; ST = Sustainable Transformation.

The demand for natural gas is projected to see continued growth, mostly driven by demand for blue hydrogen (hydrogen produced from natural gas with CCUS) and gas-fired power generation.

By 2050, blue hydrogen demand is projected to grow to between 40 and 100 Mtpa globally, depending on the scenario, up from less than 1 Mtpa today and between 1 and 10 Mtpa in 2030.

Installed gas-fired power generation capacity is also projected to increase, reaching 3.0 terawatts (TW) in 2050, up from 1.5 TW today and 2.0 TW in 2030.

Gas is expected to continue playing a role in industrial applications, especially in high-heat applications where heat pumps are not a viable solution, and where green hydrogen may not make sense economically. However, alternative technologies for electrification of high temperature heat and steam may emerge.

Bottlenecks

Maintaining or accelerating the pace of the global energy transition will require overcoming several bottlenecks impacting the continued uptake of low-carbon technologies. The global energy system is fragile, lacks redundancy, and is highly complex, all of which means that bottlenecks could have significant effects if they go unresolved. Additionally, as the energy transition progresses, difficult trade-offs will need to be made between multiple objectives, including affordability, reliability, industrial competitiveness, and energy security. The major bottlenecks identified affect electricity generation, as discussed in Chapter 2, but other low-carbon energy sources, for example, sustainable fuels and key low-carbon technologies such as EV batteries, face bottlenecks of their own.

Because bottlenecks are, in general, caused by the lack of affordability and strong business cases, a common thread in solving them is ensuring a viable business case for technology uptake or build-out, with the right policy and financial frameworks and incentives in place—and willingness from stakeholders to adopt these solutions. Pragmatic and adaptive regulation, informed by the evolving energy transition landscape, could also be an important component in resolving bottlenecks.

The net-zero transition is also changing the materials demand profile as low-carbon technologies require more and different materials than conventional technologies. Low-carbon technologies are often more material-intense than conventional technologies, and typically require a diverse set of metals and minerals, including materials that only accounted for a small share of metals demand in the past, such as battery materials (including lithium, nickel, and cobalt) or magnet materials (rare earth minerals). Together, these account for only a small percentage of the global mining value pool today. The business economics for extracting these resources will need to be viable and extraction needs to be environmentally sustainable. With downstream technology developing quickly and sometimes in unexpected ways, knowing where to invest remains challenging. Across all low-carbon technologies, this uncertainty creates hesitancy where business cases remain unproven.

The availability of an appropriately skilled workforce is another bottleneck for both renewables and fossil fuels. These industries may struggle to attract skilled workers, with new talent choosing to work in less traditional sectors and older workers retiring.

As electrification continues, significant grid build-out will be needed. Electrification requires purpose-built and resilient grids that can connect new RES and support bidirectional flows—requiring a significant amount of infrastructure to be built. Achieving this required build-out may be challenging in many areas, resulting in grid congestion and preventing new RES projects from being connected to the grid.

The grid build-out needed to enable the uptake of electrification requires significant capital. T&D investments would need to grow about threefold by 2050 to recover from underinvestment and to accommodate intermittent RES. This would result in an increase in the share of grid cost in total average delivered power costs to customers. Demand management, such as demand-side response (DSR), could alleviate increases in delivered power cost as share of grid cost rises. The acceleration of technologies that can increase the capacity of new or existing grids could also be an important part of the solution, both in the near and longer terms. However, the deployment of these new technologies may require changes in grid regulation, particularly a move away from regulatory asset base (RAB), as this assumes a constant relationship between investment into infrastructure and energy moved.

Another factor affecting electrification is the recent slowdown in the growth of electrification technologies, including EVs, heat pumps, and electrolyzers, driven by reduced demand. If the expected electricity demand does not materialize, this could result in more emissions throughout the economy, a lack of learning opportunities to decrease costs, and increased uncertainty in power demand—making it more difficult to build new clean energy projects.

Bottlenecks

Globally, there has been a large uptake in LNG (eight times faster than the growth of total gas demand), but several bottlenecks need to be overcome to enable LNG uptake to continue. LNG requires a large amount of infrastructure, including regasification plants, ships, and harbor infrastructure. These investments are capital intensive, and a lack of required infrastructure or delays in deployment could cause a return to more emissions-heavy fuels—as seen during Europe's recent energy crisis, when several countries refired coal plants to meet their energy needs.

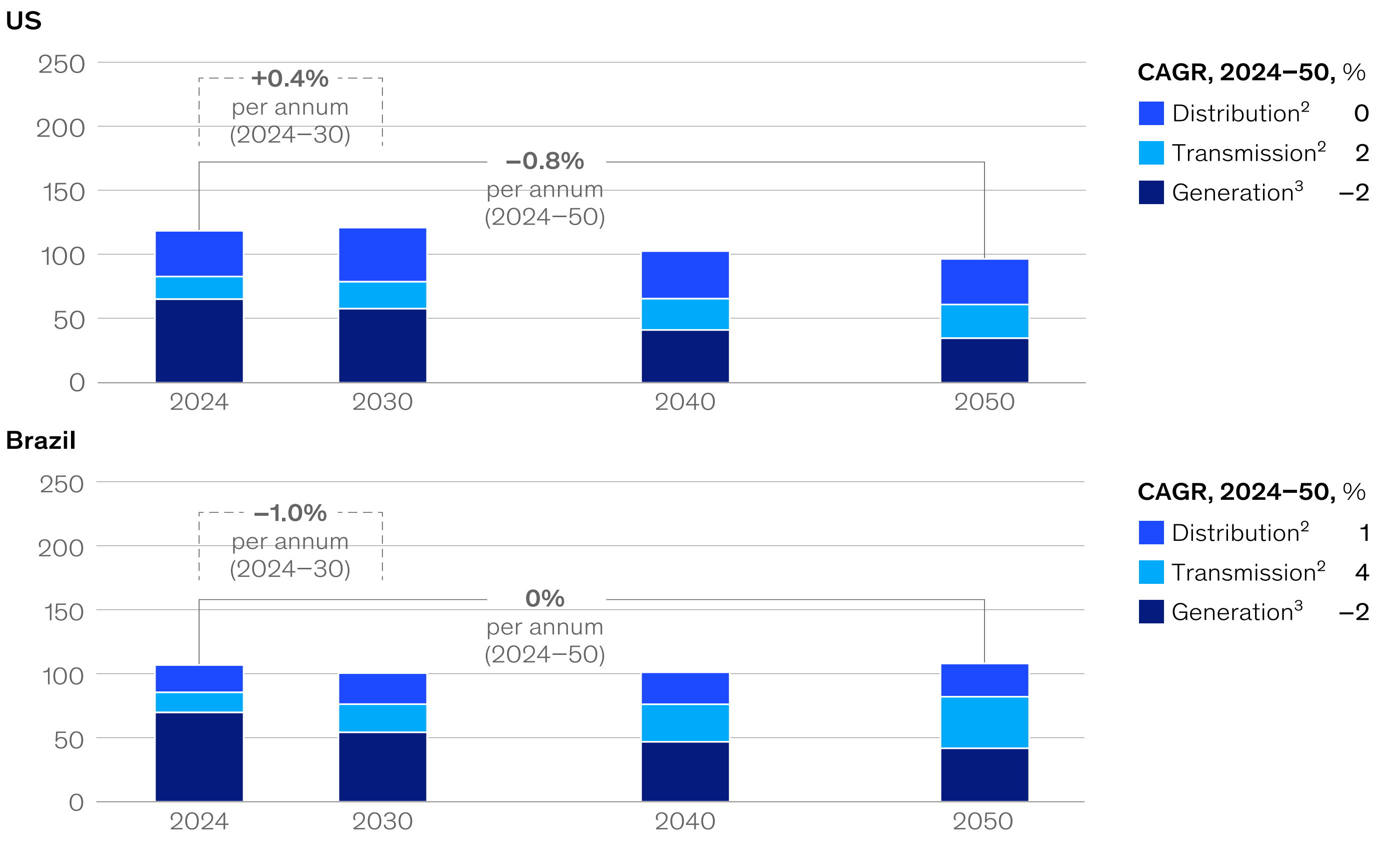
Nuclear, meanwhile, is facing bottlenecks in every part of the value chain. Since most of the nuclear fuel value chain is geographically managed in China and Russia, geopolitical challenges could be a major barrier to growth. More uranium exploration and refining would be needed, and attracting new, appropriately skilled talent would be necessary to facilitate growth—a challenge, given the aging nuclear workforce. Negative public perception, as well as concerns around safety and how to deal with waste, would also need to be resolved. And even if they were, permitting for next-generation projects (including small scale reactors and salt reactors) takes longer, given these risks.

As a result of these factors, one major cross-cutting bottleneck facing the energy transition is a lack of firm commitment to project pipelines—not helped by concerns surrounding project economics and long-term returns, and much less by the fact that there is no precedent for the global energy transition. Despite significant announced investment and a supportive policy environment, this lack of firm commitment could put a significant number of RES projects at risk. Currently, less than half of the deployment pipeline to 2030 for low-carbon power has reached FID.

Increased T&D investments will be needed, increasing the share of grid cost in system costs for power to customers

Congested grids and labor shortages could also materialize

System cost of electricity,[1] Continued Momentum, 2023 $/MWh



Increasingly congested grids could mean that T&D investments need to grow by around three times by 2050 to recover from underinvestment and to accommodate for intermittent RES. This will likely result in an increase in the share of grid cost in total average delivered power costs to customers.

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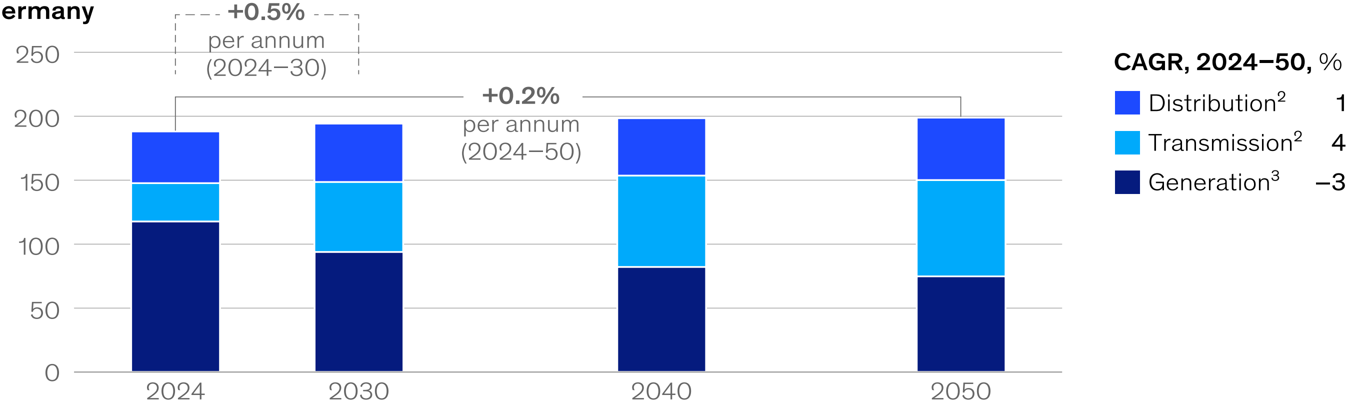
[1] Excludes retail margin, VAT, carbon taxes, and subsidy recovery.
[2] Transmission and distribution costs include lines, transforms, and operating expenditure (opex) of existing and new lines required for the capacity buildout. Additional grid service costs (eg, balancing) are not included.
[3] Generation costs include all capital expenditure (capex) and opex recovery for generation assets (thermal, renewable energy sources, storage, etc).

Increased T&D investments will be needed, increasing the share of grid cost in system costs for power to customers

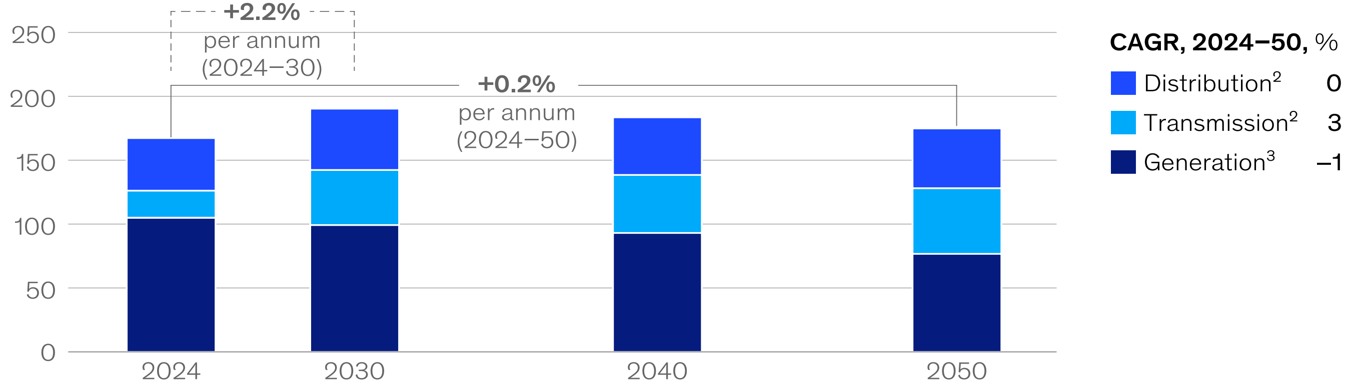
Congested grids and labor shortages could also materialize

System cost of electricity,[1] Continued Momentum, 2023 $/MWh

Germany



UK



As costs increase, grids could become congested and labor shortages emerge. Demand management (for example, DSR) could help alleviate increases in delivered power costs. Nevertheless, as the grid decarbonizes with an increased share of renewables, the average generation cost per MWh is projected to decline, which could bring down the system cost of electricity in some cases.

[1] Excludes retail margin, VAT, carbon taxes, and subsidy recovery.

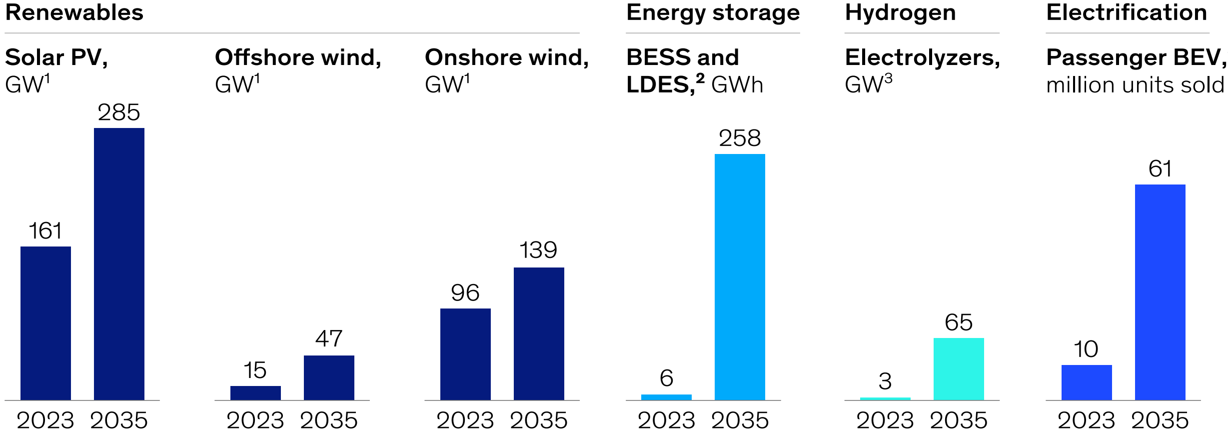
[2] Transmission and distribution costs include lines, transforms, and operating expenditure (opex) of existing and new lines required for the capacity buildout. Additional grid service costs (eg, balancing) are not included.

[3] Generation costs include all capital expenditure (capex) and opex recovery for generation assets (thermal, renewable energy sources, storage, etc).

The net-zero transition is changing the materials demand profile

Climate technologies in general require more, and different, materials

Global demand



	Solar PV, GW[1]	Offshore wind, GW[1]	Onshore wind, GW[1]	BESS and LDES,[2] GWh	Electrolyzers, GW[3]	Passenger BEV,[4] million units sold
Material intensity[5]	137 t/MW	614 t/MW	229 t/MW	5.2 t/MWh	-	1.9 t/car
Material intensity vs conventional tech[5]	1.4×	6.3×	2.4×	-	-	1.2×
Metals and minerals[6]	Aluminum, copper, nickel, steel, tin, zinc	Aluminum, chromium, copper, magnesium, molybdenum, nickel, REEs,[7] steel, zinc	Aluminum, chromium, copper, magnesium, molybdenum, nickel, REEs, steel, tin, zinc	Aluminum, chromium, cobalt, copper, germanium, lithium, manganese, nickel, steel, tin, vanadium, zinc	Iridium, palladium, platinum, steel	Aluminum, carbon, cobalt, copper, lithium, manganese, nickel, REEs, steel, tin, zinc

Note: Select technologies—nonexhaustive.
[1] Energy capacity additions. [2] Battery energy storage systems and long-duration energy storage. [3] Based on hydrogen capacity additions. [4] Battery electric vehicle. [5] Minerals and metals only, renewables compared to coal/gas in kg/MW and battery electric vehicle compared to an internal combustion engine in kg/unit. [6] Not exhaustive. [7] Rare earth elements.

To enable the energy transition, low-carbon technologies will need to scale up rapidly. These technologies typically require more, and different, materials compared to conventional technologies. For instance, solar PV requires 137 tons[17] of minerals and metals per megawatt (MW) of power generated (a material intensity of 1.4 times compared to coal and gas[18]), while offshore wind has a material intensity of 614 tons per MW, 6.3 times higher than coal and gas.

The business cases for extracting and processing these crucial materials will need to be viable and environmentally sustainable to enable low-carbon technologies to be deployed at scale. However, this can be challenging, particularly in a context where the development timelines of a project may be longer than ten years, requiring investors to look far ahead in a time of significant demand shift.

As such, a major challenge for known assets is the uncertainty surrounding long-term demand profiles. This can be driven by the rapid development of downstream technology. For example, the shift from nickel manganese cobalt (NMC) to lithium iron phosphate (LFC) batteries would greatly reduce the demand for nickel and fundamentally impact the economics of the industry, creating increased hesitation among investors and uncertainty around the business cases for new mining and refining assets. Other drivers of demand uncertainty include geopolitical uncertainties and political instability in key geographies.

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[17] Metric tons: 1 metric ton = 2,205 pounds.

[18] Excluding the material intensity of producing and transporting fuels.

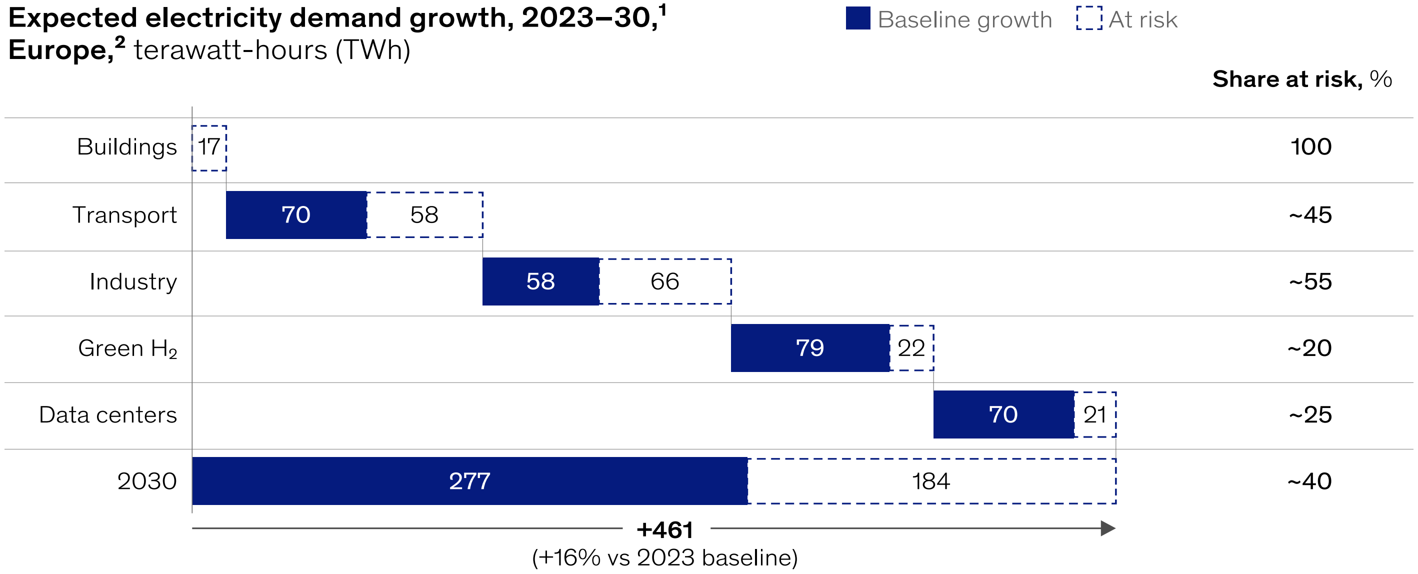
In Europe, up to 40 percent of the anticipated 460 TWh increase in electricity demand from 2023 to 2030 may not materialize

Reduced industrial output, delayed electrification in industry, and stalling EV sales could lower expected demand growth

Despite the projected growth in electricity demand, it remains uncertain whether this demand will fully materialize, particularly in Europe. Drivers include a slowdown in heat pump installations, slower-than-expected EV sales, lack of investment into industrial electrification, and uncertainties in project development. The expected reduction in industrial output in some sectors, such as iron and steel, paper and pulp, and chemicals is another contributing factor.

The lack of clarity in how demand will unfold could dampen the appetite to invest in next-generation clean energy projects, potentially stalling or slowing the energy transition.

Expected electricity demand growth, 2023–30,[1] Europe,[2] terawatt-hours (TWh)



By demand source, heat pump growth might not materialize at the expected pace, which would translate to zero or negative growth in demand for electricity, as the projected improvement in insulation, appliances, and lighting would counterbalance the increase in demand from a reduced number of heat pumps.

Lower-than-expected EV sales, as evidenced by the slowdown in sales in 2023, might reduce circulating stock and related power demand, partly driven by uncertainty around the expected ICE ban in 2035.

Low investments in the electrification of existing assets, as well as a decrease in production and an increase in offshoring due to the high cost of capital and power prices, could further reduce electricity demand.

Uncertainty in green hydrogen project development, as well as the low proportion of projects that have reached FID, could cause delays in investment approvals and slow down project deployments.

Nevertheless, while factors such as the gen-AI-related boom in data centers could drive demand, EU regulation might limit this growth to control the impact on the grid.

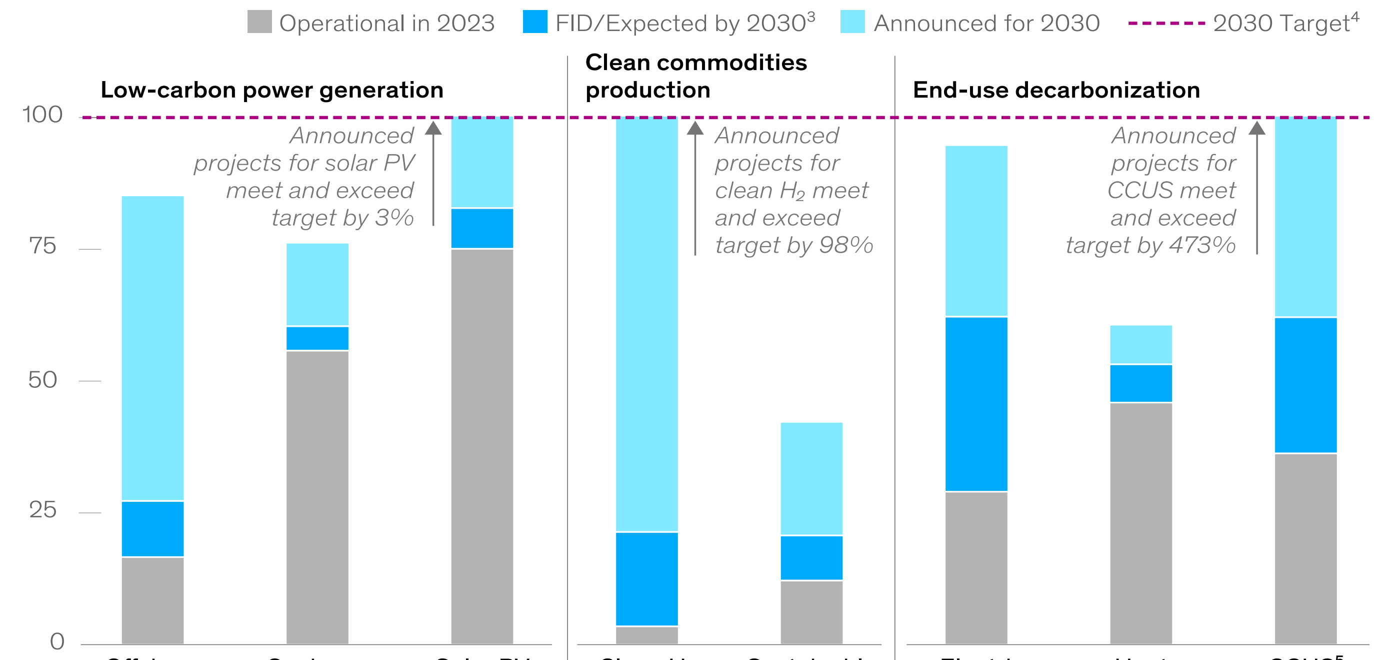
[1] Base case projection from McKinsey's Continued Momentum 2024 scenario; demand at risk estimated with a sensitivity to technology adoption rates and industrial output reductions.

[2] EU-27, Norway, Switzerland, and the United Kingdom.

Although significant investment has been announced, less than half of the deployment pipeline for low-carbon power has reached FID

Market design and infrastructure challenges impact low-carbon power generation

Technology deployment pipeline in EU27+3[1] and US vs targets,[2] % of target, normalized



	Offshore wind	Onshore wind	Solar PV	Clean H_2	Sustainable fuels	Electric vehicles (EVs)	Heat pumps	CCUS[5]
2030 target[4]	205 GW[6]	695 GW	705 GW	15 mtpa[7]	136 mtpa	56 million	156 million	75 mtpa
Additions needed	30 GW	165 GW	On trajectory	11.8 mtpa	78 mtpa	On trajectory	61 million	28 mtpa

Despite continued reductions in the LCOE, the deployment of low-carbon power generation faces challenges related to broader market design and infrastructure.

Notwithstanding numerous announcements spurred by policies such as the US IRA, clean commodities production faces a significant shortfall in firm commitments. The pace of FID is not on track to meet net-zero targets, following concerns over feedstock availability and competitive pricing.

The European Union and the United States have introduced several policies, which include incentives, to promote CCUS. However, the deployment of CCUS faces barriers including lack of market readiness and logistical issues. Moreover, CCUS is as yet unproven at scale for post-combustion plants.

EV adoption and heat pump initiatives are progressing in both regions but are hindered by high costs and supply chain dependencies.

[1] EU27 + Norway, Switzerland, and the United Kingdom. [2] Technology deployment is a measurement to understand the gap between actual vs needed deployment.
[3] Final investment decision (FID) except for EVs and heat pumps (expected sales based on average sales over the last few years). [4] Target as defined for 2030 for both EU27+3 and the US; for solar, sustainable fuels, and heat pumps, no target exists, and the McKinsey Sustainable Transformation scenario was used.
[5] Carbon capture, utilization, and storage. [6] Gigawatts. [7] Metric tons per annum.
Source: EHPA; EIA; Eurostat; IEA; Rystad; Wind 4C; McKinsey Energy Solutions; McKinsey Hydrogen Insights

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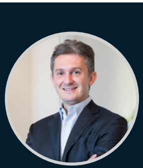

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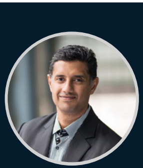

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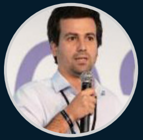

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