

Executive summary

The net-zero transition

What it would cost, what it could bring



McKinsey Global Institute
in collaboration with
McKinsey Sustainability and
McKinsey's Global Energy &
Materials and Advanced
Industries Practices

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MGI is led by McKinsey & Company senior partners James Manyika and Sven Smit, who serve as co-chairs, and Chris Bradley, Kweilin Ellingrud, Marco Piccitto, Olivia White, and Jonathan Woetzel, who serve as directors. Michael Chui, Mekala Krishnan, Anu Madgavkar, Jan Mischke, Jaana Remes, Jeongmin Seong, and Tilman Tacke are MGI partners. Project teams are led by the MGI partners and include consultants from McKinsey offices around the world. These teams draw on McKinsey’s global network of partners and industry and management experts. The MGI Council is made up of McKinsey leaders and includes Hemant Ahlawat, Michael Birshan, Andrés Cadena, Sandrine Devillard, André Dua, Katy George, Rajat Gupta, Eric Hazan, Solveigh Hieronimus, Acha Leke, Clarisse Magnin, Jurica Novak, Gary Pinkus, Hamid Samandari, Sha Sha, Oliver Tonby, and Eckart Windhagen. The Council members help shape the research agenda, lead high-impact research, and share the findings with decision makers around the world. In addition, leading economists, including Nobel laureates, advise MGI research.

In collaboration with McKinsey Sustainability and the Global Energy & Materials and Advanced Industries practices

McKinsey Sustainability is the firm’s client-service platform with the goal of helping all industry sectors transform to get to net zero by 2050 and to cut carbon emissions by half by 2030. McKinsey Sustainability seeks to be the preeminent impact partner and adviser for our clients, from the board room to the engine room, on sustainability, climate resilience, energy transition, and environmental, social, and governance (ESG). We leverage thought leadership, innovative tools and solutions, top experts, and a vibrant ecosystem of industry associations and knowledge partnerships to lead a wave of innovation and economic growth that safeguards our planet and advances sustainability.

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Preface

More than 10,000 years of continuous and accelerating progress have brought human civilization to the point of threatening the very condition that made that progress possible: the stability of the earth's climate. The physical manifestations of a changing climate are increasingly visible across the globe, as are their socioeconomic impacts. Both will continue to grow, most likely in a nonlinear way, until the world transitions to a net-zero economy, and unless it adapts to a changing climate in the meantime. No wonder, then, that an ever-greater number of governments and companies are committing to accelerate climate action.

At present, though, the net-zero equation remains unsolved: greenhouse gas emissions continue unabated and are not counterbalanced by removals, nor is the world prepared to complete the net-zero transition. Indeed, even if all net-zero commitments and national climate pledges were fulfilled, research suggests that warming would not be held to 1.5°C above preindustrial levels, increasing the odds of initiating the most catastrophic impacts of climate change, including the risk of biotic feedback loops. Moreover, most of these commitments have yet to be backed by detailed plans or executed. Nor would execution be easy: solving the net-zero equation cannot be divorced from pursuing economic development and inclusive growth. It would require a careful balancing of the shorter-term risks of poorly prepared or uncoordinated action with the longer-term risks of insufficient or delayed action. Indeed, a more disorderly transition could impair energy supply and affect energy access and affordability, especially for lower-income households and regions. It could also have knock-on impacts on the economy more broadly, potentially creating a backlash that would slow down the transition.

None of these challenges should come as a surprise. Achieving net zero would mean a fundamental transformation of the world economy, as it would require significant changes to the seven energy and land-use systems that produce the world's emissions: power, industry, mobility, buildings, agriculture, forestry and other land use, and waste. To bring about these changes, nine key requirements (encompassing physical building blocks, economic and societal adjustments, and governance, institutions, and commitment) would need to be fulfilled against the backdrop of many economic and political challenges.

This means addressing dozens of complex questions, including: what is the appropriate mix of technologies that need to be deployed to achieve emissions reductions while staying within a carbon budget, limiting costs, and delivering required standards of performance? Where are supply chain and infrastructure bottlenecks most likely to occur? Where might physical constraints, whether related to the availability of natural resources or the scale-up of production capacity, limit the pace of the transition? What levels of spending on physical assets would the transition require? Who would pay for the transition? How would the transition affect companies' markets and operations? What would it spell for workers and consumers? What opportunities and risks would it create for companies and countries? And how could consumers be encouraged to make changes to consumption and spending habits that will be necessary to ensure the transition?

In this report, we attempt to answer some of these questions, namely, those pertaining to the economic and societal adjustments. We provide estimates of the economic changes that would take place in a net-zero transition consistent with 1.5°C of warming. We seek to build and expand upon the vast external literature on the net-zero transition, in order to offer a more detailed and granular view of the nature and magnitude of the economic changes that it would entail. As a result, our estimates of the annual spending on physical assets for a net-zero transition exceed to a meaningful degree the \$3 trillion–\$4.5 trillion total spending estimates that previous analyses have produced.

This report is a first-order analysis of a hypothetical 1.5°C scenario. As such, it has several limitations.

First, it is not clear whether a 1.5°C scenario is achievable in the first place, nor what pathway the world would take to achieve it if it were. Indeed, some believe that 1.5°C is already out of reach, given the current trajectory of emissions and their potential to activate climatic feedback loops, as well as prevailing challenges with revamping energy and land-use systems. This research does not take a position on such questions. Instead, it seeks to demonstrate the economic shifts that would need to take place if the goal of 1.5 degrees is to be attained through a relatively orderly transition between now and 2050.

Second, this report is by nature and necessity limited in its scope. In particular it does not focus on such issues as technology breakthroughs, physical constraints related to scale-up capacity and the availability of natural resources, delayed-transition costs, the role of adaptation, or other imponderables or uncertainties, nor have we yet modeled the full range of economic outcomes likely under a net-zero transition. As a result, it is likely that real outcomes will diverge from these estimates, particularly if the net-zero transition takes a more disorderly path or restricting warming to 1.5°C proves unachievable. Spending requirements could be higher, for example due to the additional investment needed to maintain flexibility and redundancy in energy systems, or heightened physical risks and commensurate adaptation costs.

Third, this report does not explore the critical question of who pays for the transition. What is clear is that the transition will require collective and global action, particularly as the burdens of the transition would not be evenly felt. The prevailing notion of enlightened self-interest alone is unlikely to be sufficient to help achieve net zero, and the transition would challenge traditional orthodoxies and require unity, resolve, and ingenuity from leaders.

We nonetheless hope that our scenario-based analysis will help decision makers refine their understanding of the nature and the magnitude of the changes the net-zero transition would entail and the scale of response needed to manage it. We also hope that our attempts to describe as accurately as we can the challenges that lie ahead are seen as what they are: a call for more thoughtful and more decisive action, urgency, and resolve.

The report is joint research by McKinsey Sustainability, McKinsey's Global Energy and Materials Practice, McKinsey's Advanced Industries Practice, and the McKinsey Global Institute. McKinsey has long focused on issues of environmental sustainability, dating to client studies in the early 1970s. We developed our global greenhouse gas abatement cost curve in 2007, updated it in 2009, and have since conducted national abatement studies in countries including Brazil, China, Germany, India, Russia, Sweden, the United Kingdom, and the United States. Recent research on which we build in this publication includes the January 2020 report *Climate risk and response: Physical hazards and socioeconomic impacts*, a January 2021 article, "Climate math: What it takes to limit warming to 1.5°C," and two October 2021 articles, "Our future lives and livelihoods: Sustainable and inclusive and growing" and "Solving the net-zero equation: Nine requirements for a more orderly transition."

This research was led by Mekala Krishnan, a McKinsey Global Institute (MGI) partner in Boston; Hamid Samandari, a McKinsey senior partner in New York; Jonathan Woetzel, a senior partner and MGI director in Shanghai; Sven Smit, a senior partner in Amsterdam and co-chair of MGI; Daniel Pachtod, a senior partner in New York; Dickon Pinner, a senior partner in San Francisco; Tomas Naucler, a senior partner in Stockholm; and Humayun Tai, a senior partner in New York. The research team was led in different periods by Annabel Farr, Danielle Imperato, Johanneke Tummers, Sophie Underwood, and Weige Wu. Team members: Wouter van Aanholt, Rishi Arora, Carolyne Barker, Ryan Barrett, Anna Benkeser, Mélanie Bru, Gene Chang, Jonas DeMuri-Siliunas, William Désilets, Julia Dhert, Spencer Dowling, William Edwards-Mizel, Karina Gerstenchlager, Jakob Graabak, Chantal de Graaf, Pragun Harjai, Laura Hofstee, Jania Kesarwani, Dhiraj Kumar, Joh Hann Lee, Youting Lee, Diego Miranda, Ian Murphy, Prit Ranjan, Shresth Sanghai, Lex Razoux Schultz, Ruben Robles, Kevin Russell, Nick Thiros, Ben D. Thomas, Sarah Vargese, Colin Varn, and Jan-Paul Wiringa.

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This report contributes to our mission to help business and policy leaders understand the forces transforming the global economy. As with all MGI research, it is independent and has not been commissioned or sponsored in any way by any business, government, or other institution.

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The net-zero transition: What it would cost, what it could bring

Governments and companies are increasingly committing to climate action. Yet significant challenges stand in the way, not least the scale of economic transformation that a net-zero transition would entail and the difficulty of balancing the substantial short-term risks of poorly prepared or uncoordinated action with the longer-term risks of insufficient or delayed action. In this report, we estimate the transition's economic effects on demand, capital allocation, costs, and jobs to 2050 globally across energy and land-use systems that produce about 85 percent of overall emissions and assess economic shifts for 69 countries. Our analysis is not a projection or a prediction and does not claim to be exhaustive; it is the simulation of one hypothetical, relatively orderly path toward 1.5°C using the Net Zero 2050 scenario from the Network for Greening the Financial System (NGFS), to provide an order-of-magnitude estimate of the economic transformation and societal adjustments associated with net-zero transition. We find that the transition would be universal, significant, and front-loaded, with uneven effects on sectors, geographies, and communities, even as it creates growth opportunities:

Capital spending on physical assets for energy and land-use systems in the net-zero transition between 2021 and 2050 would amount to about \$275 trillion, or \$9.2 trillion per year on average, an annual increase of as much as \$3.5 trillion from today. To put this increase in comparative terms, the \$3.5 trillion is approximately equivalent, in 2020, to half of global corporate profits, one-quarter of total tax revenue, and 7 percent of household spending. An additional \$1 trillion of today's annual spend would, moreover, need to be reallocated from high-emissions to low-emissions assets. Accounting for expected increases in spending, as incomes and populations grow, as well as for currently legislated transition policies, the required increase in spending would be lower, but still about \$1 trillion. The spending would be front-loaded, rising from 6.8 percent of GDP today to as much as 8.8 percent of GDP between 2026 and 2030 before falling. While these spending requirements are large and financing has yet to be established, many investments have positive return profiles (even independent of their role in avoiding rising physical risks) and should not be seen as merely costs. Technological innovation could reduce capital costs for net-zero technologies faster than expected.

In this scenario, the global average delivered cost of electricity would increase in the near term but then fall back from that peak, although this would vary across regions. As the power sector builds renewables and transmission and distribution capacity, the fully loaded unit cost of electricity production, accounting for operating costs, capital costs, and depreciation of new and existing assets, in this scenario could rise about 25 percent from 2020 until 2040 and still be about 20 percent higher in 2050 on average globally. Cost increases in the near term could be significantly higher than those estimated here, for example, if grid intermittency issues are not well managed. The delivered cost could also fall below 2020 levels over time because of the lower operating cost of renewables—provided that power producers build flexible, reliable, and low-cost grids.

The transition could result in a gain of about 200 million and a loss of about 185 million direct and indirect jobs globally by 2050. This includes demand for jobs in operations and in construction of physical assets. Demand for jobs in the fossil fuel extraction and production and fossil-based power sectors could be reduced by about nine million and four million direct jobs, respectively, as a result of the transition, while demand for about eight million direct jobs would be created in renewable power, hydrogen, and biofuels by 2050. While important, the scale of workforce reallocation may be smaller than that from other trends including automation. Displaced workers will nonetheless need support, training, and reskilling through the transition.

While the transition would create opportunities, sectors with high-emissions products or operations—which generate about 20 percent of global GDP—would face substantial effects on demand, production costs, and employment. In the NGFS Net Zero 2050 scenario, coal production for energy use would nearly end by 2050, and oil and gas production volumes would be about 55 percent and 70 percent lower, respectively, than today. Process changes would increase production costs in other sectors, with steel and cement facing increases by 2050 of about 30 and 45 percent, respectively, in the scenario modeled here. Conversely, some markets for low-carbon products and support services would expand. For example, demand for electricity in 2050 could more than double from today.

Poorer countries and those reliant on fossil fuels are most exposed to the shifts in a net-zero transition, although they have growth prospects as well. These countries are more susceptible to changes in output, capital stock, and employment because exposed sectors make up relatively large parts of their economies. Exposed geographies including in sub-Saharan Africa and India would need to invest 1.5 times or more than advanced economies as a share of GDP today to

support economic development and build low-carbon infrastructure. The effects within developed economies could be uneven, too; for instance, more than 10 percent of jobs in 44 US counties are in fossil fuel extraction and refining, fossil fuel-based power, and automotive manufacturing. At the same time, all countries will have growth prospects, from endowments of natural capital such as sunshine and forests, and through their technological and human resources.

Consumers may face additional up-front capital costs and have to spend more in the near term on electricity if cost increases are passed through, and lower-income households everywhere are naturally more at risk. Consumer spending habits may also be affected by decarbonization efforts, including the need to replace goods that burn fossil fuel, like transportation vehicles and home heating systems, and potentially modify diets to reduce high-emissions products like beef and lamb. The up-front capital spending for the net-zero transition could yield lower operating costs over time for consumers. For example, total cost of ownership for EVs is expected to be lower than ICE cars in most regions by 2025.

Economic shifts could be substantially higher under a disorderly transition, in particular because of higher-order effects not considered here. The economic and social costs of a delayed or abrupt transition would raise the risk of asset stranding, worker dislocations, and a backlash that delays the transition. Even under a relatively gradual transition, if the ramp-down of high-emissions activities is not carefully managed in parallel with the ramp-up of low-emissions ones, supply may not be able to scale up sufficiently, making shortages and price increases or volatility a feature. Much therefore depends on how the transition is managed.

For all the accompanying costs and risks, the economic adjustments needed to reach net zero would come with opportunities and prevent further buildup of physical risks. Incremental capital spending on physical assets creates growth opportunities, in connection with new low-emissions products, support services, and their supply chains. Most importantly, reaching net-zero emissions and limiting warming to 1.5°C would reduce the odds of initiating the most catastrophic impacts of climate change, including limiting the risk of biotic feedback loops and preserving our ability to halt additional warming.

Government and business would need to act together with singular unity, resolve, and ingenuity, and extend their planning and investment horizons even as they take immediate actions to manage risks and capture opportunities. Businesses would need to define, execute, and evolve decarbonization and offsetting plans for scope 1 and 2 emissions and potentially expand those plans to include scope 3 emissions, depending on the nature of their operations, and the materiality, feasibility, and need of doing so. Over time, they would need to adjust their business models as conditions change and opportunities arise; integrate climate-related factors into decision-making processes for strategy, finance, and capital planning, among others; and consider leading action with others in their industry or ecosystem of investors, supply chains, customers, and regulators. Financial institutions in particular have a pivotal role to play in supporting large-scale capital reallocation, even as they manage their own risks and opportunities. Governments and multilateral institutions could use existing and new policy, regulatory, and fiscal tools to establish incentives, support vulnerable stakeholders, and foster collective action. The pace and scale of the transition mean that many of today's institutions would need to be revamped and new ones created to disseminate best practices, establish standards and tracking mechanisms, drive capital deployment at scale, manage uneven impacts, and support further coordination of efforts.

The goal of this research is to provide stakeholders with an in-depth understanding of the nature and magnitude of the economic and societal adjustments a net zero transition would entail. Our hope is that this analysis provides leaders with the tools to collectively secure a more orderly transition to net-zero by 2050. The findings serve as a clear call for more thoughtful and decisive action, taken with the utmost urgency. The rewards of the net-zero transition would far exceed the mere avoidance of the substantial, and possibly catastrophic, dislocations that would result from unabated climate change, or the considerable benefits they entail in natural capital conservation. Besides the immediate economic opportunities they create, they open up clear possibilities to solve global challenges in both physical and governance-related terms. These include the potential for a long-term decline in energy costs that would help solve many other resource issues and lead to a palpably more prosperous global economy. More importantly, they presage decisive solutions to age-old global economic and political challenges as the result of the unprecedented pace and scale of global collaboration that such a transition would have required. And while the immediate tasks ahead may seem daunting, human ingenuity can ultimately solve the net-zero equation, just as it has solved other seemingly intractable problems over the past 10,000 years. The key issue is whether the world can muster the requisite boldness and resolve to broaden its response during the upcoming decade that will in all likelihood decide the nature of the transition.

Six characteristics of the net-zero transition

1 Universal

All carbon dioxide and methane emissions today come from seven energy and land-use systems.



2 Significant

Capital spending on physical assets for energy and land-use systems will need to rise by \$3.5 trillion per year for the next 30 years, to an annual total of:

\$9.2 trillion

■ New spending
■ Current spending

\$3.5 trillion

Increase in spending on low-emissions assets vs. today

\$1 trillion

Spending reallocated from high- to low-emissions assets

\$2 trillion

Continued spending on low-emissions assets

\$2.7 trillion

Continued spending on high-emissions assets

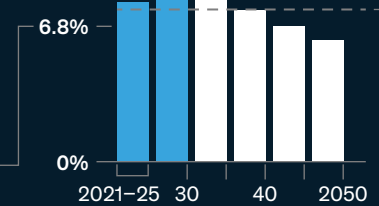


3 Front-loaded

Global capital spending in the transition could rise in the short term before falling back.

8.8% of global GDP in 2026–30

2020 spending level

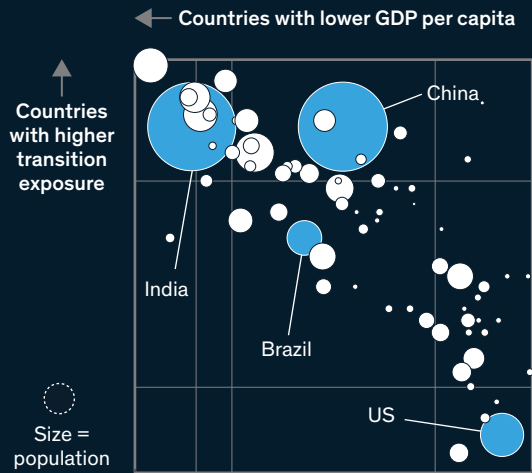


Cumulative spending of around **\$275 trillion**

About 7.6% of global GDP across 2021–50

4 Uneven

Developing countries and fossil fuel-rich regions are more exposed to the net-zero transition compared with other geographies.



Some industry sectors are also more exposed.



Percentage of GDP generated by sectors with highest degree of exposure

5 Exposed to risks

As high-emissions assets are ramped down and low-emissions ones ramped up in the transition, risks include rising energy prices, energy supply volatility, and asset impairment.



\$2.1 trillion

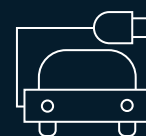
Value in power assets alone that could be stranded by 2050

6 Rich in opportunity

The shift to a net-zero emissions world will create opportunities for businesses and countries. These could be in three areas:



Decarbonizing processes and products



Replacing high-emissions products and processes with low-emissions ones



New offerings to aid decarbonization
Including supply chain inputs, infrastructure, and support services

Estimates based on Net Zero 2050 scenario from Network for Greening the Financial System, which has an even chance of limiting warming to 1.5°C, a hypothetical scenario, not a prediction or projection. See technical appendix for further details on approach.



Executive summary

As of this writing, in December 2021, more than 70 countries accounting for more than 80 percent of global CO₂ emissions and about 90 percent of global GDP have put net-zero commitments in place, as have more than 5,000 companies, as part of the United Nations' Race to Zero campaign.¹ Yet even if all the existing commitments and national climate pledges were fulfilled, estimates suggest that warming would exceed 1.5°C above preindustrial levels, increasing the odds of initiating the most catastrophic impacts of climate change, including biotic feedback loops.² Moreover, most of these commitments have yet to be supported by detailed plans or executed. Nor will execution be trivial, as it would require a careful balancing of shorter- and longer-term risks.

Today, while the imperative to reach net-zero is increasingly recognized, the net-zero equation is not solved. This state of affairs should not be surprising, given the scale of the task at hand. Achieving net-zero emissions by 2050 would entail a fundamental transformation of the global economy. To bring about these changes, nine key requirements encompassing the three categories of physical building blocks, economic and societal adjustments, and governance, institutions, and commitment would need to be fulfilled against the backdrop of many economic (for example, inflation) and political challenges (for example, polarization within and among countries).³

In this report, we focus on the second category, namely, understanding the nature and extent of the economic and societal adjustments. We simulate the global shifts in demand, capital allocation, costs, and jobs that would take place between now and 2050 in the context of a net-zero transition, examining potential gains and opportunities as well as losses and costs. Our analysis covers the energy and land-use systems that produce about 85 percent of overall emissions and takes a closer look at how the transition might affect 69 countries.

This analysis is not a projection or a prediction; it provides point estimates of specific economic transformations likely under a given hypothetical net-zero transition scenario from the Network for Greening the Financial System (NGFS), an organization set up by central banks and supervisors in December 2017 with the goal of strengthening the global response to climate change. (We describe our methodology and its limitations in Box E1, "Our research methodology: Approach, scenarios, limitations, and uncertainties.") This scenario has an even chance of limiting warming to 1.5°C; however, it is not clear whether the world will be able to keep the temperature increase to that level, or which of numerous pathways it may take in an effort to do so. This research does not take a position on such questions. Instead, it seeks to demonstrate the economic shifts that would need to take place if the goal of 1.5 degrees is to be attainable and a relatively orderly transition achieved.

¹ Includes countries that have achieved their net-zero targets, or have put them in law, in policy documents, or made a declaration or a pledge. Net Zero Tracker, Energy and Climate Intelligence Unit, Data-Driven EnviroLab, NewClimate Institute, and Oxford Net Zero, 2021. GDP data for 2019 from *World Development Indicators Data Bank*, World Bank. Emissions data for 2018 from Emissions Database for Global Atmospheric Research (EDGAR), v6.0, May 2021. "Race to Zero campaign," United Nations Framework Convention on Climate Change.

² Based on policies currently enacted into law, UNEP, Climate Action Tracker, and the International Energy Agency project that warming will be 2.6–2.7°C by 2100. In alternate scenarios, where current net-zero targets and 2030 pledges are fully implemented, these organizations project that warming would be restricted between 2.1 and 2.2°C. IEA lowers this estimate to 1.8°C if targets that are still under discussion are also fully implemented. *Emissions gap report 2021: The heat is on*, UNEP, 2021; *Warming projections global update*, Climate Action Tracker, November 2021; and *World energy outlook 2021*, International Energy Agency, October 2021. Estimates from the Network for Greening the Financial System (NGFS) similarly suggest that if current implemented policies continue, approximately 1,250 additional gigatons of CO₂ would enter the atmosphere by 2050, breaching the limit that scientists consider necessary to keep warming below 1.5°C. Based on an analysis of the NGFS Current Policies scenario, using the REMIND-MAGPIE 2.1/4.2 model. See also *Climate change 2021: The physical science basis: Contribution of Working Group I to the Sixth Assessment Report*, Intergovernmental Panel on Climate Change (IPCC), 2021.

³ Mekala Krishnan, Tomas Nauclér, Daniel Pachthod, Dickon Pinner, Hamid Samandari, Sven Smit, and Humayun Tai, "Solving the net-zero equation: Nine requirements for a more orderly transition," McKinsey & Company, October 2021.

Our research methodology: Approach, scenarios, limitations, and uncertainties

We assess the net-zero transition along two dimensions: sectors and geographies. For the first, we examine energy and land-use systems that account for about 85 percent of global emissions: power, industry (steel and cement production), mobility (in particular, road transportation), buildings, agriculture and food, and forestry and other land use. We also looked at fossil fuels that supply energy to many of these systems. For the geographic dimension, we analyze effects in depth in 69 countries, which make up about 95 percent of global GDP.

We chose not to develop our own transition scenarios and rely instead on widely used scenarios created by other institutions. Specifically, we analyze potential effects under the Net Zero 2050 scenario defined by the Network for Greening the Financial System (NGFS). This hypothetical scenario mirrors global aspirations to cut emissions by about half by 2030 and to net zero by 2050 (Exhibit E1). It reaches net-zero CO₂ emissions by 2050 for the economy as a whole; this means there are some low residual gross CO₂ emissions in hard-to-abate sectors and some regions that are counterbalanced by CO₂ removals. We chose to work with the NGFS scenarios because they cover all major energy and land-use systems in a coherent manner, provide regional granularity, are designed for use in risk and opportunity analysis, and are becoming the standard scenarios used by financial institutions, regulators, and supervisors.¹

In some cases, as a counterfactual for comparison, we also use the NGFS Current Policies scenario. This scenario projects the greenhouse gas emissions that would occur if only today's mitigation policies remain in place (based on an NGFS assessment of policies as of the start of 2020), and it anticipates a little over 3°C of warming by 2100.² The comparison allows us to account for how other factors such as GDP growth or population growth could affect the economy between now and 2050. We also collaborated with Vivid Economics to use the two NGFS scenarios to generate more granular sector variables where needed (for example, sales of new automobiles), in a manner that was based on and compliant with the NGFS scenarios. In such cases, we still refer to the specific sector variable as being based on the relevant NGFS scenario.

We performed the analysis as follows. First, we used the NGFS scenarios and downscaling by Vivid Economics to quantify changes in important variables in each energy and land-use system (for example, changes in power production by source). The downscaling was done to provide sectoral or technological granularity where not available from NGFS. We used this to assess changes in demand, and then assessed the implications for capital stock and investment, producer and consumer costs, and employment based on information about decarbonization technologies and their capital and operating costs, labor intensity, and effects on value chains. Where possible, we used region-specific costs and labor assumptions, as well as expected technology learning curves over time, based on McKinsey analysis.

Limitations of our approach and uncertainties. We recognize the limitations of the NGFS scenarios, as with any transition scenario, given that this is an emerging field of research. First, while some variables are explored at the sector level, the scenarios sometimes do not provide enough detail to explore how different types of activities will be affected, thus requiring downscaling to achieve the necessary sectoral granularity. Second, the models underpinning the NGFS scenarios may not capture important dynamics or constraints within a sector. For example, the model we used favors more economy-wide use of biomass in energy and industry (for example, hydrogen production) than may be considered feasible in other sector-specific decarbonization pathways. Third, although the models do capture ongoing learning and technological innovation, they may fail to sufficiently anticipate the emergence of disruptive technologies that may change decarbonization pathways and lower cost trajectories faster than anticipated. Fourth, while some NGFS scenarios have begun to incorporate damages from physical risks in the economic modeling, further work is needed to fully integrate physical risks into the decarbonization pathways. As a result, we have focused here on scenarios that do not incorporate physical risk. This approach also allows us to focus our analysis on the effects of the transition alone.³ Finally, the scenarios reflect climate policies and technological trends in place before the COVID-19 pandemic and climate negotiations and pledges at COP26 in Glasgow in November 2021.

Our analysis largely consists of an analysis of first-order effects. Various uncertainties could influence the magnitude of outcomes highlighted here. While some of these factors could result in lower outcomes than those sized in this research, some factors suggest that additional costs and effects will likely occur as the transition unfolds. By the same token, the costs of physical climate risks could likely prove higher than those described here.

¹ NGFS says this scenario "limits global warming to 1.5°C through stringent climate policies and innovation, reaching net-zero CO₂ emissions around 2050, giving at least a 50 percent chance of limiting global warming to below 1.5°C by the end of the century, with no or low overshoot (< 0.1°C) of 1.5°C in earlier years." We use the REMIND-MAgPIE scenario from NGFS (2021 release), which allows a CO₂ budget of about 440 gigatons (Gt) after 2020.

² For further details, see NGFS Scenarios Portal and Climate Scenarios Database, NGFS, June 2021.

³ For further discussion of the uncertainties associated with modeling physical risks, see *Climate risk and response: Physical hazards and socioeconomic impacts*, McKinsey Global Institute, January 2020.

Key uncertainties include the following:

- *Warming scenario and emissions pathway.* A higher warming scenario (for example, 2.0°C above preindustrial levels) may lead to smaller transition effects than a 1.5°C warming scenario, given the lower degree of emissions reduction and deviation from today's production and consumption patterns it entails (though physical risks would naturally be higher).
- *Sectors' decarbonization actions and activity levels.* Because the focus of our work is assessing the nature and magnitude of economic shifts and not identifying decarbonization actions, we used a prespecified net-zero scenario from NGFS. It is feasible that an alternate technology mix could result in lower costs and different shifts than those described here, and that further technological innovation could result in a different pathway with lower costs. It is also feasible that the path the world undertakes to decarbonize is different from the one described here. An alternate scenario may consist of more use of carbon capture and storage (CCS) technologies and a focus on decarbonizing the hydrocarbon value chain, for example, this could happen if capture costs fall, regulatory frameworks are put in place to incentivize CCS use, and markets mature for recycled CO₂ as a material feedstock.⁴
- *Magnitude of direct and indirect socioeconomic effects.* Some effects could be larger than described here, for example, if executing the transition is more complex than the scenario here suggests, and additional capital spending is needed to maintain flexibility and redundancy in energy systems. If supply of key materials or low-emissions sources of energy does not keep up with demand, this could result in shortages and price increases, which we have not considered in our quantification. Higher-order effects could magnify risks and increase costs, particularly in the short term. For example, depending on how the transition is financed, the effects on the overall economy could be substantially higher than sized here. Finally, effects could also be larger under an abrupt or delayed transition.
- *Economic and societal adjustments needed for the transition.* Costs and investments could be higher than sized here, for example to implement social support schemes to aid economic and societal adjustments. Similarly, additional costs may arise from delays, setbacks, and urgently needed adaptation measures, particularly if restricting warming to 1.5°C proves not to be possible. For our analysis, we quantify the scale of first-order effects and describe qualitatively the adjustments needed.

Aspects we did not cover. Topics we did not cover include the likelihood, validity, and comparative costs associated with various decarbonization scenarios; the comparative merits of different emissions-reduction technologies; constraints to implement and deploy decarbonization technologies (for example, scaling up supply chains); the actions needed to drive and incentivize decarbonization; quantification of higher-order economic effects of the transition, including on output, growth, value pools, valuations, trade flows, and human well-being; relative costs and merits of decarbonization and adaptation; and impacts that could result from physical climate hazards. We use benchmarks from the external literature and our past research to describe these latter possibilities. As discussed above, our analysis here represents first-order estimates. Fully quantifying the costs of rising physical risks and the transition is complex. It would require estimating impacts from rising physical risks and the cost of adaptation actions, building robust estimates of the impact of the net-zero transition on the economy that takes into account the higher-order effects described above, and doing so over time and while grappling with the various uncertainties described previously.

Full details of our methodology are in the technical appendix.

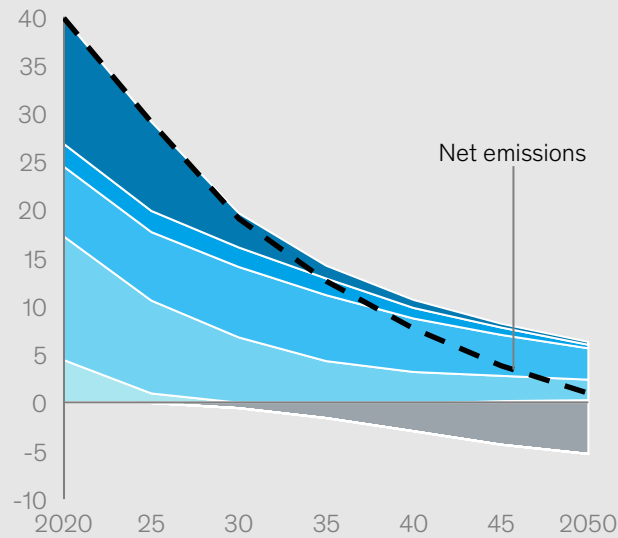
⁴ For more on CCS, see also chapter 1.

Exhibit E1

Our analysis uses the Net Zero 2050 scenario from the Network for Greening the Financial System (NGFS).

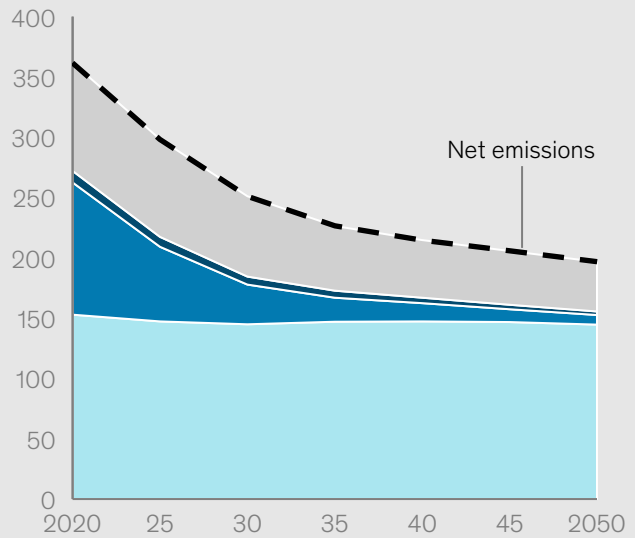
Net Zero 2050 scenario pathway from NGFS¹

CO₂ emissions, billion metric tons



- Power
- Buildings²
- Mobility³
- Industry⁴
- Agriculture, forestry, and other land use
- CO₂ removal⁵

Methane emissions, million metric tons



- End-use sectors⁶
- Supply of energy⁷
- Agriculture, forestry, and other land use⁸
- Other⁹

1. The net-zero scenario is based on the NGFS Net Zero 2050 scenario using REMIND-MAgPIE from the 2021 release of NGFS (phase 2).
2. CO₂ emissions from energy use in residential and commercial buildings.
3. CO₂ emissions from energy use in transportation sector (road, rail, shipping, and aviation).
4. CO₂ emissions from energy use in industry and industrial process emissions, energy conversion excluding electricity, fugitive emissions from fuels, and emissions from carbon dioxide transport and storage.
5. Total CO₂ emissions captured through bioenergy carbon capture and storage (BECCS). BECCS is deployed across multiple energy systems (eg, electricity generation, hydrogen production, and industry).
6. Methane emissions from energy use.
7. Methane emissions from energy conversion including electricity and fugitive emissions from fuels.
8. Methane emissions from agriculture, forestry, and other land use.
9. Methane emissions from all other sources (eg, waste).

Note: This is based on the NGFS database. Today's emissions may vary across other emissions databases depending on the methodology used.

Source: Network for Greening the Financial System scenario analysis 2021 phase 2 (Net Zero 2050 scenario) REMIND-MAgPIE model; McKinsey Global Institute analysis

Outcomes may well exceed our estimates here, particularly if the net-zero transition takes a disorderly path or if it proves impossible to restrict warming to 1.5°C (see Box E2, “Who will pay for the transition?”). We nonetheless hope such an exercise will help decision makers refine their understanding of the nature and the magnitude of the changes the net-zero transition would entail, and the scale of response needed to manage it.

Six characteristics of the net-zero transition emerge from our scenario-based analysis. First, the transition would be universal. Indeed, net-zero emissions can be achieved if and only if all energy and land-use systems that contribute to emissions are decarbonized, as these contributions are significant in all cases. All economic sectors and all countries would need to participate.

Second, the scale of the required economic transformation would be significant. In particular, we estimate that the cumulative capital spending on physical assets for the net-zero transition between 2021 and 2050 would be about \$275 trillion. This means that spending would need to rise from about \$5.7 trillion today to an annual average of \$9.2 trillion through 2050, an increase of \$3.5 trillion. Accounting for expected increases in spending, as incomes and populations grow, as well as for currently legislated transition policies, the required increase in spending would be lower, but still about \$1 trillion.

Third, these effects would be front-loaded: spending would need to rise to almost 9 percent of GDP between 2026 and 2030 from about 7 percent today before falling. Likewise, we estimate that the delivered cost of electricity (across generation, transmission, distribution, and storage, and including operating costs, capital costs, and depreciation of existing and new assets) would rise by about 25 percent between 2020 and 2040 in the scenario modeled here before falling from that peak, although this would vary across regions.

Fourth, the transition would be felt unevenly among sectors, geographies, and communities, resulting in greater challenges for some constituencies than others.

Fifth, the transition is laden with short-term risks, even as the transition will help manage long-term physical risks. If poorly managed, it could increase energy prices, with implications for energy access and affordability, especially for lower-income households and regions. It would also have knock-on effects on the economy more broadly. If not well managed, there is a risk that the transition itself would be derailed.

Sixth is that, despite the challenges with making economic and societal adjustments, the transition would give rise to growth opportunities across sectors and geographies—and, critically, it would help avoid the buildup of physical risks.

This research aims to highlight the nature and magnitude of the economic transformation that a net-zero transition would require. While the challenges ahead are large, the findings of this research should be seen for what they are: a call for more thoughtful, decisive, and urgent action to secure a more orderly transition to net-zero emissions by 2050. Everyone would have a role to play, including governments, businesses, and individuals. To ease stakeholders' adjustments to these effects, governments and businesses will likely need to adopt a long-term perspective and coordinate action in a spirit of unity, resolve, and cooperation and, at the same time, take near-term actions to manage their own risks and capture opportunities.

This research is a call for more thoughtful, decisive, and urgent action.

Who will pay for the transition?

As discussed later in this report, the spending needed on physical assets for the net-zero transition is significant. It represents a substantial scale-up of spending relative to today's levels. It is also capital that will be spent very differently relative to today, with capital reallocated away from high-emissions assets and toward low-emissions ones. While some of this spending would eventually yield a return, various challenges with raising capital at this scale will need to be effectively managed. These include addressing technological uncertainty of investment, managing risk/return trade-offs, driving capital flows to developing countries, and ensuring demand for this capital exists in the sectors and geographies in which emissions reduction is most needed.

This raises the question of how to best pay for the transition. Various aspects to consider include who provides the financing (for example, public versus private actors, and the mix of financing provided by developed and developing countries), how capital is raised (for example, debt versus equity, through taxes on companies or consumers), and various combinations thereof. For example, public financing can come through raising taxes on companies, carbon taxes, taxes on consumers, or through taking on debt, to name a few approaches.

In deciding the optimal approach to financing the transition, stakeholders will need to consider three factors. First, which approach would raise capital at the speed and scale needed, and incentivize the deployment of this capital. Second, how financing can best include principles of equity, including what equity would require based on the history of emissions and who has the ability to pay. And finally, what are broader knock-on consequences of different financing approaches.

The latter is especially important, because it can profoundly influence the socioeconomic consequences of a net-zero transition. First, some ways of raising capital—for example, taxes on consumers—could curtail spending in other parts of the economy if not balanced, for example, with fiscal stimulus elsewhere. This in turn could have knock-on effects on corporate revenues for affected sectors, on job creation, and on growth more broadly. Second, the source of financing could exacerbate existing inequalities if not carefully managed. Developing countries, for example, may find it challenging to raise the capital needed for the transition on their own. Third, the type of financing could have a role in influencing the pace of the net-zero transition. Certain technologies, such as electric vehicle (EV) charging infrastructure, may require public financing at scale to reach the speed of deployment needed to achieve net-zero.

The results presented here do not factor in these considerations, as our focus is on sizing the magnitude of the need. However, the question of “who pays” is unavoidable as stakeholders undertake the economic transformation needed for the net-zero transition, and do so with the consequences mentioned above in mind.

Net-zero emissions can be achieved only through a universal transformation of energy and land-use systems

To stabilize the climate and limit physical climate risks, climate science tells us that it is necessary to reduce the addition of GHGs to the atmosphere to net zero (see Box E3, “Physical risks will continue to build up until net zero is achieved”). Seven energy and land-use systems act as direct sources of global emissions (Exhibits E2 and E3).⁴ One system—forestry and other land use—also acts as a natural sink for carbon dioxide and would need to increase its rate of emissions absorption. The systems and their emissions footprints are the following:

- Power, consisting of electricity and heat generation: 30 percent of CO₂ emissions, and 3 percent of nitrous oxide (N₂O) emissions⁵
- Industry, consisting of various industrial processes, including production of steel, cement, and chemicals, and extraction and refining of oil, gas, and coal: 30 percent of CO₂ emissions, 33 percent of methane emissions, 8 percent of N₂O emissions
- Mobility, consisting of road, aviation, rail, maritime, and other forms of transportation: 19 percent of CO₂ emissions, and 2 percent of N₂O emissions
- Buildings, including heating and cooking: 6 percent of CO₂ emissions
- Agriculture, consisting of direct on-farm energy use and emissions from agricultural practices and fishing: 1 percent of CO₂ emissions, 38 percent of methane emissions, and 79 percent of N₂O emissions
- Forestry and other land use, primarily land cover change: 14 percent of CO₂ emissions, 5 percent of methane emissions, and 5 percent of N₂O emissions
- Waste, consisting of solid waste disposal and treatment, incineration, and wastewater treatment: 23 percent of methane emissions, 3 percent of N₂O emissions

Carbon dioxide in each case is emitted through the combustion of fossil fuels to produce energy (oil, gas, and coal), as well as through non-energy emissions (for example, emissions associated with industrial processes like the reduction of iron ore to produce steel and with deforestation). Based on current accounting methodologies, energy-related emissions make up as much as 83 percent of carbon dioxide emissions.⁶

Reaching net-zero emissions will require a transformation of the global economy.

⁴ UN Food and Agriculture Organization (FAO), 2020; “Energy use,” FAOSTAT; EMIT database, McKinsey Sustainability Insights, September 2021; and McKinsey Global Energy Perspectives.

⁵ Heat generation includes heat from combined heat and power plants.

⁶ Notably, this is based on the current system of emissions measurement, in which forestry emissions in particular are considered as net emissions, considering their role as both sources and sinks of greenhouse gases. Considering only their role as gross sources of emissions, and accounting for second-order effects of deforestation, would substantially increase the contribution of forestry as sources of emissions. For further details, see chapter 3.

Physical risks will continue to build up until net zero is achieved

As average temperatures rise, acute hazards such as heat waves and floods increase in frequency and severity, and chronic hazards, such as drought and rising sea levels, intensify.¹ These hazards and changes could lead to rising, nonlinear, and systemic socioeconomic impacts, as described in our 2020 report on physical climate risk.² Most recently, the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR6) reaffirmed that continued GHG emissions will result in increasingly severe consequences for the Earth system and, potentially, abrupt and catastrophic changes that might occur as the climate passes tipping points.³

As physical climate risk spreads, it could trigger broader economic, financial, and social disruptions.⁴ Estimates suggest that failing to limit the rise of greenhouse gas emissions could affect between 2 and 20 percent of global GDP by 2050 under a high-emissions (RCP 8.5) scenario.⁵ The wide range reflects the intrinsic difficulty in making these estimates. The effect of hard-to-predict biotic feedback loops (for example, the thawing of permafrost) or knock-on economic effects (for example, from impacts on financial valuations) could push losses well beyond the high-end estimate.

To stabilize the climate and limit physical climate risks, climate science tells us that it is necessary to reduce the addition of GHGs to the atmosphere to net zero and limit warming to 1.5°C above preindustrial levels to reduce the odds of initiating the most dangerous and irreversible effects of climate change.⁶ Global emissions of carbon dioxide are about 40 gigatons (GtCO₂) today. Emissions of CO₂ have risen significantly since 1970, though the rate of growth has slowed in recent years.⁷ The IPCC AR6 report estimated that restricting all future net CO₂ emissions to 400–500 Gt, combined with substantial decreases in emissions of short-lived GHGs like methane, would result in a 50 to 67 percent probability of limiting warming to 1.5°C above preindustrial levels.⁸ At current emissions rates, the carbon budget for 1.5°C of warming would thus likely be exceeded within about the next decade. Climate science tells us that the Earth system will continue to change along the journey to net zero and that some changes will continue even after we have stopped the planet from warming; thus, actions to reduce emissions will also need to go hand-in-hand with adaptation.⁹ Decisions taken over the next decade will thus be crucial.

¹ Noah S. Diffenbaugh and Christopher B. Field, "Changes in ecologically critical terrestrial climate conditions," *Science*, volume 341, number 6145, August 2013; Seth D. Burgess, Samuel Bowring, and Shu-zhong Shen, "High-precision timeline for Earth's most severe extinction," *Proceedings of the National Academy of Sciences*, volume 111, number 9, March 2014.

² *Climate risk and response: Physical hazards and socioeconomic impacts*, McKinsey Global Institute, January 2020.

³ *Climate change 2021: The physical science basis: Contribution of Working Group I to the Sixth Assessment Report*, Intergovernmental Panel on Climate Change (IPCC), 2021.

⁴ See Box 1 in *Climate risk and response: Physical hazards and socioeconomic impacts*, McKinsey Global Institute, January 2020.

⁵ Making estimates of this kind is challenging, and we have not attempted to do so in our research. The ranges here come from a review of the literature focused on quantifying the various impacts of physical climate effects on real GDP or GDP growth. For detailed sources, see chapter 1 and the bibliography.

⁶ "Summary for policymakers," in *Climate change 2021: The physical science basis: Contribution of Working Group I to the Sixth Assessment Report*, IPCC, 2021.

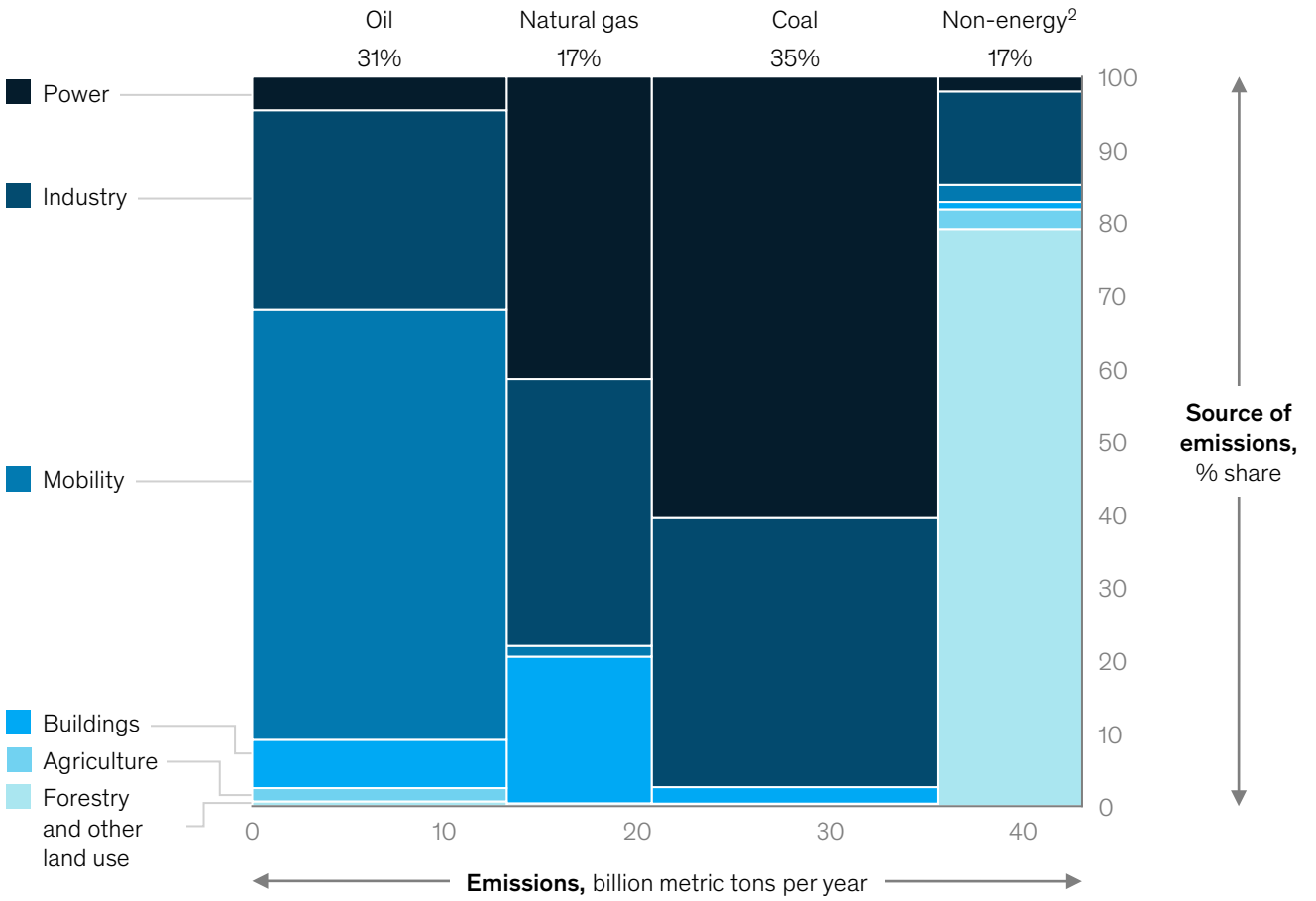
⁷ Emissions data for other greenhouse gases are less frequently reported. In 2019, annual emissions were 364 megatons of methane (CH₄), and 10 megatons of nitrous oxide (N₂O). See also Global Carbon Budget, 2021; EMIT database by McKinsey Sustainability Insights, September 2021. For more on the impact of the pandemic, see Corinne Le Quéré et al., *Temporary reduction in daily global CO₂ emissions during the COVID-19 forced confinement*, Global Carbon Project, March 2021.

⁸ Restricting future net emissions to 1,150–1,350 GtCO₂ would result in a 50–67 percent probability of limiting warming to 2.0°C. At current emissions rates, the carbon budget for 1.5°C of warming would be exceeded in approximately the next decade, and the 2.0°C budget would be exceeded in about three decades.

⁹ H. Damon Matthews et al., "Focus on cumulative emissions, global carbon budgets, and the implications for climate mitigation targets," *Environmental Research Letters*, volume 13, number 1, January 2018.

Energy use accounts for 83 percent of the CO₂ emitted across energy and land-use systems.

CO₂ emissions per fuel and energy and land-use system, 2019, share¹



1. Includes all fossil fuel CO₂ sources as well as short-cycle emissions (eg, large-scale biomass burning, forest fires). Power includes emissions from electricity and heat generation (i.e., from combined heat and power plants); Industry includes various industrial processes, including production of steel, cement, and chemicals, and extraction and refining of oil, gas, and coal; Mobility includes emissions from road, aviation, rail, maritime, and other forms of transportation; Buildings includes emissions from heating, cooking, and lighting of commercial and residential buildings; Agriculture includes emissions from direct on-farm energy use and fishing; Forestry includes net flux of CO₂ from land use and land cover change but not the opportunity cost of lost carbon capture. The global CO₂ emissions in this exhibit represent the total emissions of the full sectors, not of the subsectors considered in this report. Based on 2019 emissions.

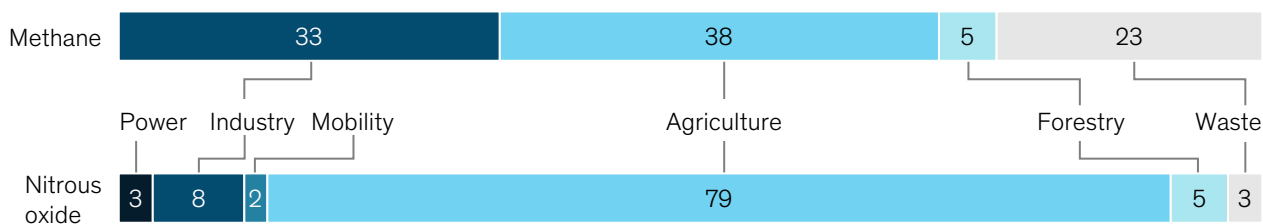
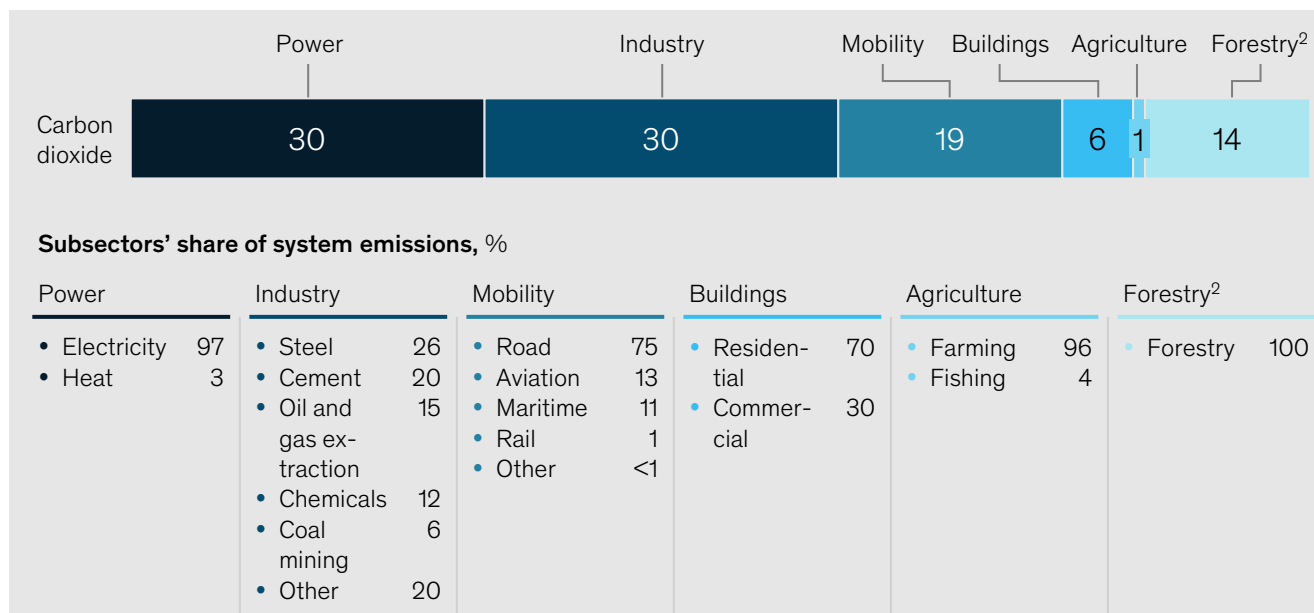
2. In addition to energy-related CO₂ emissions, anthropogenic emissions include industry process emissions and deforestation.

Note: This is based on the McKinsey EMIT database that draws on a variety of bottom-up sources. Depending on the emissions database used, data per sector and the economy as a whole may vary. Figures may not sum to 100% because of rounding.

Source: EMIT database by McKinsey Sustainability Insights (September 2021, data for 2019); International Energy Agency; McKinsey Global Energy Perspectives; McKinsey Global Institute analysis

Power and industry are major energy consumers and together generate about 60 percent of CO₂ emissions.

Share of emissions¹ per energy and land-use system, 2019, %



1. Includes all fossil fuel CO₂ sources as well as short-cycle emissions (eg, large-scale biomass burning, forest fires). Power includes emissions from electricity and heat generation (i.e., from combined heat and power plants); Industry includes various industrial processes, including production of steel, cement, and chemicals, and extraction and refining of oil, gas, and coal; Mobility includes emissions from road, aviation, rail, maritime, and other forms of transportation; Buildings includes emissions from heating, cooking, and lighting of commercial and residential buildings; Agriculture includes emissions from direct on-farm energy use and fishing; Forestry includes net flux of CO₂ from land use and land cover change but not the opportunity cost of lost carbon capture; Waste includes emissions from solid waste disposal and treatment, incineration, and wastewater treatment. The global CO₂ emissions in this exhibit represent the total emissions of the full sectors, not of the subsectors considered in this report. Based on 2019 emissions.

2. Forestry and other land use.

Note: This is based on the McKinsey EMIT database that draws on a variety of bottom-up sources. Depending on the emissions database used, data per system and the economy as a whole may vary. Figures may not sum to 100% because of rounding.

Source: EMIT database by McKinsey Sustainability Insights (September 2021, data for 2019); McKinsey Global Institute analysis

Effective decarbonization actions include shifting the energy mix away from fossil fuels and toward zero-emissions electricity and other low-emissions energy carriers such as hydrogen; adapting industrial and agricultural processes; increasing energy efficiency and managing demand for energy; utilizing the circular economy; consuming fewer emissions-intensive goods; deploying carbon capture, utilization, and storage (CCS) technology; and enhancing sinks of both long-lived and short-lived greenhouse gases. Avoiding deforestation and enabling forest restoration are particularly important for restoring and enhancing GHG sinks.⁷ Recent McKinsey research on what it would take to achieve a 1.5°C pathway examined a range of scenarios and found that the above actions would need to be deployed across all sectors in the economy and would require emissions-reduction efforts beginning today.⁸

⁷ Estimates suggest that over a 30-year period, a tree can store an additional 60 to 85 percent as much carbon as is released when the tree is cut down or burned, and that overall secondary emissions and forgone carbon sequestration resulting from deforestation can be three to nine times higher than the direct emissions alone. Research indicates that forgone carbon sequestration and forest degradation are highly underestimated in current evaluations of deforestation emissions. For details, see chapters 1 and 3.

⁸ Kimberly Henderson, Dickon Pinner, Matt Rogers, Bram Smeets, Christer Tryggstad, and Daniela Vargas, "Climate math: What a 1.5-degree pathway would take," McKinsey & Company, April 2020. See also "Curbing methane emissions: How five industries can counter a major climate threat," McKinsey & Company, September 2021.

A key feature of any transition to net-zero emissions is its universality, across energy and land-use systems and throughout the global economy. This is for two reasons. First, each of these energy and land-use systems contributes substantially to emissions. Thus, every one of these systems will need to undergo transformation if the net-zero goal is to be achieved. Second, these systems are highly interdependent; actions to reduce emissions must thus take place in concert and at scale across systems, economic sectors, and geographies. For instance, electric vehicles are valuable only to the extent that low-emissions electricity production has been achieved. All sectors of the economy participate in these energy and land-use systems across global value chains. Similarly, all countries contribute to emissions, either directly or through their role in value chains. Reaching net-zero emissions will thus require a transformation of the global economy.

A net-zero transition would have a significant and often front-loaded effect on demand, capital allocation, costs, and jobs

Decarbonizing the energy and land-use systems described previously will be possible only if nine system-level requirements are met. They encompass physical building blocks, economic and societal adjustments, and governance, institutions, and commitment (see Box E4, “The net-zero ‘equation’ and system-level requirements to help solve it”).

This report focuses on the economic and societal adjustments needed for a net-zero transition. We illustrate the significant adjustments that would need to be made through an analysis of the nature and the magnitude of the transition on demand, capital allocation, costs, and jobs. Various other knock-on effects could also ensue and affect, for example, value pools, financial valuations, GDP, and global trade flows. While we do not quantify these, we discuss some of them qualitatively throughout the report.⁹ Specific aspects include the following:

- **Demand:** Changes in policies, technologies, and consumer and investor preferences under a net-zero transition could increase demand for low-emissions goods and services and lower demand for high-emissions ones, in turn causing changes across value chains.
- **Capital allocation:** Decarbonizing the global economy and securing low emissions going forward would require significant capital spending on the formation of new physical assets and the transformation of existing ones.
- **Costs:** Operating and production costs would change as low-emissions processes are implemented, investment is made, and energy consumption shifts toward low-emissions sources.
- **Jobs:** Workforce requirements would evolve as markets are reshaped and organizations institute new operational practices and processes.

Our analysis using the NGFS Net Zero 2050 scenario is a hypothetical simulation, not a projection or a prediction. Our perspectives on demand, investment, costs, and jobs below represent a consistent and interdependent view of the world under this scenario. The analysis is not exhaustive, and we acknowledge its limitations and uncertainties.

⁹ We have focused on quantifying the direct shifts, given the vast uncertainties involved in modeling these higher-order effects, and because their outcome could vary based on specific actions taken to manage them. For further details on our methodology, see Box E1.

The net-zero ‘equation’ and system-level requirements to help solve it

Prior research by McKinsey Sustainability makes the point that achieving net zero is akin to solving an equation—one that balances sources and sinks of emissions by reducing GHG emissions as much as possible while increasing GHG stores to remove any remaining emissions from the atmosphere.¹ To help solve this equation, that research identified nine fundamental, interrelated system-level requirements for a net-zero transition. Our research in this report uses these requirements as a starting point. We place them into the following three groups:

Physical building blocks, encompassing (1) technological innovation; (2) ability to create at-scale supply chains and support infrastructure; and (3) availability of necessary natural resources. Past McKinsey research suggests that there is a line of sight to the technologies needed to limit warming to 1.5°C above preindustrial levels, although continued innovation is still needed.² Further innovation, both to develop new technologies that can be deployed at scale and to reduce their costs, will be needed nonetheless. For example, under a 1.5°C pathway, the number of solar panels installed globally per week would be approximately eight times higher than the number today. The rate of wind-turbine installations would need to increase fivefold.³ And natural resources, including raw materials such as copper, nickel, rare-earth metals, land, and water, would also need to be carefully managed to ensure sufficient availability and minimize bottlenecks, and prevent price spikes and inflation. Building out supply chains to support the kind of step change in deployment needed requires not only significant capital and the right capabilities but also extensive coordination.

Economic and societal adjustments, comprising (4) effective capital reallocation and financing structures; (5) management of demand shifts and near-term unit cost increases; and (6) compensating mechanisms to address socioeconomic impacts. As we discuss in this research, an orderly transition to net zero would require significant changes to capital allocation. Companies and countries would need to manage the demand shift and cost changes from a wholesale revamping of energy and land-use systems, even as the implications for individuals and communities for livelihoods and expenditures could be substantial.

Governance, institutions, and commitment, consisting of (7) governing standards, tracking and market mechanisms, and effective institutions; (8) commitment by, and collaboration among, public-, private-, and social-sector leaders globally; and (9) support from citizens and consumers. The pace, scale, and systemic nature of the required transition mean that all stakeholders will need to play a role, working together in new ways. Securing an orderly transition will require leaders who have the commitment and capabilities to develop coherent, reliable, and workable policies and help their organizations navigate the changes that lie ahead. The transition is also unlikely to occur without the support of citizens and consumers, and in some cases, consumers may need to fundamentally shift behaviors to reduce their own emissions.

As stakeholders have increased their commitments to net zero, moving to action has not proven easy or straightforward. This is for five reasons: first, the scale and pace of the step-up in spending needed on physical assets, given that entire energy and land-use systems evolved over a century or two and would need to be transformed over the next 30 years; second, the collective and global action required, particularly as the burdens of the transition would not be evenly felt; third, the near-term shifts needed for longer-term benefits; fourth, the shifts needed in business practices and lifestyles that have evolved over decades; and fifth, the central role of energy in all economic activity, which means that transformation would need to be carefully managed. Indeed, the transition involves the transformation of the most important systems supporting our lives and well-being. Even small disturbances to these systems could affect daily lives, from raising producer and consumer costs to impairing energy access, and could lead to delays and public backlash. Together, these factors highlight why the prevailing notion of enlightened self-interest alone is unlikely to be sufficient to help achieve net zero.

In this report, we focus on the second of these groupings of requirements, the economic and societal adjustments, to better understand these challenges and how stakeholders can respond. There is a real risk that transition costs could be unbearable to many in the absence of compensating measures; for example, if companies and countries do not manage the shifts in demand or cost impacts to their existing products and services, or if communities are left behind as the world transitions to a net-zero economy.

¹ Mekala Krishnan, Tomas Naclér, Daniel Pachthod, Dickon Pinner, Hamid Samandari, Sven Smit, and Humayun Tai, “Solving the net-zero equation: Nine requirements for a more orderly transition,” McKinsey & Company, October 2021.

² See, for example, Paolo d’Aprile, Hauke Engel, Godart van Gendt, Stefan Helmcke, Solveigh Hieronimus, Tomas Naclér, Dickon Pinner, Daan Walter, and Maaïke Witteveen, “How the European Union could achieve net-zero emissions at net-zero cost,” McKinsey & Company, December 2020. Our work on decarbonization in Europe found that more than 85 percent of today’s emissions in Europe can be abated with already demonstrated technologies, including 28 percent that are mature and 32 percent that are in the early-adoption phase (although it is important to note that the pathway to deploying these technologies is still uncertain and would require addressing the other requirements mentioned here).

³ See also Kimberly Henderson, Dickon Pinner, Matt Rogers, Bram Smeets, Christer Tryggestad, and Daniela Vargas, “Climate math: What a 1.5-degree pathway would take,” *McKinsey Quarterly*, April 2020.

Demand: In the net-zero scenario examined here, high-emissions products would see shrinking demand, while uptake of low-emissions products would create growth opportunities

Our analysis suggests that under the NGFS Net Zero 2050 scenario, changes in policies, technologies, and consumer and investor preferences would lead to considerable shifts in demand for various goods and services (Exhibit E4). By 2050, oil and gas production volumes would be 55 percent and 70 percent lower, respectively, than they are today. Coal production for energy use would nearly end by 2050. Similarly, the transition would affect demand for products that use fossil fuels. Demand for internal combustion engine (ICE) cars would eventually cease as sales of battery-electric and fuel cell-electric cars increase from 5 percent of new car sales in 2020 to virtually 100 percent by 2050.

In other sectors, demand could shift, with a substitution of products manufactured with emissions-intensive operations to lower-emission alternatives. For example, steel production would increase by about 10 percent relative to today, but with low-emissions steel rising from one-quarter of all production to almost all production by 2050. In the agriculture and food system, the dietary shifts necessary for a net-zero transition would, over time and in the case of some consumers, move protein demand from emissions-intensive beef and lamb to lower-emissions foods like poultry.

In other areas, in particular those related to low-emissions energy sources, demand would grow.¹⁰ Power demand in 2050 would be more than double what it is today. Production of both hydrogen and biofuels would increase more than tenfold between 2021 and 2050.¹¹ Other industries, such as those that manage carbon with nature-based solutions or carbon capture and storage technologies, could also grow (see also discussion later on opportunities from the transition). For example, forestry and other land use would contribute to sequestering approximately nine metric gigatons of CO₂ by the middle of the century.

Capital allocation: About \$275 trillion of cumulative spending on physical assets would be needed through 2050 under the NGFS Net Zero 2050 scenario

Shifts in demand during the net-zero transition would trigger the retirement or transformation of some existing physical assets and the acquisition of new ones. Our analysis suggests that these moves would influence spending on physical assets in two ways. First, spending would increase significantly relative to today. Second, a portion of the capital that is now being spent on high-emissions assets would be spent on low-emissions assets, including those with CCS installed.¹²

Our analysis of the NGFS Net Zero 2050 scenario suggests that about \$275 trillion in cumulative spending on physical assets, or approximately \$9.2 trillion per year, would be needed between 2021 and 2050 across the sectors that we studied (Exhibit E5).¹³

¹⁰ Increased energy access relative to today and growing population and incomes globally would also drive some of the increase described here.

¹¹ For hydrogen, this excludes captive production for industrial end uses such as refineries and chemicals.

¹² Our analysis divides high-emissions assets from low-emissions assets and enabling infrastructure. Low-emissions assets have a relatively low emissions footprint; the term does not always mean carbon neutral. This segmentation was done to allow us to size the scale of capital reallocation needed for the net-zero transition. In doing so, we recognize that the demarcation between high and low emissions is not always clear. Low-emissions assets and enabling infrastructure include assets for blue-hydrogen production with CCS; green-hydrogen production using electricity and biomass; biofuel production; generation of wind, solar, hydro-, geothermal, biomass, gas with CCS, and nuclear power along with transmission and distribution and storage infrastructure; heat production from low-emissions sources such as biomass; steel furnaces using EAF, DRI with hydrogen, basic oxygen furnaces with CCS; cement kilns with biomass or fossil fuel kilns with CCS; zero-emissions vehicles and supporting infrastructure; heating equipment for buildings run on electricity or biomass, including heat pumps; district heating connections; cooking technology not based on fossil fuels; building insulation; GHG-efficient farming practices; food crops, poultry and egg production; land restoration.

¹³ Based on analysis of systems that account for about 85 percent of overall GHG emissions today. This estimation includes spend for physical assets across various forms of energy supply (for example, power systems, hydrogen, and biofuel supply), energy demand (for example, for vehicles and alternate methods of steel and cement production), and various forms of land use (for example, GHG-efficient farming practices). This includes both what is typically considered investment in national accounts and spend, in some cases, on consumer durables such as personal cars. We typically consider spending to replace physical assets at the point of emissions (for example, cars for mobility); additional spending would also occur through the value chain. We have not sized this, to minimize double counting.

The NGFS Net Zero 2050 scenario entails a transformation of energy and land-use systems. (1 of 2)

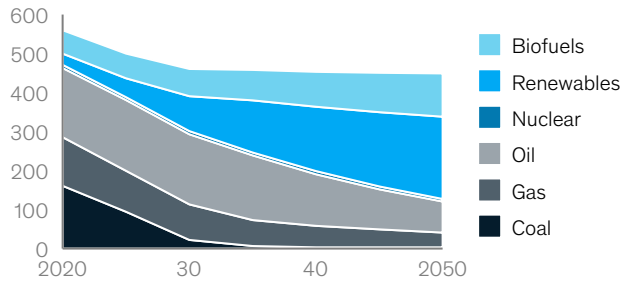
Not exhaustive

Activity level trajectory, 2020–50¹

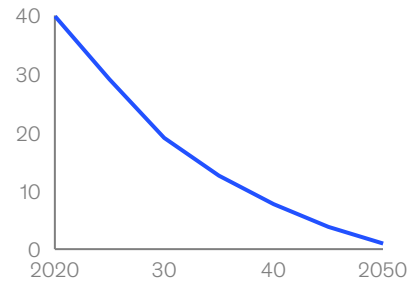
Emissions trajectory, 2020–50¹

Overall

Primary energy, Exajoule

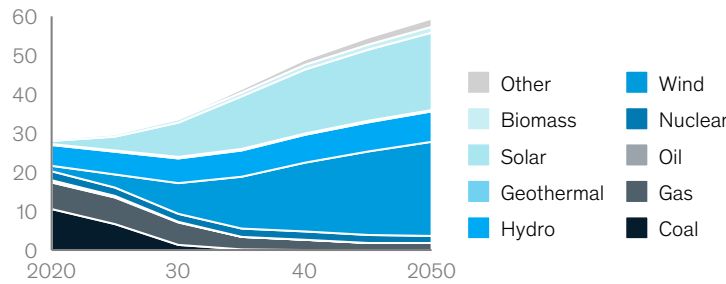


Global CO₂ emissions, billion metric tons²

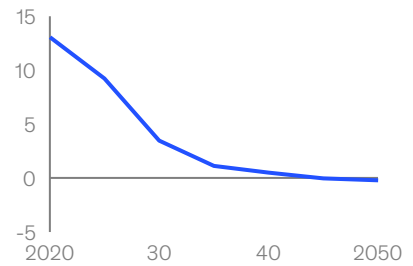


Power

Electricity generation by source, Peta-Watt hours

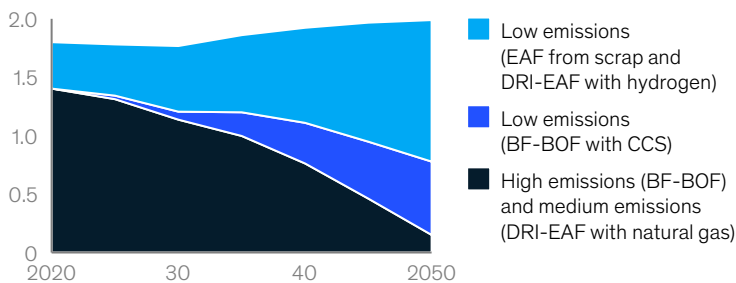


Electricity generation CO₂ emissions, billion metric tons

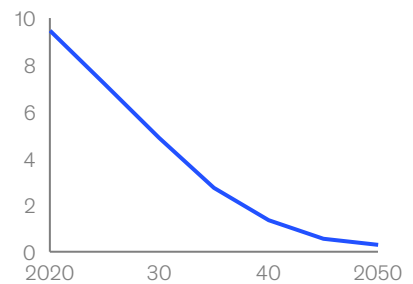


Industry: Steel

Steel production, billion metric tons

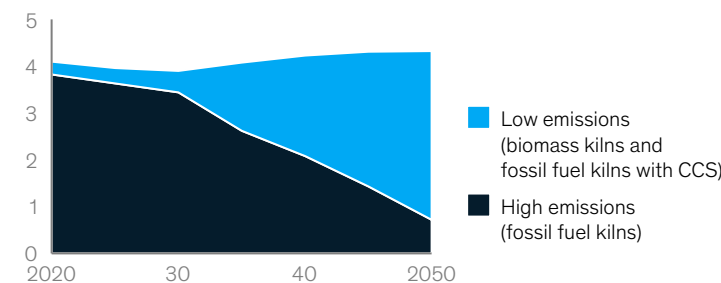


Industrial process and energy demand, CO₂ emissions, billion metric tons³



Industry: Cement

Cement production, billion metric tons



1. Based on the NGFS Net Zero 2050 scenario using REMIND-MAgPIE. In some instances, variables were downscaled by Vivid Economics. This represents global activity levels and emissions. In the Net Zero 2050 scenario, different systems reach zero emissions at different times.
 2. The overall trajectory of CO₂ emissions will be influenced in large part by the trajectory and mix of primary energy use. However, other factors, for example rates of afforestation and deforestation as well as industrial processes, will also play a role.
 3. Emissions for the entire industry system, not only for cement and steel.

Source: NGFS Net Zero 2050 scenario using REMIND-MAgPIE (phase 2); Vivid Economics; McKinsey Sustainability Insights; McKinsey Global Institute analysis

The NGFS Net Zero 2050 scenario entails a transformation of energy and land-use systems. (2 of 2)

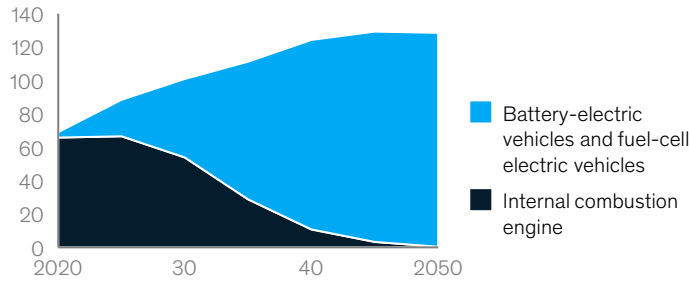
Not exhaustive

Activity level trajectory, 2020–50¹

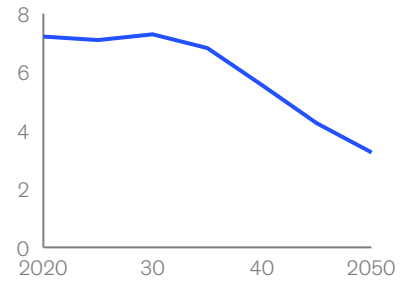
Emissions trajectory, 2020–50¹

Mobility

Total new passenger cars sold per year, million

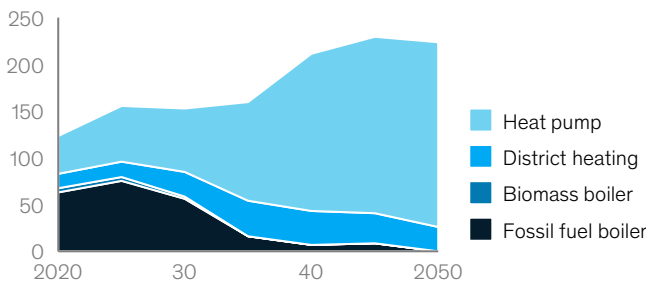


Transportation CO₂ emissions, billion metric tons²

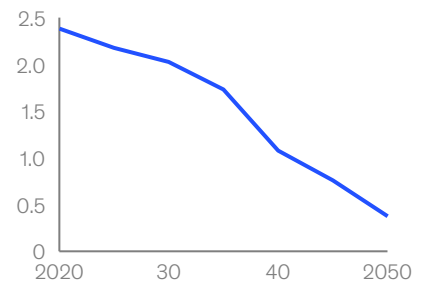


Buildings

Total heating systems sold per year, million

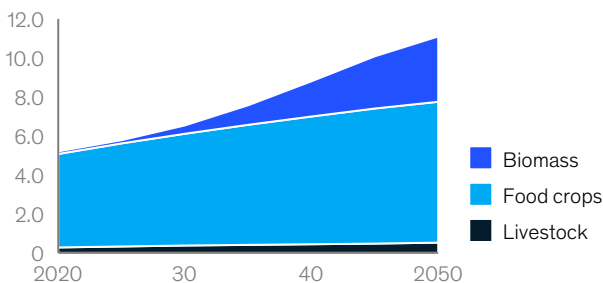


Buildings CO₂ emissions, billion metric tons

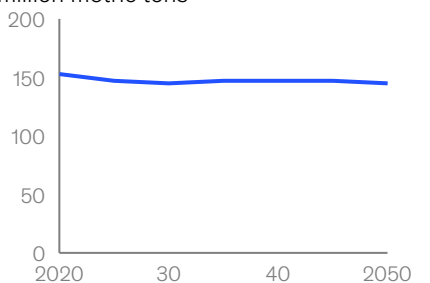


Agriculture

Agriculture production, %, billion metric tons dry matter

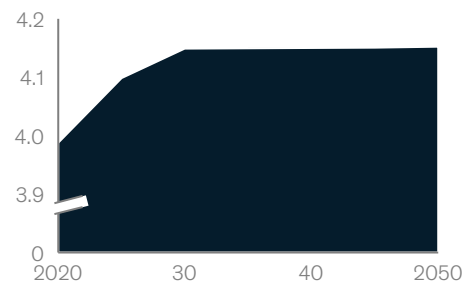


Agriculture, forestry, and other land use (AFOLU) methane emissions, million metric tons³

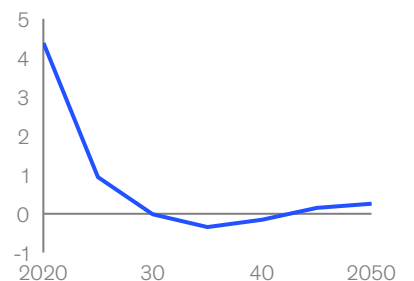


Forestry and other land use

Forest cover, billion hectares



AFOLU CO₂ emissions, billion metric tons⁴

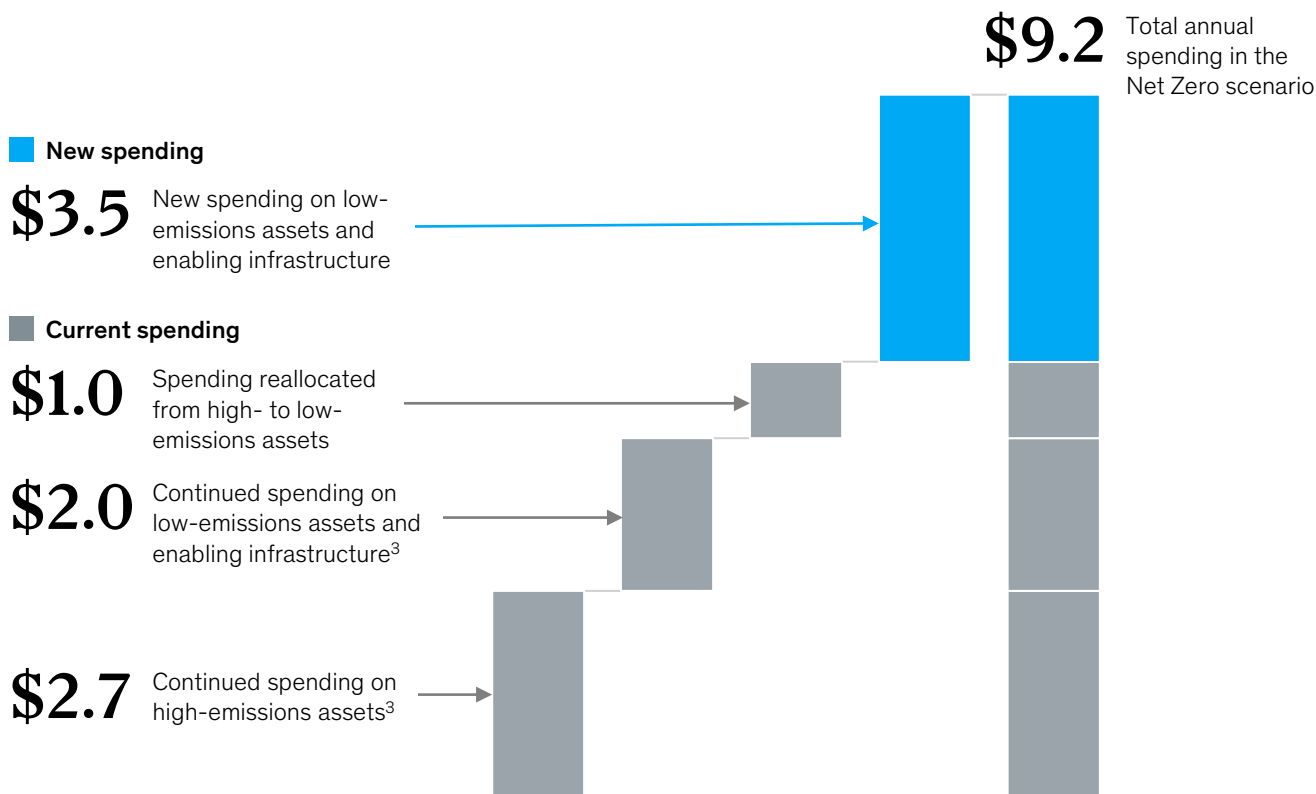


1. Based on the NGFS Net Zero 2050 scenario using REMIND-MAgPIE. In some instances, variables were downscaled by Vivid Economics. This represents global activity levels and emissions. In the Net Zero 2050 scenario, different systems reach zero emissions at different times.
 2. Includes road transportation, aviation, freight, and rail.
 3. Methane emissions from agriculture, forestry, and other land use are mostly influenced by agriculture, but they also include a small amount of emissions from forestry and other land use.
 4. Carbon dioxide emissions are mostly influenced by forestry and other land use, but they also include a small amount of emissions from agriculture. Afforestation contributes to cumulatively sequestering approximately nine metric gigatons of carbon dioxide by 2050 in the NGFS Net Zero scenario.

Source: NGFS Net Zero 2050 scenario using REMIND-MAgPIE (phase 2); Vivid Economics; McKinsey Sustainability Insights; McKinsey Global Institute analysis

Spending on physical assets for energy and land-use systems in the NGFS Net Zero 2050 scenario would rise to about \$9.2 trillion annually, or about \$3.5 trillion more than today.

Annual spending on physical assets for energy and land-use systems¹ in the Net Zero 2050 scenario,² average 2021–50, \$ trillion



1. We have sized the total spending on physical assets in power, mobility, fossil fuels, biofuels, hydrogen, heat, CCS (not including storage), buildings, industry (steel and cement), agriculture, and forestry. Estimation includes spend for physical assets across various forms of energy supply (eg, power systems, hydrogen, and biofuel supply), energy demand (eg, for vehicles, alternate methods of steel and cement production), and various forms of land use (eg, GHG-efficient farming practices).
2. Based on the NGFS Net Zero 2050 scenario using REMIND-MAGPIE (phase 2). Based on analysis of systems that account for ~85% of overall CO₂ emissions today. Spend estimates are higher than others in the literature because we have included spend on high-carbon technologies, agriculture, and other land use, and taken a more expansive view of the spending required in end-use sectors.
3. Our analysis divides high-emissions assets from low-emissions assets. High-emissions assets include assets for fossil fuel extraction and refining, as well as fossil fuel power production assets without CCS; fossil fuel heat production, gray-hydrogen production; steel BOF; cement fossil fuel kilns; ICE vehicles; fossil fuel heating and cooking equipment; dairy, monogastric, and ruminant meat production. Low-emissions assets and enabling infrastructure include assets for blue-hydrogen production with CCS; green-hydrogen production using electricity and biomass; biofuel production; generation of wind, solar, hydro-, geothermal, biomass, gas with CCS, and nuclear power along with transmission and distribution and storage infrastructure; heat production from low-emissions sources such as biomass; steel furnaces using EAF, DRI with hydrogen, basic oxygen furnaces with CCS; cement kilns with biomass or fossil fuel kilns with CCS; low-emissions vehicles and supporting infrastructure; heating equipment for buildings run on electricity or biomass, including heat pumps; district heating connections; cooking technology not based on fossil fuels; building insulation; GHG-efficient farming practices; food crops, poultry and egg production; and land restoration.

Source: McKinsey Center for Future Mobility Electrification Model (2020); McKinsey Hydrogen Insights; McKinsey Power Solutions; McKinsey–Mission Possible Partnership collaboration; McKinsey Sustainability Insights; McKinsey Agriculture Practice; McKinsey Nature Analytics; McKinsey Global Institute analysis

This represents spending related specifically to the deployment of new physical assets and to the decarbonization of existing assets. It does not include spending to support other adjustments—for example, to reskill and redeploy workers, compensate for stranded assets, or account for the loss of value pools in specific parts of the economy. Spending could also be higher than sized here, for example, in order to build redundancy into energy systems during the transition to avoid supply volatility. Other research to date that has sized investment needs for the transition has largely focused on estimating required energy investment. Here we expand this to include additional spending categories.¹⁴ As a result, our estimates exceed to a meaningful degree the \$3 trillion to \$4.5 trillion of annual spending for the net-zero transition that others have estimated.¹⁵

The amount of cumulative spending is equivalent to about 7.5 percent of GDP from 2021 to 2050. The required spending would be front-loaded, rising from about 6.8 percent of GDP today to about 9 percent of GDP between 2026 and 2030 before falling. In dollar terms, the increase in annual spending is about \$3.5 trillion per year, or 60 percent, more than is being spent today, all of which would be spent in the future on low-emissions assets. This incremental spending would be worth about 2.8 percent of global GDP between 2020 and 2050. To put this in comparable terms, the increase is approximately equivalent, in 2020, to half of global corporate profits, one-quarter of total tax revenue, 15 percent of gross fixed capital formation, and 7 percent of household spending.

The second aspect, the reallocation of spending, would also be significant. At present, \$3.7 trillion—or 65 percent of total spending—goes annually toward high-emissions assets, such as coal-fired power plants and vehicles with internal combustion engines. In this net-zero scenario, about \$1 trillion of today's spend on high-emissions assets would need to be reallocated to low-emissions assets. Of the overall \$9.2 trillion needed annually for a net-zero transition over the next 30 years, \$6.5 trillion—or 70 percent of total spending—would be on low-emissions assets, reversing today's trend. Three sector groups—mobility, power, and buildings—would account for approximately 75 percent of the total spending on physical assets in this net-zero scenario (see the next section for a detailed discussion of spending needed by sector).

Our estimates exceed to a meaningful degree the \$3 trillion to \$4.5 trillion of annual spending for the net-zero transition that others have estimated.

¹⁴ We broadened the analysis to include a more comprehensive view of spending by households and businesses on assets that use energy (for example, the full cost of passenger cars and heat pumps), capital expenditures in agriculture and forestry, and some continued spend in high-emissions physical assets like fossil fuel-based vehicles and power assets.

¹⁵ See *Net Zero by 2050: A roadmap for the global energy sector*, IEA, 2021; *NGFS climate scenarios for central banks and supervisors*, NGFS, 2021; Christoph Bertram et al., "Energy system developments and investments in the decisive decade for the Paris Agreement goals," *Environmental Research Letters*, volume 16, number 7, June 2021; David McCollum et al., "Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals," *Nature Energy*, volume 3, June 2018; *Making mission possible: Delivering a net-zero economy*, Energy Transitions Commission, September 2020; and *Better growth, better climate: The new climate economy report*, The Global Commission on the Economy and Climate, 2014.

If we consider the likely evolution of this spending given population growth, GDP growth, and current momentum toward the net-zero transition, the capital outlay would be smaller but remain significant. If we take as a basis the NGFS Current Policies scenario—which accounts for expected income and population growth, as well as currently legislated policies and expected cost reductions in key low-emissions technologies—the incremental annual spend in a net-zero scenario would be about \$0.9 trillion rather than the \$3.5 trillion increase noted above (Exhibit E6).¹⁶ Approximately 50 percent of the \$8.3 trillion in annual spending in the Current Policies scenario would be on low-emissions assets, which highlights that already some shift to low-emission spending is anticipated in this scenario from existing technological trends and policies today.

The transition could also lead to asset stranding, whereby existing physical assets are either underutilized or retired before the end of their useful life. In the context of the net-zero transition, the capital stock associated with fossil fuels and emissions is worth many trillions of dollars, a significant share of the total global capital stock—and even more capital stock depends indirectly on these assets.

Stranding large portions of this capital stock in a disorderly or abrupt way could impede value generation in many industrial sectors and indeed the global economy and would therefore need to be carefully managed. In power alone, for example, we estimate that some \$2.1 trillion worth of assets could be stranded by 2050. About 80 percent of these stranded assets would pertain to fossil fuel–based power plants in operation today, primarily coal-fired plants in countries such as China and India that are relatively new (less than 15 years old) and would normally have many more years of productive life.¹⁷

Moreover, many assets that could be stranded are capitalized on the balance sheets of listed companies. Early retirement of these assets would potentially lead to the reduction of (currently perceived) value and to bankruptcies and credit defaults, with potential knock-on effects on the global financial system. And markets may well pronounce their verdict before the actual stranding has taken place. Unsurprisingly, then, the possibility of asset stranding has prompted concerns about financial-sector risk and the need to build the capabilities to quantify and manage it.¹⁸

While the scale of the capital that would need to be deployed in a net-zero transition is substantial, it is important to put it in context. First and foremost, as we discuss later, the economic adjustments involved in reaching net zero in a coordinated and orderly manner would prevent the further buildup of physical risks and the additional costs arising from a more disorderly transition. Second, in the long run, the up-front capital expenditures for a net-zero transition could result in operating savings for some sectors through reduced fuel consumption, improved material and energy efficiency, and lower maintenance costs.

The up-front capital expenditures for a net-zero transition could result in operating savings for some sectors in the long run.

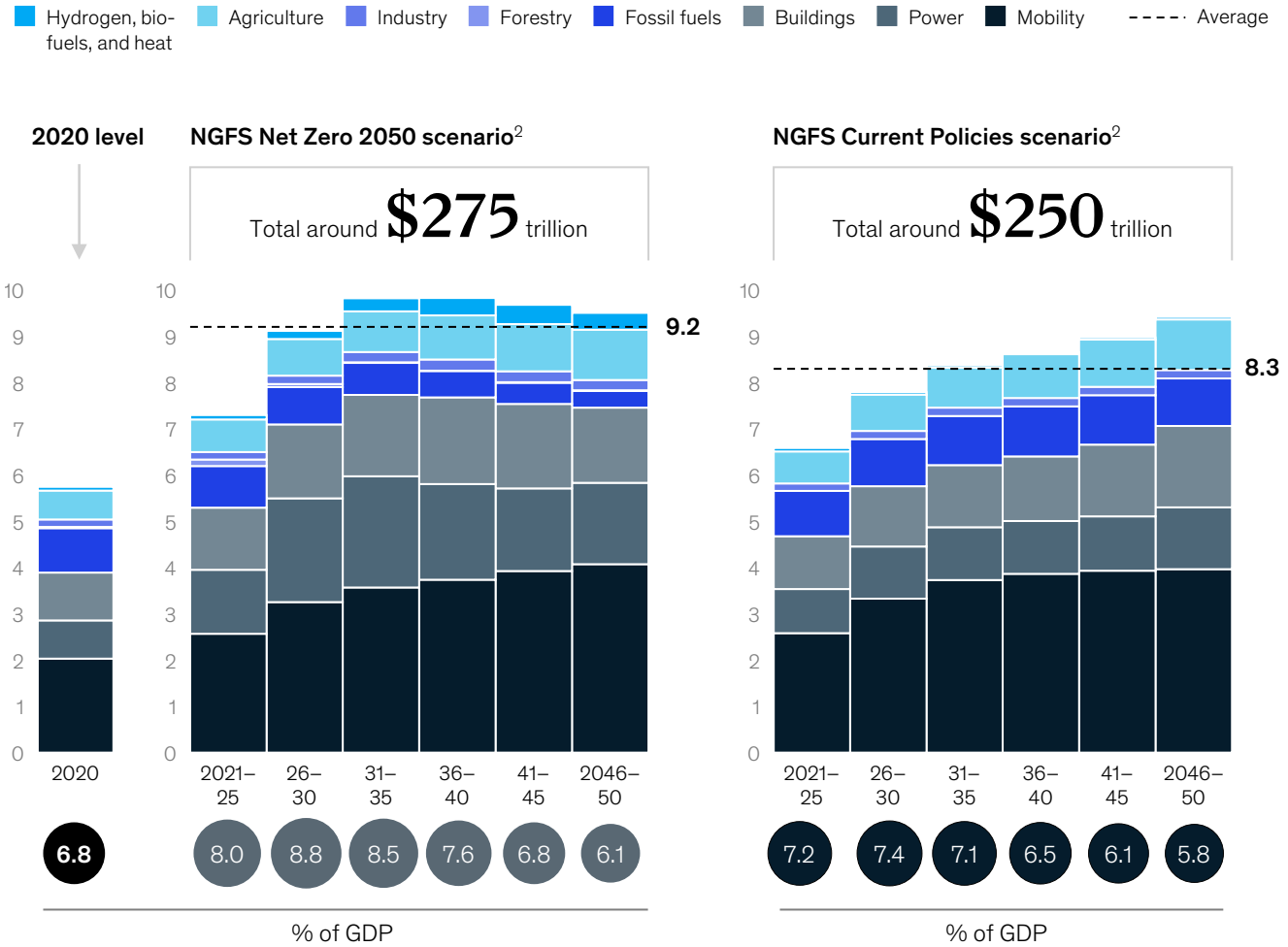
¹⁶ The NGFS Current Policies scenario projects the greenhouse gas emissions that would occur if only today's policies remained in place, and it anticipates about 3°C of warming by 2100. See Box E1 and the technical appendix.

¹⁷ Our definition of stranded assets represents the cumulative value of prematurely retired and underutilized assets in 2020–50, undiscounted. We estimate it by first identifying the level of yearly depreciation that is expected given asset life and assumed economic life using data from the WRI Global Power Plant database as input. That figure was multiplied by the fraction of assets that are underutilized relative to past average utilization rates (between 2005 and 2020) and summed across years. Other research has found similar effects on the power sector, and other sectors. See, for example, *Stranded assets and renewables: How the energy transition affects the value of energy reserves, buildings and capital stock*, International Renewable Energy Agency, 2017; David Nelson et al., *Moving to a low-carbon economy: The impact of policy pathways on fossil fuel asset values*, Climate Policy Initiative, October 2014; and Jean-Francois Mercure et al., "Reframing incentives for climate policy action," *Nature Energy*, November 2021.

¹⁸ See, for example, David Nelson et al., *Moving to a low-carbon economy: The impact of policy pathways on fossil fuel asset values*, Climate Policy Initiative, October 2014.

The NGFS Net Zero 2050 scenario would entail around \$275 trillion in cumulative investments over 30 years—around \$25 trillion more than the Current Policies scenario.

Annual spend on physical assets for energy and land-use systems,¹ \$ trillion per year



1. We have sized the total spending on physical assets in power, mobility, fossil fuels, biofuels, hydrogen, heat, CCS (not including storage), buildings, industry (steel and cement), agriculture, and forestry. Estimation includes spend for physical assets across various forms of energy supply (for example, power systems, hydrogen, and biofuel supply), energy demand (for example, for vehicles, alternate methods of steel and cement production), and various forms of land use (for example, GHG-efficient farming practices). This includes both what are typically considered “investments” in national accounts and spend, in some cases, on consumer durables such as personal cars. Annual average over 5-year periods.

2. Scenario based on the Network for Greening the Financial System Net Zero 2050 scenario using REMIND-MAgPIE (phase 2). Current policies is based on the NGFS Current Policies scenario using REMIND-MAgPIE (phase 2). Based on analysis of systems that account for ~85% of overall CO_{2e} emissions today. Our analysis includes a more comprehensive view of spending by households and businesses on assets that use energy, capital expenditures in agriculture and forestry, and some continued spend in high-emissions physical assets. See technical appendix.

Source: Network for Greening the Financial System 2021 (Net Zero 2050 scenarios) REMIND-MAgPIE model; Vivid Economics; McKinsey Center for Future Mobility Electrification Model (2020); McKinsey Hydrogen Insights; McKinsey Power Solutions; McKinsey–Mission Possible Partnership collaboration; McKinsey Sustainability Insights; McKinsey Agriculture Practice; McKinsey Nature Analytics; McKinsey Global Institute analysis

It is also important to recognize that capital spending is not merely a cost. Much of this investment is already cost-effective and comes with a return. For example, research analyzing other net-zero scenarios has found that about 40–50 percent of spending can come with a positive investment case.¹⁹

Various challenges will need to be managed in the short run to achieve such outcomes. They include raising capital and securing financing at this scale, managing technological uncertainty of investment, considering risk/return trade-offs, and driving capital flows to both developed and developing countries. Raising and deploying capital could be more challenging for specific sectors and geographies.

Capital spending is not merely a cost: much of this investment is already cost-effective and comes with a return.

¹⁹ McKinsey research finds that about half of the required investments to reach net-zero emissions in Europe have a positive investment case. This means that switching to the relevant low-emissions technology would represent a cost saving at the cost of capital for each sector and segment. See Paolo D'Aprile, Hauke Engel, Godart van Gend, Stefan Helmcke, Solveigh Hieronimus, Tomas Nauclér, Dickon Pinner, Daan Walter, and Maaïke Witteveen, "How the European Union could achieve net-zero emissions at net-zero cost," McKinsey & Company, November 2020. The IEA also examined the actions required to be taken by consumers in the IEA Net Zero 2050 scenario such as switching to low-emissions vehicles. They find that 40 percent would result in overall cost savings relative to an Announced Policies scenario where governments follow through on their climate targets and commitments. See *World economic outlook*, IEA, 2021. On the macroeconomic level, higher levels of public and private investment could provide economic stimulus, leading to negligible net negative impacts, or even modest net positive impacts, on GDP growth (though as discussed, much depends on how the transition is financed and managed). For example, the European Commission found in conducting an impact assessment for proposed 2030 net-zero-aligned emissions targets for the European Union that raising policy ambition would result in a cumulative impact of between -0.7 percent and +0.55 percent on GDP by 2030 compared to a baseline forecast. See *Impact assessment: Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people*, Commission Staff Working Document SWD/2020/176, September 2020.

Costs: Steel, cement, and power would see cost increases in the Net Zero 2050 scenario, due to shifts in production processes and capital expenditures, while total cost of ownership of EVs would fall

The transition's financial implications reach beyond spending on physical assets. Production costs, which reflect changing operating costs as well as capital costs for new investment and asset depreciation, would also shift as processes are changed and high-emissions assets are replaced or retrofitted. And any changes in production costs could possibly affect the costs of consumer goods, if costs are passed through. We examine these effects in turn.

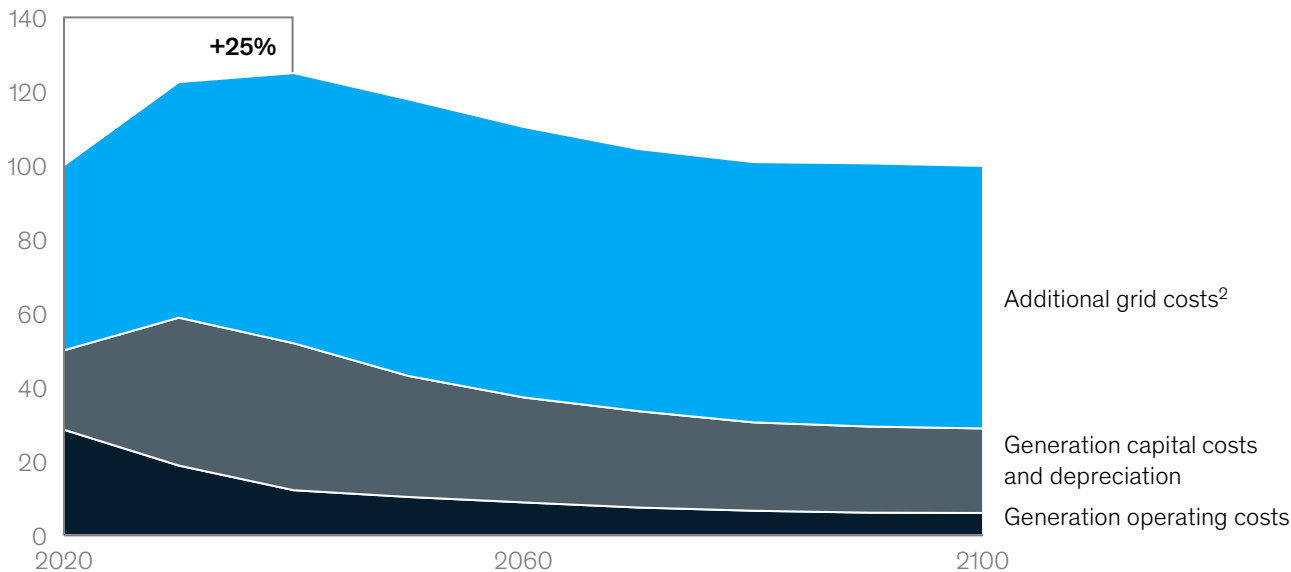
In the steel and cement sectors, production costs, including operating costs, capital charges, and depreciation, could rise by about 30 percent and 45 percent, respectively, from their current levels, though continued innovation could lower these estimates. In the power sector, our analysis indicates that the global average delivered cost of electricity across generation, transmission, distribution, and storage would increase before falling from their peak, in the scenario modeled here. The impact would be front-loaded: costs would increase by about 25 percent by 2040, including operating costs, capital costs, and depreciation of new and existing assets, from 2020 levels (Exhibit E7). This is for two main reasons: firstly, investments will be needed in building renewables and grid and storage capacity, creating capital costs and depreciation charges. Secondly, some fossil-based power assets would continue to incur capital costs, even if they are underutilized or retired prematurely.²⁰ This analysis represents a global average perspective. The picture could look different across regions depending on the current state of the power system, the availability of natural resources like sunshine and wind, and the age of fossil power fleets, among other factors. It is conceivable that innovation and economies of scale could drive down capital and grid spending. Delivered cost of electricity in the first half of the century could then be lower than anticipated in the scenario.

On the other hand, impacts could be significantly higher than those sized here (though it is important to note that costs as sized here are not the same as consumer electricity prices). Various factors could contribute to this, including potential grid intermittency issues as renewable assets are scaled up, shortage of fossil fuel-based capacity to serve peak loads and provide backup for renewables, and shortage of coal and gas inputs for fossil fuel power plants, to name a few. The potential impacts of such outages would be even greater with electricity being used more extensively across the economy than today under a net-zero transition, for example for heating, mobility, and industry. If the shift from high-emissions fossil fuel-based power assets and the ramp-up of low-emissions assets that replace them is not well managed, this could increase both energy prices and volatility and there could be challenges with reliable power. (See Box E5, "How rising energy prices can create risk.")

²⁰ To assess cost changes for power, we first quantified the change in three main cost drivers: power generation capital charge and depreciation (at a weighted average cost of capital of 6.5 percent), power generation operating costs, and transmission, distribution, and storage investments. These were then translated into a delivered cost of electricity by dividing by electricity production in each time period. This metric indicates how the underlying costs are changing for the entire power sector. Our methodology is broader than other studies focused on the levelized cost of energy for new assets which often highlight the competitive cost position of renewables in the power mix. Our analysis also takes into account infrastructure spending on grids, capital charges, and depreciation of legacy assets even if they are prematurely retired or underutilized. See also Rupert Way et al., *Empirically grounded technology forecasts and the energy transition*, Institute for New Economic Thinking Oxford, working paper number 2021-01, September 2021. Note that our metric is different from the actual cost paid by consumers, and eventual energy prices for consumers could look substantially different. Consumer electricity prices depend on a multitude of factors, including decisions on how the power system transformation is paid for and over what time frame. For example, a key question is how to best manage coal generation decommissioning and write-down costs. Moreover not all expected changes in delivered costs are due to decarbonization. For instance, some transmission and distribution investments would happen regardless, as countries increase electricity access. This analysis does not take into account short-term variations in supply and demand, subsidies, or taxes.

Global average delivered cost of electricity in the NGFS Net Zero 2050 scenario would rise in the short run and then fall back from its peak.

Delivered cost of electricity,¹ \$ per MWh, index (100 = 2020), NGFS Net Zero 2050 scenario, global average



1. This metric represents a full system cost for power, across generation, transmission, and storage. It includes operating costs, capital costs, and depreciation. To assess cost changes for power, we first quantified the change in three main cost drivers: power generation capital charge (at a weighted average cost of capital of 6.5 percent), power generation operating costs, and transmission, distribution and storage investments. These were then translated into the delivered cost of electricity by dividing by electricity production in each time period. This metric indicates how the underlying costs are changing for the power sector and is not the same as consumer electricity prices. The trends described here are global averages and would vary across regions.
2. Transmission and distribution plus storage.

Source: Network for Greening the Financial System scenario analysis 2021 phase 2 (Net Zero 2050 scenario) REMIND-MAgPIE (phase 2) model; Vivid Economics; World Resources Institute Power Plant Database; McKinsey Power Solutions; McKinsey Global Institute analysis

In the scenario modeled here, costs would subsequently decrease from the 2040 peak; for example, by 2050, operating costs for generation could drop by more than 60 percent relative to 2020 as the energy mix shifts to renewables. Some of the reduction in operating and other costs for generation would be offset by an increase in the operating and other costs associated with grid flexibility, transmission, and distribution. As a result, delivered cost of electricity in this scenario would still be about 20 percent higher in 2050 than 2020 levels. In the long run, there is more uncertainty about how delivered cost of electricity could evolve, and costs could at some point be lower than 2020 levels, depending on innovations to power technologies, grid design, and evolution of the power system to manage flexibility issues.

Other sectors could see overall cost decreases. A key example of this is mobility. Our analysis suggests that the total cost of ownership for electric cars could be cheaper than ICE cars in most regions by 2025, as we describe in more detail below.²¹ Medium-duty BEV trucks covering 200–300 km a day are expected to reach total cost parity with ICEs by around 2025, with heavy-duty long-haul trucks reaching parity by 2030 in Europe and later in other regions.

²¹ Total cost of ownership accounts for purchase price, operating costs, for instance fuel and maintenance costs, and resale value; based on three years of ownership of a new car.

How rising energy prices can create risk

Global energy prices surged in the third quarter of 2021, providing a glimpse of the speed with which market imbalances can feed through to consumers and prompt swift government reactions including subsidies to low-income households.

Natural gas price benchmarks in Europe and Asia were ten times higher in October 2021 than one year prior, while US month-ahead natural gas prices reached their highest level since 2008. International coal prices were also sharply higher, at five times their fall 2020 levels.¹ Rising primary fuel prices sparked large increases in consumer electricity prices in Germany, Spain, and elsewhere in Europe. In the United States, gasoline pump prices of \$3.50 per gallon were the highest in seven years.² Deteriorating margins for energy providers and electricity-intensive industries such as fertilizer production forced several companies to curtail operations.³

Energy prices are already a highly critical topic given the centrality of energy to consumers and economic activity—even under normal circumstances. For example, according to the European Commission, 31 million Europeans live in energy poverty and are unable to adequately heat their homes.⁴ To help alleviate price rises, India, Japan, South Korea, the United Kingdom, and the United States announced in November 2021 they would be tapping into their respective strategic oil reserves.⁵ Some governments also initiated subsidy programs. These included the US making available a \$4 billion budget for the Low Income Energy Assistance Program, providing aid to more than five million families.⁶ Italy and Spain capped home energy bills and redirected utility company profits to subsidize low-income households and small enterprises.⁷

A confluence of factors led to the price fluctuations, including a rebound in consumer activity as lockdowns related to the COVID-19 pandemic eased along with persistent labor and supply chain shortages. In some instances, weather events exacerbated the situation, including low wind speeds in the North Sea, a cold snap in Texas that led to a gas production shut-in, drought in Brazil that depleted hydropower reservoir levels to 25 percent below their five-year average, and flooding of Chinese coal mines that exacerbated shortages driven in part by the recent freeze on coal imports from Australia.⁸

Such events, while not directly attributed to a net-zero transition, nonetheless shine a light on supply chain and grid vulnerabilities. In doing so, they can serve as a cautionary preview of potential future energy market volatility that can be triggered by rapid simultaneous shifts on the supply and demand sides of the global energy and materials landscape. For example, as reliance on renewables grows and investment in fossil fuel-based power generation declines, tight supply for raw material inputs for technologies like solar panels and batteries may compound energy price volatility given long lead times in the capital-intensive mining sector. As the world acts on net-zero pledges, periods of energy price volatility like those in the last months of 2021, among others, thus serve as a reminder of the importance of careful transition management.

Exposure to these risks would also increase with electrification as a key pillar of the transition. Power outages, whether due to the energy mix, weather or operator error, would have far-reaching consequences where households and businesses are depending on a reliable source of electricity for day-to-day needs such as heating, cooling, appliances, vehicles, and industrial applications. As the mix of the power system shifts to renewables in the net-zero transition we have analyzed here, various factors could influence the delivered cost of electricity, and also electricity prices for consumers. First, as already noted, the delivered cost of electricity would initially rise in the Net Zero 2050 scenario as power generation assets are replaced and transmission, distribution, and storage capacity is built. Increases in these costs could even be higher than calculated here, with implications for prices and with more volatility, for the various reasons discussed previously. Second, storage and transmission costs, which constitute a substantial portion of the cost of electricity, could feed through to consumers in an uneven way, with some paying more while others experience savings. This will depend in part on a range of localized factors including existing transmission and distribution capacity and the need for long duration storage. Finally, market design could be an important factor: as the power system changes, power markets may need to change with it. Today, power is sold through the spot market, in which prices are set according to production costs of the marginal power producer, and through bilateral purchase agreements between power producers and consumers. Capacity markets have historically accounted for a relatively small share of power sales, but they may play a larger role in the future to fully compensate flexible producers that help balance the grid. New market mechanisms may be needed to encourage some marginal fossil fuel power producers to decommission their plants earlier. Key questions remain about how this would be paid for, and also how cost increases, if any, would affect end consumers.

¹ Carlos Fernández Alvarez and Gergely Molnar, "What is behind soaring energy prices and what happens next?" International Energy Agency, October 2021.

² US retail gasoline price data, all grades, all formulations, US Energy Information Administration.

³ Carlos Fernández Alvarez and Gergely Molnar, "What is behind soaring energy prices and what happens next?" International Energy Agency, October 2021.

⁴ *State of the energy union 2021*, European Commission, October 2021.

⁵ Zolan Kanno-Youngs, Stanley Reed and Jim Tankersley, "The United States and other world powers will tap oil reserves," *New York Times*, November 23, 2021.

⁶ *Biden administration deploys American Rescue Plan funds to protect Americans from rising home heating costs; calls on utility companies to prevent shut offs this winter*, White House Fact Sheet, November 18, 2021.

⁷ "Italy sets aside more than 3 bln euros to curb energy bills," Reuters, September 23, 2021; "Spain targets energy firms as European bills surge," BBC News, September 14, 2021.

⁸ Joe Wallace, "Energy prices in Europe hit records after wind stops blowing," *Wall Street Journal*, September 13, 2021. Carlos Fernández Alvarez and Gergely Molnar, "What is behind soaring energy prices and what happens next?" International Energy Agency, October 2021.

Consumers would face additional up-front capital costs and may need to spend more in the near term on electricity if cost increases are passed through; lower-income households everywhere are naturally more at risk

The net-zero transition could also affect consumer spending. Consumers may face higher prices and up-front capital costs in the near term and may need to adjust their spending if significant emissions reductions are to be achieved, although the extent of the impact could vary depending on the composition of consumers' spending baskets and whether companies pass on costs, among other factors.²² Low-income households are particularly at risk. Over time, all consumers could see some benefits.

First, consumers' spending habits may be affected by decarbonization efforts. For example, they may need to replace goods that burn fossil fuels, like transportation vehicles and home heating systems that rely on fossil fuels, and potentially modify diets to reduce beef and lamb consumption.

Second, any rise in electricity prices would affect consumers, particularly lower-income consumers, whose spend on energy makes up a large share of wallet. However, this depends on how cost recovery is allocated among consumers, up to and including the extent any increases in delivered cost of electricity are passed through to end consumers.

Third, consumers would incur up-front capital costs related in particular to the mobility and buildings transition. For example, as ICE vehicles are phased out, households would shift spending to EVs, which cost more than comparable ICE cars because of their large batteries. Even though, in the long term, consumers could benefit over the life of the asset—for example, because of the lower total cost of ownership for EVs or savings from energy efficiency measures in homes. McKinsey analysis suggests that the total cost to own an EV, which takes into account purchase price, maintenance, fuel cost, and resale value, would be cheaper than an ICE car in most regions by 2025. For example, the total cost of ownership for battery-electric cars in Europe may be cheaper compared to that of ICEs by 2025, and the United States by 2030.²³ A faster decline in battery prices or local subsidies could accelerate this break-even point. Even so, the higher up-front costs may prove challenging for lower-income households. Food costs are one area where consumer costs could fall if the dietary shifts required to decarbonize the agriculture and food sectors manifest—that is, if eating habits move away from emissions-intensive and higher-cost ruminant protein like beef and lamb to other forms of protein like poultry.²⁴

Finally, higher production costs could also affect the price of consumer goods and services in other areas. Higher costs for low-emissions shipping could be passed on to the consumer for goods shipped internationally; however, the extent to which this will flow through to higher costs for consumers will likely be country- and product-specific.²⁵ Likewise, rising costs in hard-to-abate sectors such as steel and cement could raise the cost of end products, though this will depend on the fraction of the cost of these materials in final goods and services.²⁶ All of these could be addressed through a range of compensating mechanisms to ease the transition.

²² A comprehensive accounting of the effects on consumers would be complex, since effects vary based on such factors as a consumer's spending basket, whether companies pass through any additional operating or capital costs, and the transition's effect on government revenues and subsidies. Effects on consumers are likely to vary by region. For example, developing countries could have a higher proportion of their total spend basket affected by the climate transition, due to higher spending on energy. Individuals' incomes could also be affected by shifts in livelihood or any changes in taxation as a result of the transition.

²³ McKinsey Center for Future Mobility Electrification Model (2021), price benchmarks in key markets.

²⁴ Derek Headley and Harold Alderman, "The relative calorific prices of healthy and unhealthy foods differ systematically across income levels and continents," *Journal of Nutrition*, volume 149, issue 11, November 2019.

²⁵ For example, research has highlighted that the cost of jeans may only rise by 1 percent but this might vary for other product types. See *Hydrogen insights: A perspective on hydrogen investment, market development and cost competitiveness*, Hydrogen Council and McKinsey & Company, February 2021.

²⁶ See Eric Hannon, Tomas Nauc ler, Anders Suneson, and Fehmi Y ksel, "The zero-carbon car: Abating material emissions is next on the agenda," McKinsey & Company, September 2020.

Jobs: The net-zero transition analyzed here could lead to a reallocation of labor, with about 200 million direct and indirect jobs gained and 185 million lost by 2050

Our analysis of the NGFS Net Zero 2050 scenario suggests that the transition could result in an increase in demand for about 162 million direct and indirect jobs (referred to as “job gains”) and a decrease in demand for about 152 million direct and indirect jobs (referred to as “job losses”) in operations and maintenance by 2050 across different sectors of the economy. In addition, about 41 million jobs could be gained and 35 million lost related to direct and indirect jobs associated with spending on physical assets needed for the net-zero transition by 2050 (Exhibit E8).²⁷ Jobs in the latter category, linked to shifts in capital spending, are likely to be more transitory than those in the former, related to operations and maintenance, as discussed below. Together, this results in 202 million direct and indirect jobs gained and 187 million lost by 2050, as a result of the net-zero transition modeled here. When considering job losses and gains here, we only consider those which are directly attributable to the net-zero transition, rather than other factors like income or population growth. The effect on jobs would be especially notable not so much for its overall size in terms of net losses or gains as for its concentrated, uneven, and re-allocative nature.

The size of the job dislocation in the scenario analyzed here needs to be put in perspective with job dislocations from other trends. For example, previous research by the McKinsey Global Institute suggests that automation, remote work, and e-commerce trends could lead to job losses of about 270 million to 340 million across eight countries between 2018 and 2030, with commensurate job gains—considerably more than our estimates for net-zero transition-related job losses and gains globally.²⁸

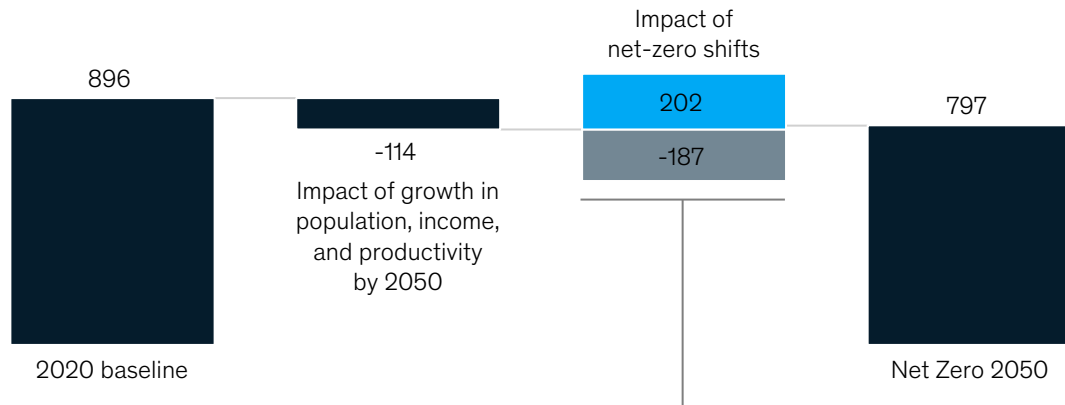
One notable characteristic in our analysis of the job losses and gains during the net-zero transition would be their concentration in specific sectors and geographic regions. Job gains would be largely associated with the transition to low-emissions forms of production, for example to renewable-power production, while the losses would particularly affect workers in fossil fuel-intensive or otherwise emissions-intensive sectors, a significant reallocation of jobs across the economy. In the NGFS Net Zero 2050 scenario, demand for direct operations and maintenance jobs in the fossil fuel extraction and production sector and the fossil fuel-based power sector could be lower by about nine million and about four million jobs, respectively—equivalent to about 70 percent and 60 percent of today’s workforce in those respective sectors, due to the net-zero transition. Jobs in the agriculture and food sectors could also be reallocated as demand for animal protein is affected under a net-zero transition. About 34 million direct jobs, mainly in livestock and feed-related jobs, could be lost by 2050, including 19 million in ruminant meat farming. These could be partially offset by a gain of 12 million direct jobs, including for example ten million in poultry farming.

²⁷ By “direct” jobs we mean jobs in the specified sector, as opposed to “indirect” jobs, which refers to the upstream jobs that produce inputs for production in the sector. Job losses and gains described in this analysis refer to those tied specifically to transition-related changes (for example, the shift from fossil fuel energy production to solar and wind power driving increases in solar and wind power jobs and decreases in coal and gas power jobs). Losses and gains due to macroeconomic forces such as income, population, and productivity growth have been excluded. A job is counted as a loss or a gain if it involves a shift in sector or subsector for a worker, indicating a changing job function, or a change in the geography of an existing job. Job losses and gains could in reality manifest as job shifts. Our methodology does not account for any higher order impacts and assumes an orderly transition, for example, without constraints created from financing the transition. For further details, see technical appendix.

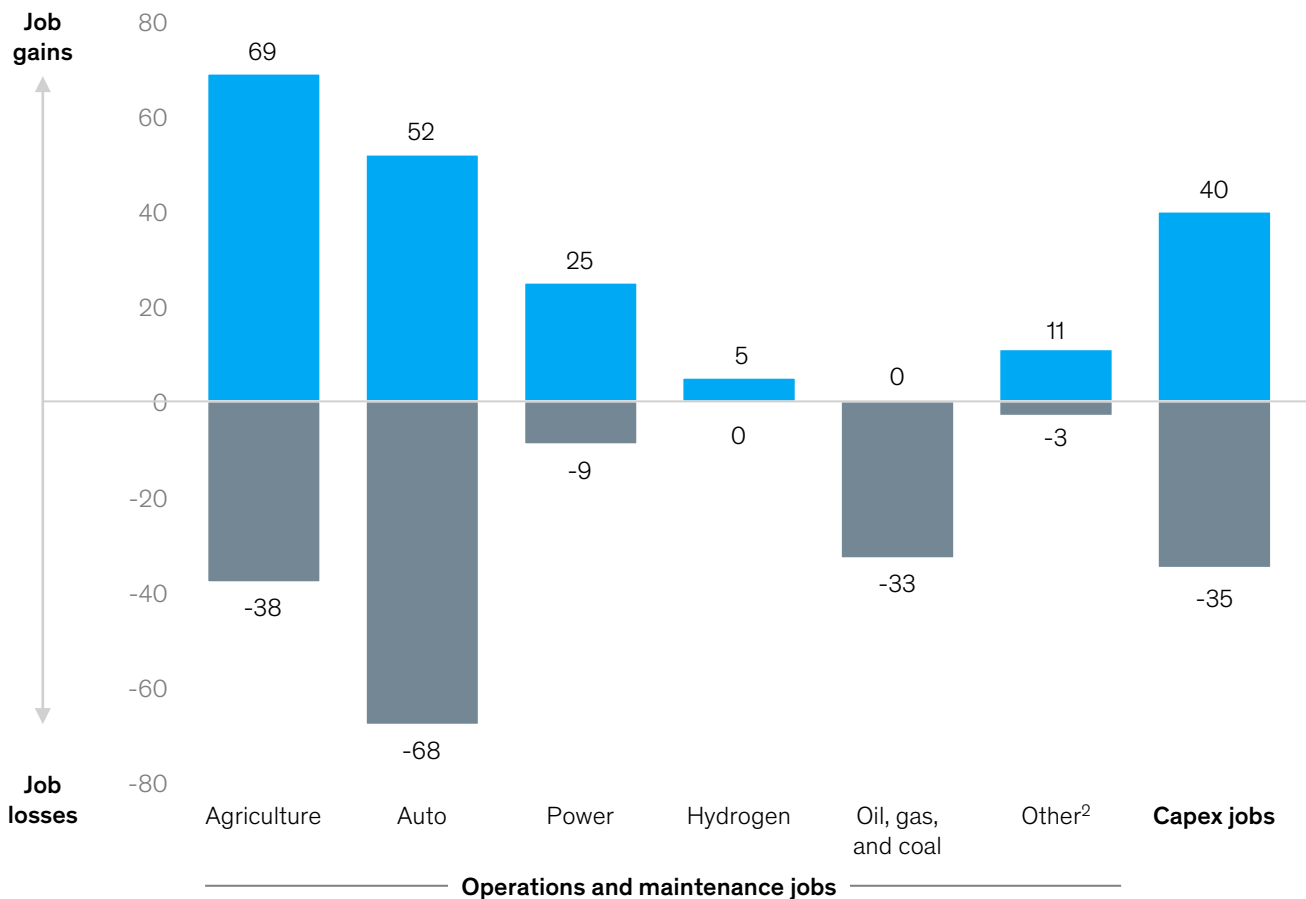
²⁸ For more information, see *The future of work after COVID-19*, McKinsey Global Institute, February 2021. It is important to note that other factors could influence the job numbers presented here, potentially leading to greater reallocations. These include whether the transition is orderly or disorderly, whether financing for the transition limits investment in other parts of the economy, and fiscal and monetary policy decisions, which we do not model.

In the NGFS Net Zero 2050 scenario, about 200 million direct and indirect jobs could be gained and 185 million lost by 2050.

Total job shifts, direct and indirect, by 2050, million¹



Total job shifts by sector,¹ direct and indirect, by 2050, million



1. Includes all direct and indirect jobs; based on the NGFS Net Zero 2050 scenario using REMIND-MAGPIE (phase 2). Based on analysis of systems that account for ~85% of overall emissions today; a job is counted as a gross loss or a gain if it involves a shift in sector or subsector for a worker (indicating a changing job function), or geography of an existing job. Operations and maintenance jobs consist of those related to the operations and maintenance activities in the sector (direct jobs), and their supply chains (indirect jobs). Capex jobs are those arising from capital investment in the sector, associated with manufacturing and construction (direct jobs), and their supply chains (indirect jobs), and are not included in the 2020 baseline number. While calculating indirect jobs, we include upstream jobs from all other sectors of the economy such as financial services, wholesale trade, retail trade, transportation, etc, but exclude a set of sectors for which we have done bottom-up calculations, including: Agriculture, forestry and fishing, mining and extraction of energy; coke and refined petroleum, other nonmetallic mineral products, manufacture of basic metals, motor vehicles, trailers and semi-trailers; power; machinery, and equipment and construction. Impacts of a net-zero transition consist of job losses and gains directly associated with the transition, and do not include other macroeconomic forces like population or income growth. See technical appendix.

2. Other comprises mineral, forestry, cement, carbon abatement, steel, and biofuels.

Note: Figures may not sum to total because of rounding.

Source: Network for Greening the Financial System 2021 (Net Zero 2050 scenarios) REMIND-MAGPIE model; Vivid Economics; McKinsey Center for Future Mobility Electrification Model (2020); McKinsey Hydrogen Insights; McKinsey Power Solutions; McKinsey Sustainability Insights; McKinsey Agriculture Practice; McKinsey Nature Analytics; Jobs baseline (ILO, OECD, MinSTAT, INDSTAT, IHS, WIOD, IEA, US BLS, India NSS-Employment Survey, China-NBS, IRENA); Jobs multipliers (McKinsey Economics Analytics Platform, GTAP, Asian Development Bank, US BEA, OECD, Oxford Economics); McKinsey Global Institute analysis

Low-emissions sectors, by contrast, would likely see job gains. For example, the renewable power sector could see an increase in demand for approximately six million direct operations and maintenance jobs by 2050 driven by the net-zero transition. As mentioned above, job gains could also occur as a result of capital outlays, particularly during the earlier years of the transition. In construction, manufacturing, and other industries associated with the build-out of low-emissions physical assets, net job gains (job gains minus job losses) could be as high as about 37 million by 2030 and could still be about five million by 2050 (which further emphasizes the potential transitory nature of these jobs). The transition might also create still more jobs, as past diffusion of new technologies has done.²⁹

One notable characteristic in our analysis of the job losses and gains during the net-zero transition would be their concentration in specific sectors and geographic regions.

Job losses that affect entire sectors or subsectors and those that are geographically concentrated in specific communities or regions will create particular needs for economic and societal adjustments during the transition.³⁰ For example, in 44 US counties, more than 10 percent of the workforce is employed in the coal, oil, and gas extraction, mining, and refining sectors, the fossil fuel-based power sector, and the automotive sector (Exhibit E9). Similarly, automotive production is a relatively large share of employment in Germany, Japan, Mexico, and South Korea (see also discussion later on how countries are exposed to the net-zero transition and could benefit from transition opportunities).

Disruptions would be substantially higher under a more disorderly transition

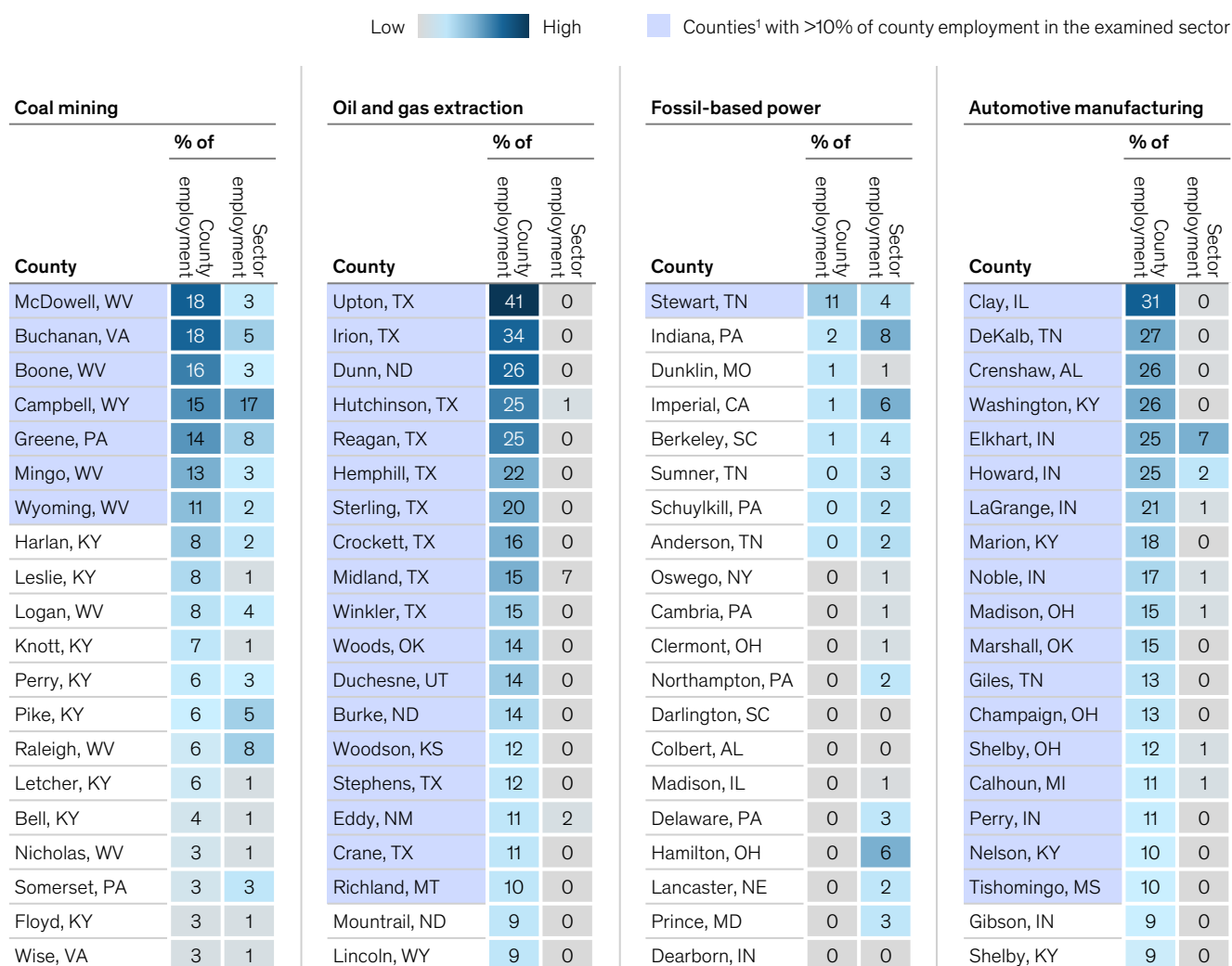
How the transition is managed will be decisive. The effects described here reflect the NGFS Net Zero 2050 scenario, in which gradual yet substantial reductions in emissions take place, resulting in a relatively orderly transition. However, the complexity of the transformation may well lead to the reality being more disorderly, and indeed it may not be feasible to limit warming levels to 1.5°C. This makes the case for action even more critical.

The key risks are threefold: the first concerns the choice of pathway to arrive at net-zero emissions, and whether this will be smooth or abrupt. The second relates to the measures taken by stakeholders to ease the adjustments needed for a net-zero transition. The third has to do with a range of constraints that could prove challenging even if the pathway chosen is a relatively smooth and gradual one.

²⁹ One study found that 0.56 percent of new jobs in the United States each year are in entirely new occupations that did not previously exist. See Jeffrey Lin, "Technological adaptation, cities, and new work," *Review of Economics and Statistics*, volume 93, number 2, May 2011. See also *Jobs lost, jobs gained: What the future of work will mean for jobs, skills, and wages*, McKinsey Global Institute, December 2017.

³⁰ As an example, analysis by McKinsey & Company in collaboration with the Greater Houston Partnership finds that Houston could lose up to 650,000 jobs by 2050 under a 1.5°C pathway, if no action is taken to respond to the changing energy landscape. However, with decisive action to lead in the energy transition, Houston could gain up to 560,000 additional jobs. For further details, see *Houston: Leading the transition to a low-carbon world*, Greater Houston Partnership, June 2021.

More than 10 percent of the employment in 44 US counties is in coal mining, oil and gas extraction and refining, fossil-based power, and automotive manufacturing.



1. Top 20 US counties by % local employment in coal mining, oil and gas extraction and refining, fossil-based power, and automotive manufacturing. Based on an analysis of 3,273 counties and county equivalents (parishes, census area, municipalities) across the United States, Puerto Rico, and Virgin Islands. Source: US Bureau of Labor Statistics

Some pathways to net-zero emissions assume that the decline in emissions begins immediately and progresses gradually to 2050, with appropriate measures in place to manage disruptions and limit costs. Others assume that reduction of emissions begins later and progresses more quickly to achieve the same amount of cumulative emissions. The latter could involve significant and abrupt changes in policy, high carbon prices, and sudden changes to investment practices—along with greater socioeconomic effects and a larger-scale response.³¹ Making job transitions would be more challenging, and there could be greater risk of stranded assets.

Second, if actions are not taken to manage transition disruptions, this could lead to more challenges, especially for vulnerable communities—for example, if rises in energy costs are passed through to low-income households, or if displaced workers are not provided appropriate support to reskill and redeploy.

³¹ See also *Inevitable Policy Response 2021: Policy Forecast*, Principles for Responsible Investment, March 2021.

Finally, even if the pathway chosen is relatively orderly, given the scale of the transformation required, supply may not be able to scale up sufficiently, making shortages and price increases or volatility a feature. Rapidly scaling up demand for low-emissions assets and other products needed for the transition, without corresponding scale-up of supply, could lead to supply/demand imbalances, shortages, price increases, and inflation.³² As already noted, a mismatch or mistiming between the ramping down of high-emissions activities and the ramping up of low-emissions activities could create energy price volatility and issues with reliability that could potentially result in a backlash that delays the transition. Another risk is that stakeholders maintain two parallel energy systems in a manner that is inefficient and not cost effective. Thus the transformation of the energy system needs to be carefully managed. And there may be other constraints, including accessing the volume of financing required in the initial phases of the transition when many of the investments would be front-loaded.

There could also be other costs incurred and investment needed beyond those mentioned in this report, for example related to the reskilling of workers, or economic diversification efforts. A key area where additional spend would be needed is related to adaptation investments. Adaptation action is needed to manage a continually increasing level of physical risk, irrespective of the decarbonization measures required to achieve net-zero emissions. Key adaptation measures include actions to protect people and assets, for example installing “gray” infrastructure such as sea walls, building resilience and backups in systems with actions like increasing global inventories and diversifying supply chains, and reducing exposure where necessary, for example by relocating assets from regions.

To illustrate the difference between transition pathways, we analyzed two NGFS scenarios consistent with limiting warming to less than 2.0°C from preindustrial levels. In the “Below-2°C scenario,” where emissions reductions start immediately on a pathway to 2.0°C of warming, our analysis suggests that only a relatively small amount of additional coal power capacity is added, about \$150 billion between 2020 and 2050. Of this, \$100 billion would be prematurely retired or underutilized. But in the scenario where emissions reductions toward 2.0°C warming start later, a substantially larger amount of capacity would be added; as much as \$600 billion would be invested in coal-power capacity, with as much as \$400 billion prematurely retired or underutilized.

Perhaps the greatest risk from delaying emissions reductions is physical climate risk. The longer it takes to initiate emissions reduction, the more of the world’s remaining carbon budget would be used up—leaving less time to cut emissions and increasing the risk that warming is not restricted to 1.5°C or even 2.0°C.

While significant, these economic adjustments would create growth opportunities and prevent further buildup of physical risk

The changing demand outlook combined with the \$3.5 trillion in incremental annual spending on physical assets in the NGFS Net Zero 2050 scenario, noted above, would create substantial growth opportunities for companies and countries in the near term. We describe the opportunities for countries later in this summary. The opportunities for companies are in the three main areas described below.

³² For example, see “The raw materials challenge: How the metals and mining sector will be at the core of enabling the energy transition,” McKinsey & Company, January 2022. The research describes a scenario based on the current pipeline of projects and without measures to incentivize further supply, in which copper and nickel demand in 2030 could exceed supply by 5 million to 8 million and 700,000 to one million metric tons, respectively. See also *2022 global outlook: Thriving in a new market regime*, Blackrock Investment Institute, 2022.

Decarbonized forms of legacy products and processes: Companies that reduce the emissions intensity of their processes and products could gain advantages as the transition progresses. In some cases, decarbonizing processes and products can make them more cost-effective. For example, improving the energy efficiency of heating systems in steel plants lowers both emissions and operating costs. Even when decarbonizing adds to operating costs, companies can benefit from taking this step—for instance, if consumers are willing to pay more for low-carbon products or if companies are subject to carbon-pricing mandates.

Low-emissions products and processes that replace established high-emissions options: Carmakers might produce EVs instead of ICE vehicles, for example. Steelmakers can implement low-carbon production processes such as direct reduced iron—electric arc furnaces (DRI-EAF) powered by green hydrogen.³³ Utilities might set up wind or solar farms to generate renewable electricity, while energy companies could introduce biofuels and hydrogen.

Inputs, physical capital, infrastructure, and support services: New offerings will be needed to support production in the other two categories. These offerings include inputs such as lithium and cobalt for battery manufacturing, physical capital such as solar panels and batteries, and infrastructure such as EV charging stations and hydrogen refueling stations.³⁴ Technical services such as forest management, engineering and design, and power-system integration will help with the management of low-carbon assets. Services such as financing, risk management, certification, emissions measurement and tracking solutions, and worker training will also be needed.

The incremental capital spending on physical assets, which we estimate at about 3 percent of GDP annually through 2050, as discussed previously, and the broader economic transformations under a net-zero transition would have another essential feature: most importantly, reaching net-zero emissions and limiting warming to 1.5°C would prevent the buildup of physical risks and reduce the odds of initiating the most catastrophic impacts of climate change, including limiting the risk of biotic feedback loops and preserving the ability to halt additional warming.³⁵

Rapidly scaling up demand for low-emissions assets and other products needed for the transition, without corresponding scale-up of supply, could lead to supply shortages and price increases.

³³ DRI is produced from the chemical reduction of iron ore into iron by either a reducing gas or elemental carbon produced from natural gas or coal, which can be used as an input, along with high-grade steel scrap, in the EAF method of steel production. Steel production in integrated blast furnaces or basic oxygen furnaces today uses iron ore and requires coal as a reductant. See Christian Hoffmann, Michel Van Hoey, and Benedikt Zeumer, "Decarbonization challenge for steel," McKinsey & Company, June 2020.

³⁴ For example, see "The raw materials challenge: How the metals and mining sector will be at the core of enabling the energy transition," McKinsey & Company, January 2022. The research finds that requirement for additional supply will come not only from relatively large-volume raw materials—for example, copper for electrification and nickel for battery EVs, which are expected to see significant demand growth beyond their current applications—but also from relatively niche commodities, such as lithium and cobalt for batteries, tellurium for solar panels, and neodymium for the permanent magnets used both in wind power generation and EVs. Some commodities—most notably steel—will also play an enabling role across technologies, as additional infrastructure is needed.

³⁵ See Box E3 in the executive summary, chapter 1, and the bibliography for a detailed list of the academic literature and broader discussion related to physical climate risks.

Sectors are unevenly exposed to the transition; those with high-emissions products or operations would be especially affected

We find that, while all sectors of the economy are exposed to a net-zero transition because of their participation in energy and land-use systems, some are more exposed than others. The sectors with the highest degree of exposure directly emit significant quantities of greenhouse gases (for example, the coal and gas power sector) or sell products that emit greenhouse gases (such as the fossil fuel sector). Approximately 20 percent of global GDP is in these sectors. A further 10 percent of GDP is in sectors with high-emissions supply chains, such as construction. Other sectors accounting for about 70 percent of GDP have less pronounced direct exposure. They are nevertheless dependent on the highly exposed sectors, for example through interconnected economic and financial systems, and therefore could be affected by the transition.

In this section, we describe the economic shifts for some of the most affected sectors. Together they account for about 85 percent of global GHG emissions through their operations or products, and we present our analysis of the economic changes they would likely experience in the Net Zero 2050 scenario.³⁶

Fossil fuels. As noted earlier, combustion of fossil fuels produces 83 percent of global CO₂ emissions. The sector is seeking to decarbonize its own emissions through energy efficiency, electrification, and managing fugitive methane emissions.³⁷ At the same time, it faces significant demand shifts from potential shifts in the energy mix under a net-zero transition, with a reduction in demand for fossil fuels and growing demand for other energy sources such as electricity, hydrogen, and biofuels. In the scenario analyzed here, oil and gas production volumes in 2050 would be 55 percent and 70 percent lower, respectively, than today. Coal production for energy use would be nearly eliminated. Under the net-zero transition, demand for jobs within the fossil fuel extraction and production sector could be lower by about nine million direct jobs by 2050. In response, McKinsey research suggests that a number of oil and gas companies are adapting to the low-carbon transition by becoming resource specialists, becoming diversified energy players, or turning themselves into low-carbon pure plays.³⁸

Power. To decarbonize, the global power sector would need to phase out fossil fuel-based generation and add capacity for low-emissions power to meet the additional demand arising from both economic development and the growing electrification of other sectors. It would require substantial annual capital spending from 2021 to 2050, which we estimate at about \$1 trillion in power generation, \$820 billion in the power grid, and \$120 billion in energy storage in the NGFS Net Zero 2050 scenario. Opportunities would arise not only for power producers but also for providers of equipment, electricity-storage hardware, and related services. Our analysis suggests that by 2050, under a net-zero transition, approximately six million direct jobs could be added in operations and maintenance for renewable power and approximately four million direct jobs could be

³⁶ We estimate how much exposure these sectors have to the transition by measuring their direct emissions (scope 1 emissions, which indicate exposure to potential demand shifts, investment needs, and cost changes from having to alter production processes), emissions from products (downstream scope 3, which may affect demand, for example, if consumers shift their preferences, and in turn also affect the capital investments made by the sector and its costs), supply chain emissions (upstream scope 3, which may expose the sector to cost shifts as its core inputs are affected by the transition), and emissions from purchased electricity (scope 2 for electricity use, which could indirectly expose the sector to the effects of changes in the world's energy mix).

³⁷ See Paul Gargett, Stephen Hall, and Jayanti Kar, "Toward a net-zero future: Decarbonizing upstream oil and gas operations," McKinsey & Company, December 2019.

³⁸ Chantal Beck, Donatella Bellone, Stephen Hall, Jayanti Kar, and Dara Olufon, "The big choices for oil and gas in navigating the energy transition," McKinsey & Company, March 2021.

lost in fossil fuel–based power. The build-out of power infrastructure and the capital spending associated with the net-zero transition could produce as many as 27 million direct jobs in the early years of the transition, and about 16 million direct jobs associated with construction and manufacturing activity in 2050. Asset stranding could be large. Our analysis suggests that about \$2.1 trillion of the sector’s capital stock could be stranded by 2050 in the Net Zero 2050 scenario.³⁹ Eighty percent of this amount is today’s capacity, while 20 percent is capacity that would be built between 2021 and 2050.⁴⁰

Mobility. Our analysis of mobility focuses on the road transportation segment, which accounts for about 75 percent of all mobility emissions.⁴¹ Decarbonization would involve replacing ICE vehicles with battery-electric vehicles or vehicles powered by hydrogen fuel cells. In the Net Zero 2050 scenario, annual spending would be \$3.5 trillion on both vehicles and to build charging and fueling infrastructure between 2021 and 2050. About 13 million direct ICE-related jobs would be lost in the Net Zero 2050 scenario, although some of this loss would be offset by gains of about nine million direct jobs related to EV manufacturing by 2050 with the difference between losses and gains driven in large part by the relatively higher productivity of zero-emissions vehicle manufacturing.

Industry. We focus on two sectors, steel and cement, that together account for approximately 14 percent of global CO₂ emissions and 47 percent of industry’s CO₂ emissions.⁴² While technology pathways are still emerging, steel and cement production could be decarbonized by installing CCS equipment or switching to processes or fuels—such as hydrogen—that can have zero or low emissions. Production costs in both sectors could increase by more than 30 percent by 2050 compared with today, though this could be lower with continued innovation.

Buildings. In the net-zero scenario, the buildings sector would decarbonize by improving energy efficiency—for example, through the use of insulation—and by replacing fossil fuel–powered heating and cooking equipment with low-emissions systems. The average annual spending on physical assets between 2020 and 2050 would be \$1.7 trillion per year. Decarbonization of buildings could result in a net gain of about half a million direct jobs by 2050 under a net-zero transition, driven by retrofitting buildings with insulation. The buildings sector’s biggest adjustment during this transition would be managing the up-front capital costs for end consumers to retrofit equipment and aligning incentives across various stakeholders (such as building owners who invest capital and tenants who may see the benefits of reduced operating costs).⁴³

Agriculture and food. In the net-zero scenario analyzed here, agricultural emissions would be reduced as a result of producers deploying GHG-efficient farming practices, and some consumers shifting their diets away from ruminant animals that generate significant quantities of methane.⁴⁴ The scenario would also entail an increase in production of

³⁹ Our definition of stranded assets represents the cumulative value of prematurely retired and underutilized assets in 2020–50, undiscounted. We estimate it by first identifying the level of yearly depreciation that is expected given asset life and assumed economic life using data from the WRI Global Power Plant database as input. That figure was multiplied by the fraction of assets that are underutilized relative to past average utilization rates (between 2005 and 2020) and summed across years.

⁴⁰ For more on the power sector, see Jason Finkelstein, David Frankel, and Jesse Noffsinger, “How to decarbonize global power systems,” McKinsey & Company, May 2020; and Rory Clune, Ksenia Kaladiouk, Jesse Noffsinger, and Humayun Tai, “A 2040 vision for the US power industry: Evaluating two decarbonization scenarios,” McKinsey & Company, February 2020.

⁴¹ EMIT database, McKinsey Sustainability Insights, September 2021; data for 2019. For more on the mobility sector, see “Why the automotive future is electric,” McKinsey & Company, September 2021; Timo Moller, Asutosh Padhi, Dickon Pinner, and Andreas Tschiesner, “The future of mobility is at our doorstep,” McKinsey Center for Future Mobility, December 2019; and Eric Hannon, Tomas Nauclér, Anders Suneson, and Fehmi Yuksel, “The zero-carbon car: Abating material emissions is next on the agenda,” McKinsey & Company, September 2020.

⁴² EMIT database, McKinsey Sustainability Insights, September 2021; data for 2019. For more details on decarbonization of the steel sector, see Christian Hoffmann, Michel Van Hoey, and Benedikt Zeumer, “Decarbonization challenge for steel,” McKinsey & Company, June 2020. For cement, see Thomas Czigler, Sebastian Reiter, Patrick Schulze, and Ken Somers, “Laying the foundation for zero-carbon cement,” McKinsey & Company, May 2020; and Thomas Hundertmark, Sebastian Reiter, and Patrick Schulze, “Green growth avenues in the cement ecosystem,” McKinsey & Company, December 2021.

⁴³ For more on the building sector, see Paolo D’Aprile, Hauke Engel, Godart van Gend, Stefan Helmcke, Solveigh Hieronimus, Tomas Nauclér, Dickon Pinner, Daan Walter, and Maaik Witteveen, “How the European Union could achieve net-zero emissions at net-zero cost,” McKinsey & Company, November 2020.

⁴⁴ Agricultural practices are also tied to forestry emissions, as much of deforestation is driven by expansion of agricultural land. See discussion on forestry elsewhere in the report.

energy crops to produce biofuels. As a result of these shifts, the net-zero transition would result in about 34 million direct jobs lost (predominately due to diminished production of ruminant meat) and 61 million gained (related in large part to increased production of energy crops and poultry) by 2050. This net gain of about 27 million direct jobs due to the transition is about 4 percent of the 720 million or so direct agriculture jobs today. These job shifts need to be considered against a long-standing trend in the agricultural sector of workers shifting to nonfarm work in addition to productivity, population, and income growth. Through 2050, more than \$60 billion of annual capital spending would be needed to enable more emissions-efficient farming. Such investment need not all be new funds; repurposing existing subsidies and spending could cover a substantial amount of this cost.⁴⁵

Forestry and other land use. This system contributes to an increase in CO₂ emissions today from land clearing and deforestation. Reaching net zero in this scenario would involve halting deforestation and accelerating efforts to restore forests and other natural environments to serve as a net sink of emissions. Making these changes would require capital spending of \$40 billion per year between 2021 and 2050 in the scenario analyzed here, about 75 percent of which would be spent in the next decade, primarily on acquiring and protecting land. Reducing deforestation would also require managing adjustments to both commercial and subsistence-level farming activity (a substantial portion of deforestation is driven by expansion of agricultural land).⁴⁶ Opportunities for economic gain might come from voluntary carbon markets and industries based on ecosystem services.⁴⁷

New energy sectors (hydrogen and biofuels). The expansion of low-emissions energy technologies will create opportunities. Expanding capacity and infrastructure for other low-carbon fuels would require additional capital spending of about \$230 billion per year between 2021 and 2050, in the scenario analyzed here. We estimate that the hydrogen and biofuel sectors would create approximately two million direct jobs by 2050.

The transition would unevenly affect lower-income and fossil fuel resource-producing countries—and low-income consumers everywhere

Our in-depth analysis of 69 countries focuses on four areas that can collectively help define a climate agenda: decarbonization actions and investment; managing transition exposures; capturing transition opportunities; and addressing physical risks. As discussed previously, low-income households across countries and regions would be most affected by a net-zero transition. Moreover, our analysis suggests that while all countries face some exposure to the transition, its effects would be unevenly distributed. Regions with lower GDP per capita and those with greater fossil fuel resources would need to invest more, relative to GDP, to reduce their emissions, build a low-emissions economy, and support economic development.

⁴⁵ For more information, see *Incentivizing food systems transformation*, World Economic Forum and McKinsey & Company, January 2020. For more on the agriculture and food sector, see Justin Ahmed, Elaine Almeida, Daniel Aminetzah, Nicolas Denis, Kimberly Henderson, Joshua Katz, Hannah Kitchel, and Peter Mannion, "Agriculture and climate change: Reducing emissions through improved farming practices," McKinsey & Company, April 2020.

⁴⁶ *The state of the world's forests 2020: Forests, biodiversity, and people*, FAO, 2020.

⁴⁷ See "Valuing nature conservation," McKinsey & Company, September 2020.

These countries also have relatively greater shares of their jobs, GDP, and capital stock in sectors that would be most exposed to the transition. And some of them will face a double burden—being exposed both to the transition adjustments and to rising physical risks.⁴⁸ This could challenge progress on economic development goals in these regions, bolstering the case for global cooperation. At the same time, the transition could create potential for economic growth in many geographies.

To better understand exposure and opportunities, we take a closer look at the 69 countries in our sample by dividing them into six archetypes based on the distribution of their most significant exposure across sectors and households.

To manage exposure, each country can consider taking actions of its own, such as investing in assets, funding worker-retraining programs, and supporting the growth of low-emissions sectors. Some countries are likely to face more difficult economic and societal adjustments than others. Collective action and solidarity would therefore help countries meet challenges and ensure that the economic and societal adjustments needed for the net-zero transition are addressed. Enabling institutions would likely play an essential role in coordinating any such efforts.

Developing countries and those with large fossil fuel sectors would likely spend more on physical assets, relative to GDP, on decarbonization and low-carbon growth

In the NGFS Net Zero 2050 scenario, every country and region would spend to reduce emissions and develop low-emissions energy sources to power their economic growth.⁴⁹ The need for capital expenditures varies considerably across geographies given differences in their economies, and their decarbonization trajectories vary in the NGFS Net Zero 2050 scenario.

The world's largest economies—the United States, China, the European Union, Japan, and the United Kingdom—would account for about half of global spend on physical assets and would spend about 6 percent of their combined GDP from 2021 to 2050. In developing regions, spend on energy and land would form a substantially larger share of national GDP: about 10 percent in sub-Saharan Africa, India and some other Asian countries, and Latin America (Exhibit E10).

For developing countries, higher projected rates of economic growth naturally create higher investment needs relative to GDP than in developed countries.⁵⁰ In our analysis of the NGFS Current Policies scenario, spending in India, sub-Saharan Africa, and Latin America would total more than 9 percent of GDP. Spending would increase to some extent from these levels in the net-zero scenario analyzed here. For example, in the Net Zero 2050 scenario, India's capital requirements would be 11 percent of GDP, compared to the global average of about 7.5 percent of GDP. It would moreover be spent differently than in the Current Policies case. Some 60 percent of annual average investments in India would be on low-emissions assets under current policies compared to 80 percent in the NGFS Net Zero 2050 scenario. Much of that capital would be used to reduce the use of existing coal power and expand low-emissions electricity capacity.

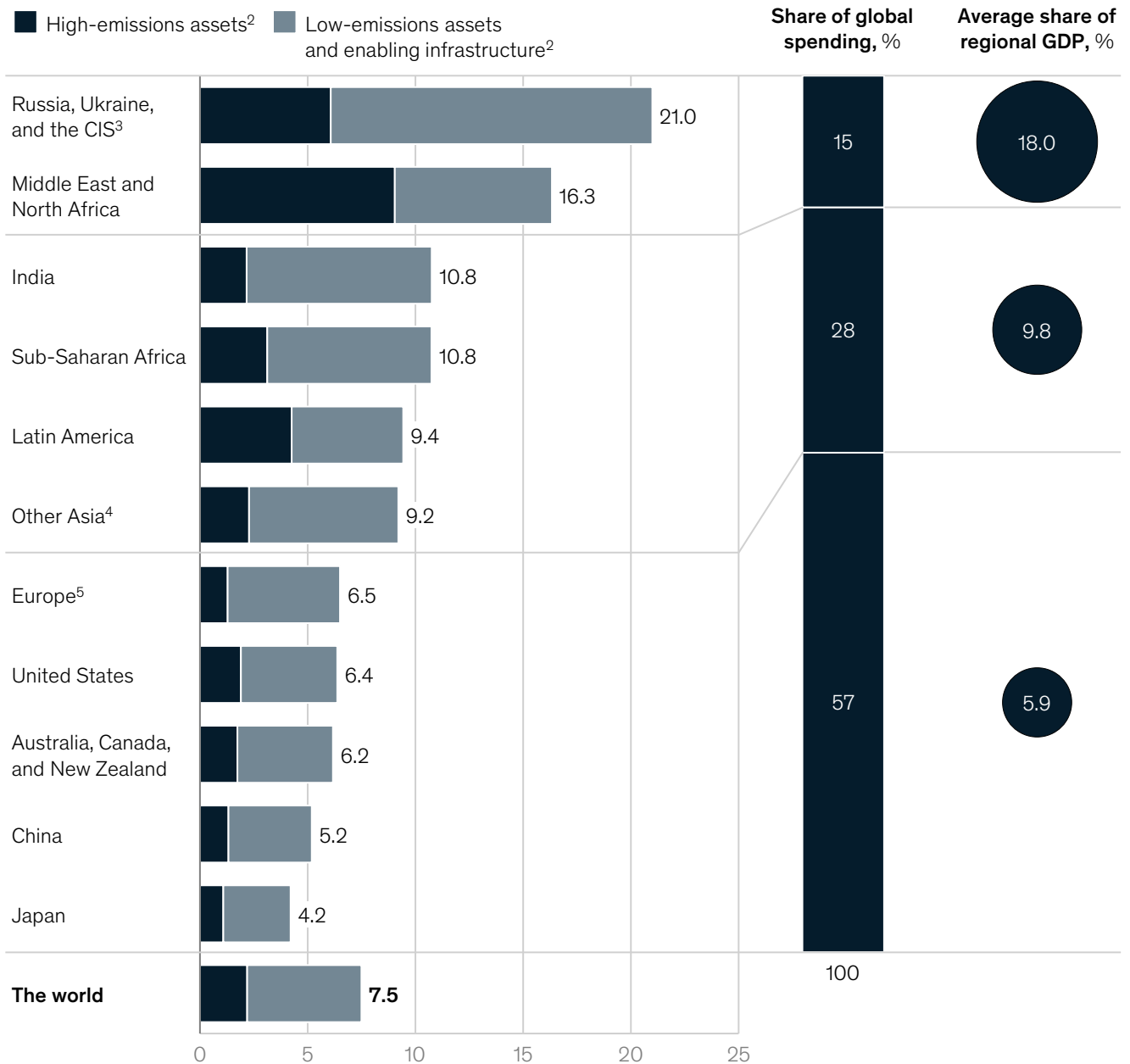
⁴⁸ For example, India faces the double burden of transition exposure and elevated physical risks. Our previous research suggests that by 2030 in India, 160 million to 200 million people could be living in urban areas with a nonzero annual probability of experiencing a lethal heat wave, in a scenario where no adaptation or mitigation measures are implemented. *Will India get too hot to work?* McKinsey Global Institute, November 2020.

⁴⁹ Our analysis looks at both individual countries and multicountry regions because the NGFS scenarios provide some decarbonization trajectories at the regional level and others at the national level.

⁵⁰ Sub-Saharan Africa and India, for example, are expected to see real GDP growth of about 4–5 percent per year on average over the next 30 years, compared with 3 percent growth for China and 1–2 percent growth for developed regions in the NGFS scenario examined here.

As a percentage of GDP, fossil fuel–producing regions and developing countries would spend more than others on physical assets for energy and land-use systems.

Spending on physical assets for energy and land-use systems under NGFS Net Zero 2050 scenario,¹
 % of 2021–50 GDP



1. Estimation includes spend for physical assets across various forms of energy supply (for example, power systems, hydrogen, and biofuel supply), energy demand (eg, for vehicles), and land use. This includes both what are typically considered "investments" in national accounts and spend, in some cases, on consumer durables such as personal cars. Scenario based on the NGFS Net Zero 2050 scenario using REMIND-MAGPIE (phase 2). Based on analysis of systems that account for ~85% of overall carbon dioxide equivalent (CO₂e) emissions today. Our analysis includes a more comprehensive view of spending by households and businesses on assets that use energy, capital expenditures in agriculture and forestry, and some continued spend in high-emissions physical assets like fossil fuel–based vehicles and power assets. For further details, see technical appendix.

2. Our analysis divides high-emissions assets from low-emissions assets. High-emissions assets include assets for fossil fuel extraction and refining, as well as fossil fuel power production assets without CCS; fossil fuel heat production, gray-hydrogen production; steel BOF; cement fossil fuel kilns; ICE vehicles; fossil fuel heating and cooking equipment; dairy, monogastric, and ruminant meat production. Low-emissions assets and enabling infrastructure include assets for blue-hydrogen production with CCS; green-hydrogen production using electricity and biomass; biofuel production; generation of wind, solar, hydro-, geothermal, biomass, gas with CCS, and nuclear power along with transmission and distribution and storage infrastructure; heat production from low-emissions sources such as biomass; steel furnaces using EAF, DRI with hydrogen, basic oxygen furnaces with CCS; cement kilns with biomass or fossil fuel kilns with CCS; low-emissions vehicles and supporting infrastructure; heating equipment for buildings run on electricity or biomass, including heat pumps; district heating connections; cooking technology not based on fossil fuels; building insulation; GHG-efficient farming practices; food crops, poultry and egg production; and land restoration. See technical appendix.

3. CIS refers to the Commonwealth of Independent States.

4. Includes, among others, South Korea and Southeast Asia.

5. Includes, among others, the 27 European Union countries, Norway, Switzerland, Turkey, and the United Kingdom.

Note: Figures may not sum to 100% because of rounding.

Source: Network for Greening the Financial System 2021 (Net Zero 2050 scenarios) REMIND-MAGPIE model; Vivid Economics; McKinsey Center for Future Mobility Electrification Model (2020); McKinsey Hydrogen Insights; McKinsey Power Solutions; McKinsey–Mission Possible Partnership collaboration; McKinsey Sustainability Insights; McKinsey Agriculture Practice; McKinsey Nature Analytics; McKinsey Global Institute analysis

Fossil fuel–based economies would also have substantial spend on physical assets as a share of their GDP: above 15 percent in the Middle East and North Africa, Russia, Ukraine, and Commonwealth of Independent States such as Kazakhstan. Much of this spending would be continued spending on fossil fuel assets in the near term. However, even these economies would allocate half or more of their spending to low-emissions assets under a net-zero transition.

While the relative scale of the spending on physical assets is substantially higher for developing and fossil fuel–based economies, this alone is not an indicator of how difficult it will be for these regions to reach a low-emissions economy. Indeed, as mentioned previously, much of this spend is to be expected as they grow their economies and increase energy access. However, specific aspects of their net-zero transition could make deploying capital challenging for these regions.

First, developing regions might face challenges in accessing capital markets. This may be particularly acute as they look to invest in low-emissions technologies, which may be harder to finance and come with different risk-return expectations. Second, as mentioned above, existing high-emissions assets in these economies are still relatively young; thus there may be less incentive to undertake low-carbon capital spending amid concerns about stranded assets. Third, there may not always be sufficient know-how and capacity on the ground to implement projects. Fourth, concerns of other socioeconomic consequences from a net-zero transition, for example, job dislocations, could exist. Finally, because the economies of these countries rely on emissions-intensive sectors, government tax revenues and public spending may be more constrained under a net-zero transition.⁵¹

Developing countries and fossil fuel–producing regions have relatively large exposure to the transition, raising concerns about growth and inequality

Beyond spending on decarbonizing their existing assets and building low-emissions assets, economies will also need to transform under a net-zero transition. We assessed each country’s exposure to the transition by measuring the proportion of employment, economic production, and physical capital stock in exposed sectors today. It is important to note that current efforts undertaken by countries could reduce this exposure going forward.⁵² According to our analysis, all countries now have some exposure to the transition—and, as discussed earlier, low-income households everywhere would be most exposed to any cost increases that feed through to consumers.

The highest levels of exposure are in countries with relatively lower GDP per capita, such as Bangladesh, India, and Kenya. These tend to be countries with relatively higher shares of jobs, GDP, and capital stock in sectors that are more exposed to the transition—which is to say, sectors with emissions-intensive operations, products, and supply chains (Exhibit E11). Significant fossil fuel resource production also creates high exposure for some countries, such as Qatar, Russia, and Saudi Arabia. Secondary effects from direct exposure could also extend to government tax revenues and exports, which are often linked with exposed sectors like fossil fuel extraction or steel (see Box E6, “Potential implications of the net-zero transition for trade flows”). By contrast, countries with higher GDP per capita tend to be less exposed because a majority of their economies are in service sectors, which have relatively lower exposure.

⁵¹ Similar conclusions were also reached by the IEA. See for example *Financing clean energy transitions in emerging and developing economies*, International Energy Agency, June 2021.

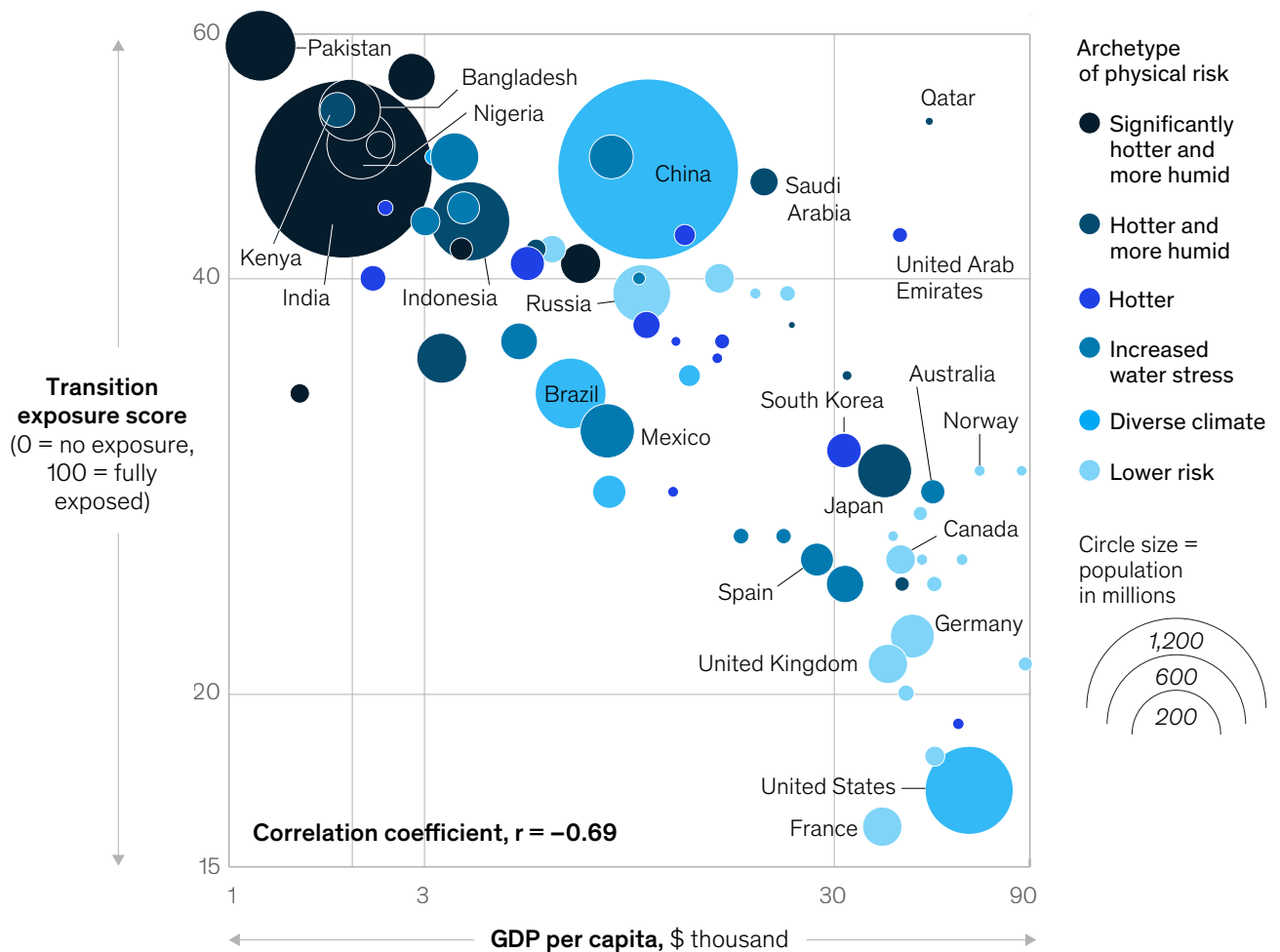
⁵² To gauge each national economy’s exposure to the transition, we calculated a score ranging from 0 (no exposure) to 100 (full exposure). The score reflects the share of each economy’s employment (jobs), production activity (GDP), and capital stock in sectors that are most exposed to the effects of the transition—for example, sectors with high emissions in their operations, in the use of their products, or in their supply chains. For details, see chapter 4 and the technical appendix.

Thus, for many lower-income and fossil fuel-producing countries, challenges associated with climate change could compound. These countries would need to balance multiple imperatives: decarbonizing their economies and funding associated capital expenditures, managing exposure of large parts of their economies to a net-zero transition, and enabling economic development and growth, particularly by expanding access to affordable, secure energy. And, as noted earlier, these challenges will be aggravated for some lower-income countries by heightened physical climate risk, such as the growing probability of lethal heat waves in parts of India.⁵³ Inequity concerns would grow as an issue, particularly as developing economies argue that they have contributed less than others to emissions and yet are being asked to shoulder a large burden in the net-zero transition.

Exhibit E11

Countries with lower GDP per capita and fossil fuel resource producers have higher transition exposures.

Archetype of physical risk¹ through transition exposure vs GDP per capita by country² (logarithmic scale)



1. For further details, see *Climate risk and response: Physical hazards and socioeconomic impacts*, McKinsey Global Institute, January 2020.
 2. Based on average share of jobs, GDP, and capital stock in exposed sectors. These sectors are identified based on their scope 1, 2, and 3 emissions intensity. For further details, see technical appendix.
 Source: Oxford Economics; OECD; ILO; World Input-Output Database; IHS Connect; World Bank; International Energy Agency; US Bureau of Labor Statistics; India NSS-Employment survey; China National Bureau of Statistics; UN; International Renewable Energy Agency (IRENA); MINSTAT; INDSTAT; Global Solar Atlas; Global Wind Atlas; US Geological Survey; WEF; McKinsey Nature Analytics; Emissions Database for Global Atmospheric Research; McKinsey Global Energy Perspectives; IPCC; OECD; IHS Global; Penn World Tables; McKinsey Global Institute analysis

⁵³ *Will India get too hot to work?* McKinsey Global Institute, November 2020.

Potential implications of the net-zero transition for trade flows

Value chains have grown in length and complexity in recent decades, and global trade has increased. Since 2000, the value of intermediate goods traded globally has tripled to more than \$10 trillion annually.¹ Increasing production of goods for export tends to increase a country's own carbon emissions since most manufacturing still involves carbon-emitting processes or energy use. For example, other researchers have estimated that in some manufacturing sectors, such as chemicals, textiles, leather, and apparel, 30 to 65 percent of the emissions in China and India are induced by foreign final demand.² Another way to think about this phenomenon is to regard exported goods as having their production emissions embedded or embodied in them. A look at the emissions that are embodied in goods traded across borders reveals that considerable quantities of CO₂ are, in effect, moved internationally every year (Exhibit E12).

As demand for high-emissions goods falls and demand for low-emissions goods increases, trade flows might shift as countries' comparative advantages change. For example, shifts in consumer preferences or the presence of carbon taxes or other regulatory measures could produce advantages for countries that make products with low emissions intensity. Countries could also pursue opportunities to meet growing overseas demand for new kinds of low-emissions goods or emerging decarbonization technologies. In some cases, decarbonization could raise production costs, which could make exports from countries that take decarbonization action less competitive. All of these factors could result in shifting trade patterns in sectors such as electric vehicles, solar panels, and minerals, and they would need to be systematically addressed.

The outlook for global trade flows thus remains uncertain, and outcomes could depend on many factors, including how consumer preferences and regulation evolve and what opportunities different regions decide to pursue. In making strategic decisions, businesses may want to account for the ongoing discussion among countries of whether to implement border-adjustment taxes that price carbon emissions into the value of traded goods and account for developments in broader regulation, consumer preferences, and evolving markets. In some cases, markets may well go from global to local; for example, global energy markets for oil and gas could transform to more local or regional markets for power or hydrogen. For some countries, the net-zero transition could also provide opportunities to grow domestic industries and reduce imports of commodities like fossil fuels.

¹ See *Risk, resilience, and rebalancing in global value chains*, McKinsey Global Institute, August 2020.

² Daniel Moran et al., *The carbon loophole in climate policy: Quantifying the embodied carbon in traded products*, ClimateWorks Foundation, August 2018.

Countries can use natural endowments or technological, human, and physical resources to harness the transition's growth potential

All countries have opportunities to tap into the transition's potential for growth and secure advantages, through their endowments of natural capital such as sunshine and wind and through the availability of technological, human, and physical capital.⁵⁴

Countries could benefit from the transition if they possess rich stocks of natural capital such as ample sunlight and wind, forestland, mineral resources, and CO₂ sequestration potential (see Exhibit E13 for one example for solar and wind power potential, and chapter 4 for other examples). Generally speaking, many developing countries have the natural resources to accommodate solar power production and forestry protection or restoration efforts, which could be supported by flows of capital through mechanisms such as voluntary carbon markets. And most countries, developing or otherwise, have at least some of the natural-capital endowments that would likely be in demand during the transition. For example, Australia and Saudi Arabia have extensive solar resources, Argentina and the United Kingdom have high wind power potential, and Chile and China have large reserves of minerals.

Some countries have already gained strong positions in the markets for sophisticated low-carbon goods, such as solar panels and EVs. Even so, these markets offer considerable growth potential, which should be accessible to countries with adequate technological capital. For example, South Korea has approximately 6,600 patents on technologies related to climate-change mitigation and human capital. Countries like China and Singapore have a high share of STEM graduates in the population, which provides an indication of the workforce's technical skill. This in turn might be applied to developing solutions for the climate transition.

A country's physical capital, in the form of low-emissions infrastructure and industrial systems, could also create growth potential in a net-zero transition, for example, if consumers shift their preferences or carbon border taxes are applied. Even currently high-emissions infrastructure could be a benefit if it can readily be retrofitted, for example, with alternate low-emissions fuel sources.

All countries have opportunities to tap into the transition's potential for growth and secure advantages, through their endowments of natural capital such as sunshine and wind and through the availability of technological, human, and physical capital.

⁵⁴ For a more detailed list of potential endowments countries can tap into and data on the same, see chapter 4.

Countries could capture potential growth opportunities from the transition to net-zero emissions: Renewable power example.

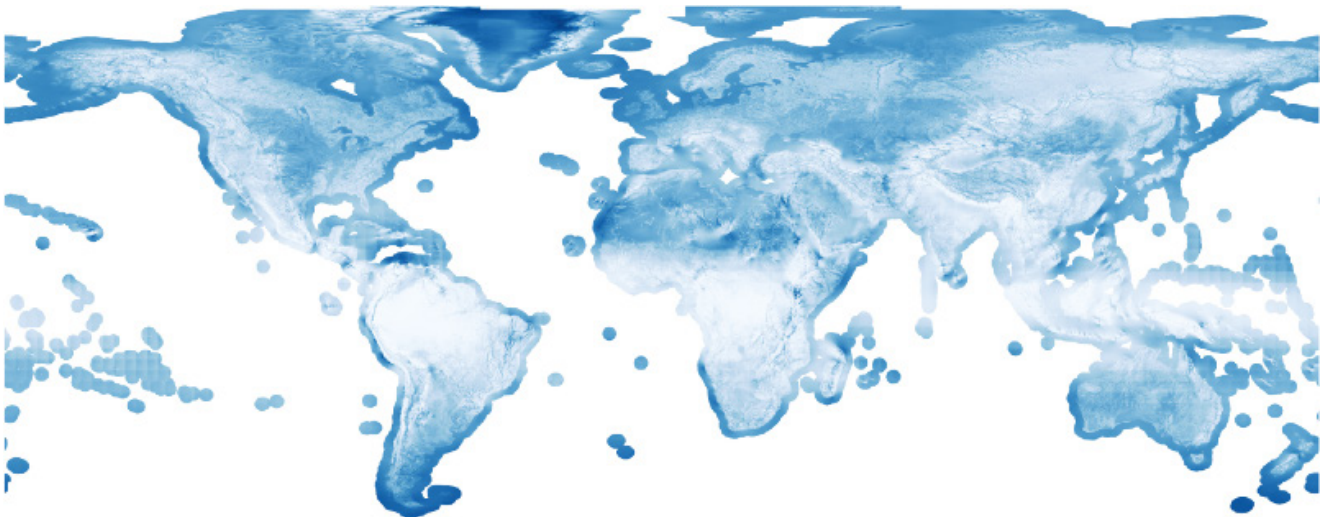
Average theoretical solar potential,¹
kilowatt-hour per square meter per day

<2.0  >6.4



Mean wind power density of 10% windiest areas at 100m height,²
watt per square meter

<25  >1,300



1. Calculated as the power output achievable by a typical configuration of the utility scale PV system, taking into account GHI (global horizontal irradiation, or the total solar radiation that reaches a horizontal surface), the air temperature affecting the system performance, the system configuration, shading and soiling, and topographic and land-use constraints.
2. Calculated by downscaling large-scale forecasting data from the European Centre for Medium-Range Weather Forecasts. These data are then entered into the DTU Wind Energy modeling system to model local wind climates for a 250m grid across the globe.

Note: The boundaries and names shown on this map do not imply official endorsement or acceptance by McKinsey & Company.
Source: Global Solar Atlas; Global Wind Atlas; McKinsey Global Institute analysis

We identify six main archetypes of countries, based on the common nature of their transition exposure

To help illustrate how the net-zero transition might play out differentially across the globe, we have defined six archetypes of countries according to the nature and magnitude of their exposure across sectors and households. We use sector exposure to define country archetypes as a way to highlight the distinct economic and societal adjustments that countries may need to make under a net-zero transition, while noting that countries will face myriad specific issues that are not reducible to a single archetype. In each case, we also describe endowments that countries possess to help them capture transition opportunities, as well as their exposure to physical risks, where relevant. (See Exhibit E14 for the archetypes based on transition exposure and chapter 4 for further detail related to opportunities for countries to benefit from the transition and their physical risk exposure.)⁵⁵

The following are the six archetypes:

Fossil fuel resource producers. Countries in this category include Australia, Bahrain, Canada, Egypt, Kuwait, Nigeria, Norway, Oman, Qatar, Russia, Saudi Arabia, the United Arab Emirates, and Venezuela. Fossil fuel resource–producing sectors account for a significant portion of GDP in these countries, ranging from 3 percent in Australia to 39 percent in Kuwait, and a large share of physical capital—an average of about 15 percent compared to 2 percent in the rest of the countries. The magnitude of exposure varies among countries in this grouping. For example, Saudi Arabia has about 25 percent of its GDP in fossil fuel–producing sectors, and Qatar has about one-third of its GDP and its capital stock in those sectors. That compares with about 3 percent of GDP and 13 percent of capital stock in Australia.

For the countries with higher shares in particular, various challenges could exist: the potential loss of government revenues from exposed sectors, the reallocation of capital spending from high- to low-emissions assets, and the potential need to diversify their economies. Many countries could also experience rising physical risks; countries in this grouping that are near the equator will become hotter and more humid as warming increases. At the same time, a net-zero transition offers opportunities that these countries can tap into, though capturing them and sufficiently compensating for loss in revenues and exports could also come with challenges. They generally have high solar power or wind power potential, which they could use to develop capacity for renewable-energy generation and make green hydrogen. Some fossil fuel producers, for example those in the Middle East, also have relatively low levels of carbon intensity associated with their oil and gas extraction and have relatively lower costs; thus, they could be the last standing providers of the remaining fossil fuels needed in a net-zero economy, in the scenario modeled here.

Emissions-intensive producers. Countries in this category include Bangladesh, China, India, Indonesia, Pakistan, South Africa, Thailand, Turkey, Ukraine, and Vietnam. These countries derive sizable portions of their GDP, about 18 percent on average, from highly exposed sectors such as high-emissions manufacturing, fossil fuel–based power, and agriculture. Jobs tend to be concentrated in agriculture (more than 20 percent), while much of their capital stock is in manufacturing and fossil fuel–based power. These countries would likely adjust to the transition mainly by decarbonizing industrial processes, expanding renewable-power capacity, and helping farmers adopt low-carbon practices or transition away from agriculture. As discussed above, many of these countries will need to make substantial investment to decarbonize their economies and secure low-carbon growth. Our analysis suggests that these countries face a particular risk of asset stranding. Capital stock in these countries (coal-fired power plants, for example) is often newer than in advanced economies. The average age of coal power plants in China and India is less than 15 years, compared with more than 30 in the United States.⁵⁶ Lower-income countries may also find that some low-carbon technologies (for example, electric-arc furnaces for steel production and CCS equipment for steel or cement factories) remain too expensive to deploy or, in some cases, unready for large-scale deployment.

⁵⁵ *Climate risk and response: Physical hazards and socioeconomic impacts*, McKinsey Global Institute, January 2020.

⁵⁶ See *World Energy Outlook 2021*, International Energy Agency, December 2021.

Without careful planning, however, they run the risk that continued spending on lower-cost, high-emissions assets could result in the need to prematurely retire or reduce utilization of these assets after only a few years as the world transitions to a net-zero path. At the same time, these countries will have potential to serve the growing markets for low-emissions goods. Asian countries—many of which are included in this archetype—more broadly possess resources that could be conducive to low-emissions innovation.⁵⁷ Capital spending for the transition would need to be complemented by investment in adaptation measures, since many countries in this archetype would become hotter, more humid, and more prone to flooding as warming increases.

Agriculture-based economies. Countries in this group include Ghana, Kenya, Morocco, the Philippines, Senegal, and Sri Lanka. Agriculture is the primary source of employment and income for a large share of the population in these countries, accounting for up to about 55 percent of jobs and up to about 30 percent of GDP. An important adjustment for these countries will be adopting low-emissions farming practices, which would require mobilizing millions of stakeholders. As discussed above, many of these countries are expected to invest substantially in new assets as they grow their economies, particularly related to the power sector; securing financing would thus be a key priority under a net-zero transition. These countries also have significant potential to produce solar power and use forestland to generate carbon credits.⁵⁸ Almost all of these countries are exposed to physical climate risk because rising heat and humidity affect their agricultural workforces, and also increase volatility of agricultural yields.

Land-use-intensive countries. This group includes Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Ecuador, Honduras, Malaysia, Panama, Peru, and Uruguay.⁵⁹ In these countries, which have generally reached the early or middle stages of industrialization, the agriculture and forestry sectors together represent significant shares of GDP (more than 5 percent), jobs (more than 10 percent), and capital stock (more than 5 percent). They would have to balance land-use needs with protection of forests and would have to support communities whose livelihoods depend on them. The contribution of other sectors such as fossil fuel production, power, and industry to GDP, jobs, and capital stock is also sizable for some countries in the archetype, like Brazil, which could also therefore be exposed to issues described for other archetypes. With their stocks of natural capital, these countries would have growth potential in sectors such as renewable energy, minerals needed for the transition, and forest management; reforestation and afforestation projects could generate valuable carbon credits and ecosystem services.

Downstream-emissions manufacturers. Countries in this group include Austria, Bulgaria, Czech Republic, Germany, Hungary, Italy, Japan, Mexico, Poland, Romania, Slovakia, South Korea, and Sweden. The main exposure for these middle-to-high-income countries relates to the manufacturing of goods, such as automobiles and industrial machinery, that could experience falling demand in their current form because they use fossil fuel-based energy. Countries in this category could manage their exposure to shifts in demand for these products by reinventing products and supply chains. Many make large investments in R&D, which position them well to develop and commercialize low-emissions technologies.

⁵⁷ See *Climate risk and response in Asia*, McKinsey Global Institute, November 2020.

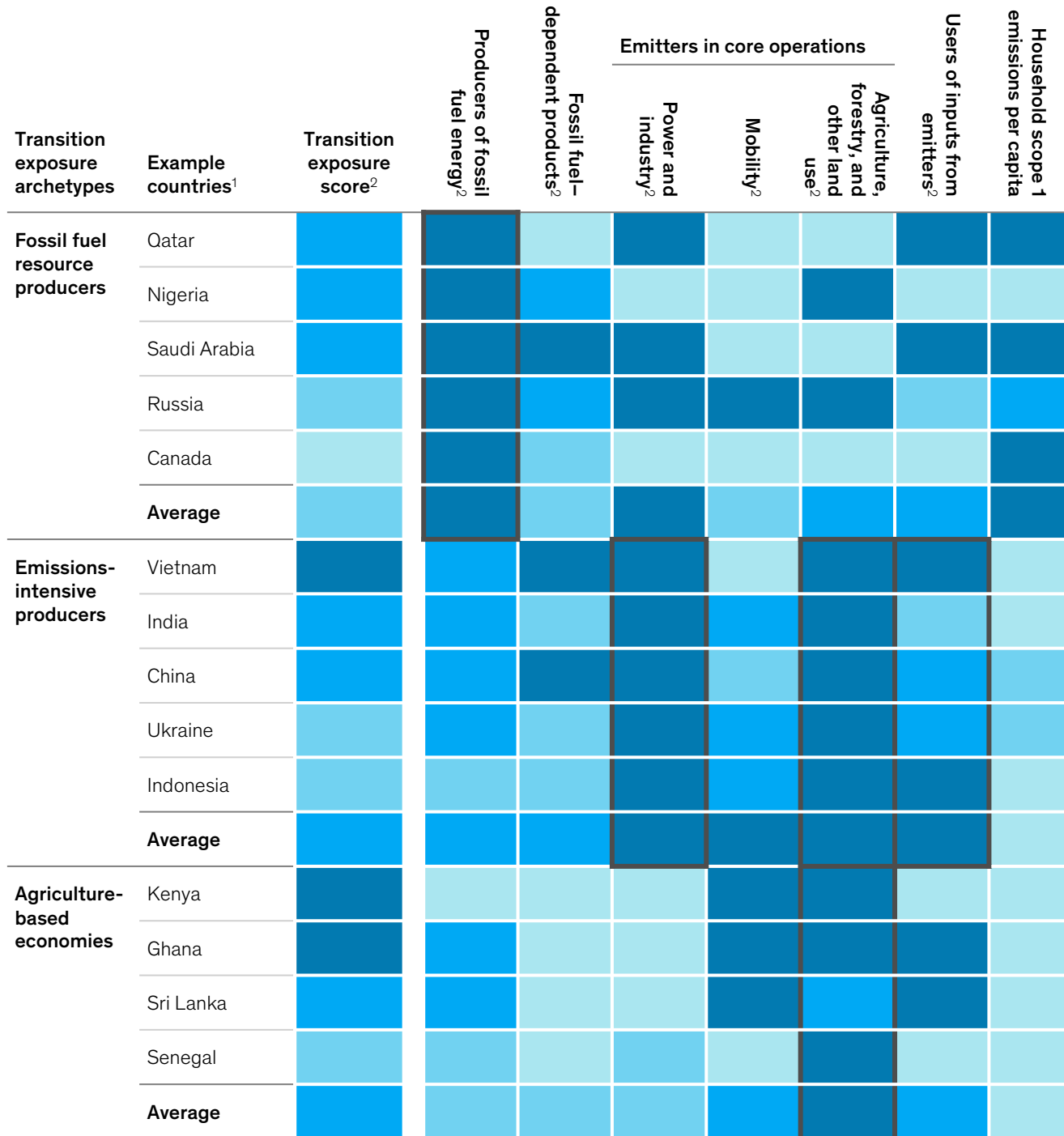
⁵⁸ For additional opportunities for African countries, see also Lynn Bouchene, Ziyad Cassim, Hauke Engel, Kartik Jayaran, and Adam Kendall, "Green Africa: A growth and resilience agenda for the continent," McKinsey & Company, October 28, 2021.

⁵⁹ As described above, countries could fall into multiple archetypes. A large share of the economy of Brazil, for example, is related to fossil fuels, and would also be exposed to the types of issues described for that archetype.

Based on the nature of their exposure to the net-zero transition, countries can be grouped into six archetypes. (1 of 2)

Countries' transition exposure by archetype, score

Low High Area of exposure most relevant to archetype



1. Averages rows within each archetype are based on a simple average of every country within that archetype, both those shown in rows and other countries in the archetype. For fossil-fuel producers, other countries include Australia, Bahrain, Egypt, Kuwait, Norway, Oman, UAE, and Venezuela; for emissions-intensive producers, Bangladesh, Pakistan, South Africa, Thailand, and Turkey; for agriculture-based economies, Morocco and the Philippines; for land-use-intensive countries, Bolivia, Chile, Colombia, Costa Rica, Ecuador, Honduras, Malaysia, Panama, and Uruguay; for downstream emissions manufacturers, Austria, Bulgaria, Czech Republic, Hungary, Italy, Poland, Romania, Slovakia, and Sweden; and for services-based economies, Belgium, Denmark, Finland, Ireland, Israel, Netherlands, Portugal, Singapore, Spain, and Switzerland.

2. Simple average of the share of GDP, jobs, and capital stock in the sectors with highest exposure to the net-zero transition.

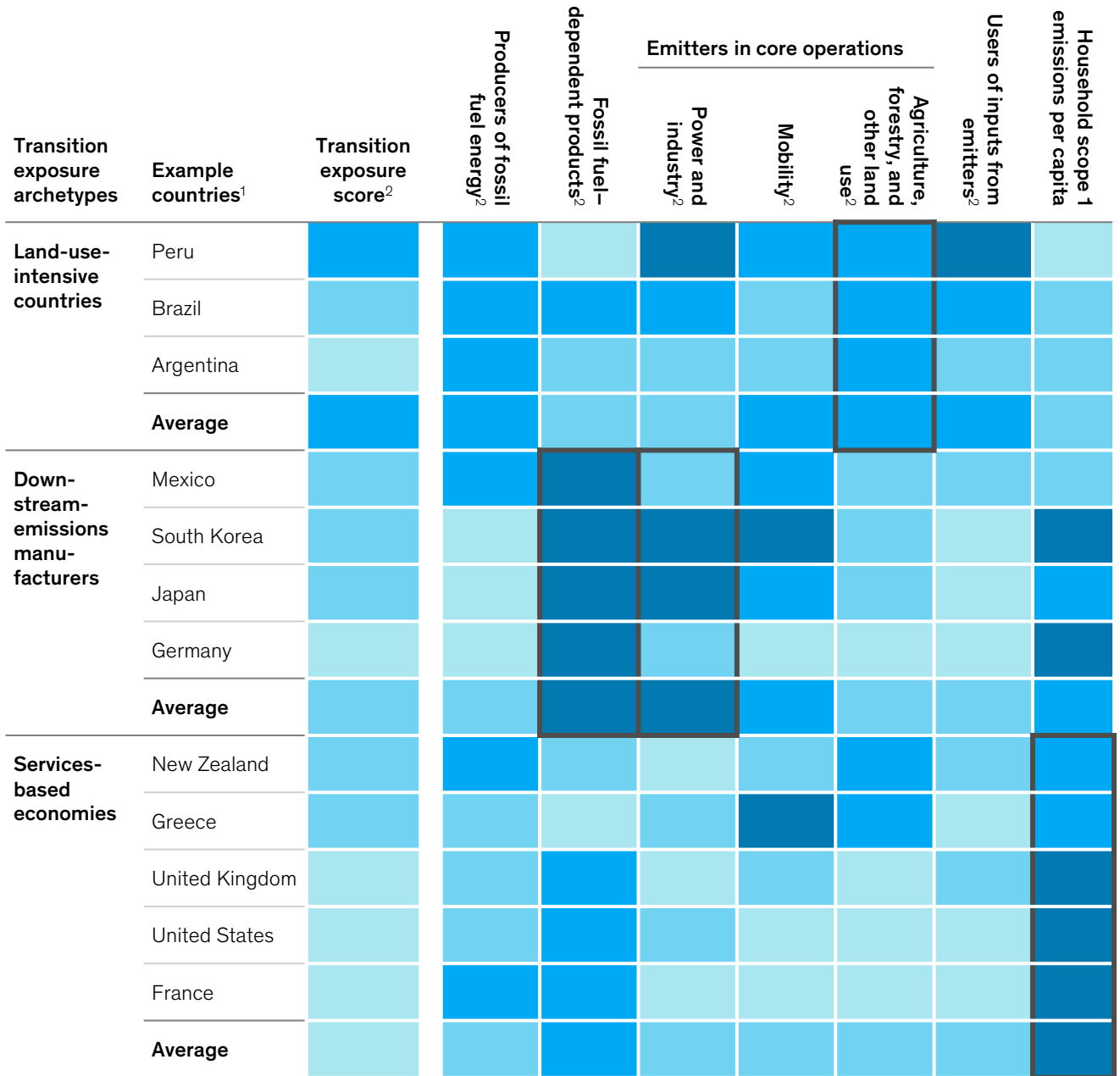
Note: Colors in each column based on relative quartiles within each column rather than across columns. Countries are allocated to an archetype to illustrate specific transition exposures they may experience. However, any given country—especially those with large diversified economies—could face some of the exposures highlighted for other archetypes. Low = below 1st quartile; high = above 3rd quartile. For exposed sectors included, see technical appendix.

Source: Oxford Economics; OECD; ILO; World Input-Output Database; IHS Connect; World Bank; International Energy Agency; US Bureau of Labor Statistics; India NSS-Employment survey; China National Bureau of Statistics; MINSTAT; INDSTAT; McKinsey Global Institute analysis

Based on the nature of their exposure to the net-zero transition, countries can be grouped into six archetypes. (2 of 2)

Countries' transition exposure by archetype, score

Low High Area of exposure most relevant to archetype



1. Averages rows within each archetype are based on a simple average of every country within that archetype, both those shown in rows and other countries in the archetype. For fossil-fuel producers, other countries include Australia, Bahrain, Egypt, Kuwait, Norway, Oman, UAE, and Venezuela; for emissions-intensive producers, Bangladesh, Pakistan, South Africa, Thailand, and Turkey; for agriculture-based economies, Morocco and the Philippines; for land-use-intensive countries, Bolivia, Chile, Colombia, Costa Rica, Ecuador, Honduras, Malaysia, Panama, and Uruguay; for downstream emissions manufacturers, Austria, Bulgaria, Czech Republic, Hungary, Italy, Poland, Romania, Slovakia, and Sweden; and for services-based economies, Belgium, Denmark, Finland, Ireland, Israel, Netherlands, Portugal, Singapore, Spain, and Switzerland.

2. Simple average of the share of GDP, jobs, and capital stock in the sectors with highest exposure to the net-zero transition.

Note: Colors in each column based on relative quartiles within each column rather than across columns. Countries are allocated to an archetype to illustrate specific transition exposures they may experience. However, any given country—especially those with large diversified economies—could face some of the exposures highlighted for other archetypes. Low = below 1st quartile; high = above 3rd quartile. For exposed sectors included, see technical appendix.

Source: Oxford Economics; OECD; ILO; World Input-Output Database; IHS Connect; World Bank; International Energy Agency; US Bureau of Labor Statistics; India NSS-Employment survey; China National Bureau of Statistics; MINSTAT; INDSTAT; McKinsey Global Institute analysis

Services-based economies. Countries in this group include Belgium, Denmark, Finland, France, Greece, Ireland, Israel, the Netherlands, New Zealand, Portugal, Singapore, Spain, Switzerland, the United Kingdom, and the United States. These countries have high GDP per capita and derive most of their economic output from service sectors, so their overall exposure to net-zero transition adjustments is low. However, in certain regions and sectors, exposure could be high. These countries also tend to have high consumer emissions—1.6 tons per capita on average, compared to 0.9 tons per capita on average for other countries—and will therefore need to induce behavioral changes in their populations and incur up-front capital costs in order to decarbonize (although, as discussed previously, this could come with long-term benefits, such as lower total cost of ownership). These countries could use their ample natural, technological, and human capital to develop new low-emissions industries or provide services, such as financial or information services, in support of the transition.

Challenges could compound for many lower-income and fossil fuel-producing countries, which would need to balance multiple imperatives.

Stakeholders will need to act with singular unity, resolve, and ingenuity, and toward equitable, long-term outcomes to support the economic transformation a net-zero transition entails

The transition to net zero we have outlined in this report will require economies and societies to make significant adjustments. Many of these adjustments can be best supported through coordinated action involving governments, businesses, and enabling institutions, and by extending planning and investment horizons. This action would need to be taken in a spirit of unity for two key reasons: first, the universal nature of the transition means that all stakeholders will need to play a role. Every country and sector contributes to emissions, either directly or indirectly, through its role in global production and consumption systems. Second, the burdens of the transition will not be evenly felt, and, for some stakeholders, the costs will be much more difficult to bear than for others. This is all the more challenging because contributions to emissions have not been even across stakeholder groups. Thus, without a real effort to address these effects in a spirit of fairness, it appears unlikely that the most affected stakeholders would be either able or willing to do their share to advance the transition.

The following three categories of action stand out:⁶⁰

- Catalyzing effective capital reallocation and new financing structures, including through scaling up climate finance, developing new financial instruments and markets, including voluntary carbon markets, deploying collaborations across the public and private sectors, and managing risk to stranded assets
- Managing demand shifts and near-term unit cost increases for sectors through building awareness and transparency around climate risks and opportunities, lowering technology costs with R&D, nurturing industrial ecosystems, collaboration across value chains to reduce or pass through cost increases from the transition, and sending the right demand signals and creating incentives for the transition
- Establishing compensating mechanisms to address socioeconomic impacts, through economic diversification programs, reskilling and redeployment programs for affected workers, and social support schemes

As these actions are undertaken, individual leaders will need to both consider risks and opportunities to their organizations and to their stakeholders, and determine the role they can play in supporting the necessary adjustments for all. We consider more detailed actions and the role of stakeholders below.

Companies can consider integrating climate considerations into their strategies and their decision-making frameworks. Companies have begun to develop comprehensive plans for achieving net-zero emissions and to integrate those plans into their strategies, combining elements of what might be called “offense” (such as entering new markets, funding R&D, and participating in innovation ecosystems) and “defense” (divesting businesses and retrofitting high-emissions assets to lower their emissions).⁶¹ As they embark on this journey, they can consider the following steps:

- Articulate and communicate a coherent case for change and upskill employees to help drive their organizations toward net-zero goals while also supporting broader economic and societal adjustments. As they initiate action, most CEOs will want to communicate a coherent case for change and take visible ownership of the sustainability agenda.
- Develop ongoing capabilities to make granular, holistic, and dynamic assessments of transition-related risks and opportunities in order to capture shifts in regulations, investor preferences, consumer behaviors, and competition. To stay abreast of new developments and emerging possibilities, organizations are likely to need new capabilities, data, infrastructure, and talent. A key part of this will also be better tracking of scope 1, 2, and 3 emissions, including through the use of digital tools to increase transparency of emissions in companies’ own operations and in their supply chains.

⁶⁰ The actions described in this section specifically relate to the economic and societal adjustments needed for the transition, given the scope of this research. An effective response to climate change, we believe, will involve not only making economic and societal adjustments to deal with the effects of the net-zero transition, but also meeting the other fundamental requirements described previously. We identify seven categories of actions. Leaders can understand and commit to the transition, including understanding the fundamentals of climate science and the transition and making personal and professional commitments; assess and plan their actions, including through building risk assessment capabilities and establishing decarbonization plans; reduce and remove emissions in accordance with these plans; conserve and regenerate natural capital to support decarbonization; adapt and build resilience to manage the physical risk that is already locked in; and reconfigure and grow, for example by reallocating capital and ramping down high-carbon businesses while scaling low-carbon ones; and seek to engage and influence their communities, across their investors, customers, suppliers, peers, and regulators. While the actions described in this section are specific to the economic and societal adjustments needed for the transition, they fall into the various categories listed above. See Mekala Krishnan, Tomas Nauclér, Daniel Pachthod, Dickon Pinner, Hamid Samandari, Sven Smit, and Humayun Tai. “Solving the net-zero equation: Nine requirements for a more orderly transition,” McKinsey & Company, October 2021.

⁶¹ Daniel Pachthod and Dickon Pinner, “Time is running out for business leaders who don’t have a ‘net zero’ strategy,” *Fortune*, April 22, 2021.

- Define decarbonization and offsetting plans and update them as competitive, financial, and regulatory conditions change. This would include scope 1 and 2 emissions (with priority given to “no regret” actions such as improving energy efficiency and making decarbonization investment with positive returns). Where feasible, needed, and material, and depending on the nature of their operations, businesses can expand these plans to include scope 3 emissions.⁶²
- Create a portfolio of agile business strategies consistent with these decarbonization plans and with the risks and opportunities emerging in a net-zero economy. They can then put these plans in place as conditions change and opportunities arise. For companies, repositioning themselves could involve investing in new physical assets and reallocating capital, redesigning products, or building new low-emissions businesses.
- Integrate climate-related factors into key business decisions for strategy, risk management, finance and capital planning, R&D, operations (including supplier management and procurement), organizational structure and talent management, pricing, marketing, and investor and government relations.
- Consider if and where to take a leadership position in the company’s industry and its ecosystem of investors, supply chains, customers, and regulators.

Financial institutions can support large-scale capital reallocation, even as they manage their individual risks and opportunities. In the near term, they will need to consider assessing and disclosing their risks and measuring and committing to reduce their financed emissions. Over time, they will need to translate these commitments into actions that lower emissions. Relevant practices for financial institutions to consider include the following:

- Rethinking conventions for risks and returns. Some decarbonization projects are likely to have longer-than-normal payback periods. This possibility may compel financial institutions to adjust their criteria for which projects they finance.
- Assessing and disclosing climate risks. For example, various regulators and supervisors already require banks to conduct climate-risk assessments, and more are planning to start these assessments.
- Measuring and reducing financed emissions. Financial institutions are increasingly making pledges to align their portfolios with 1.5°C or 2.0°C warming targets or to achieve net-zero financed emissions by a certain date. They have started translating these commitments into targets for sectors and geographies. Given that emissions ultimately are from counterparties, financial institutions may find it helpful to support the transition plans of those counterparties—for instance, by offering new financial solutions, advising them on emissions-abatement methods, and introducing partnership opportunities.
- Over time, translating these commitments into actions that lower emissions, including expanding the range of climate-finance products and services (for example, funding for low-emissions power projects, new financial instruments to support negative emissions or nature-based solutions, and well-governed voluntary carbon markets).⁶³

⁶² For purposes of this report, “scope 1” emissions are direct greenhouse emissions that occur from sources that are controlled or owned by an organization; “scope 2” emissions are associated with the purchase of electricity, steam, heat, or cooling. “Scope 3” emissions are the result of activities from assets not owned or controlled by the reporting organization but that the organization indirectly impacts in its value chain; thus “scope 3” emissions result from emissions across an organization’s value chain that are not within the organization’s scope 1 and 2 boundary. See *Greenhouse gases at EPA*, United States Environmental Protection Agency.

⁶³ Voluntary carbon markets would include markets for avoidance credits (for example, to prevent forests from being cut down) and for removal credits (for example, from afforestation or direct air capture). For further details, see *Final report*, Taskforce on Scaling Voluntary Carbon Markets, January 2021.

Governments and multilateral institutions could consider the use of existing and new policy, fiscal, and regulatory tools to establish incentives, support vulnerable stakeholders, and foster collective action. Public-sector organizations have a unique role in managing uneven effects on sectors and communities. Among other options, they could consider the following:

- Assess exposure to risks and opportunities, develop decarbonization plans, and create net-zero strategies (similar to businesses). This would include governments bringing climate considerations into decisions about such matters as urban planning, infrastructure development, and tax and subsidy regimes in an effort to anticipate future dynamics, as well as efforts to increase awareness of and transparency about climate risks and opportunities. One major adjustment that governments may need to make is developing new low-emissions industries as demand wanes for fossil fuels and emissions-intensive industries.
- Use policy measures and regulation to encourage decarbonization investment across sectors (for example, consider where and how to best use subsidies, grants, demand signals, and carbon taxes, to name a few). They can also play a role in accelerating research and development that would lower technology costs.
- Governments could establish multilateral and government funds to support low-carbon investment, and manage stranded-asset risk.
- Institute reskilling, redeployment, and social-support programs for workers and manage negative effects on lower-income households.
- Collaborate with other stakeholders to drive collective action. For example, governments can catalyze private-sector action to build new low-emissions industries in various ways; strategies might include setting road maps and convening stakeholders.

Enabling institutions such as standard setters, industry groups, and civil-society coalitions will be critical in coordinating action across sectors and geographies. Although individual actions by companies and governments can support a wide range of stakeholders during the transition, these actions may not be enough to meet all stakeholder needs. The pace and scale of the transition mean that many of today's institutions may need to be revamped, and new institutions created to disseminate knowledge, support capital deployment, manage uneven effects, and organize collective action. Enabling institutions could play valuable roles in developing and enforcing governing standards, tracking and market mechanisms (for example, related to the measurement of emissions or climate finance), convening stakeholders and facilitating collaboration (for example, to arrange collective investment or organize the build-out of infrastructure), and giving a voice to vulnerable workers and communities.

As they initiate action, most CEOs will want to communicate a coherent case for change and take visible ownership of the sustainability agenda.

Individuals will need to manage their own exposure to the transition and can play powerful roles as consumers and citizens. They can begin by continuing to learn about the effects of both ongoing climate change and the net-zero transition that they may experience as consumers or workers. The goal of net-zero emissions can only be reached if people adopt new behaviors and consumption patterns, such as switching to electric vehicles, and renovating or retrofitting homes for energy efficiency. Civic discourse has an important role to play: an informed, engaged public that recognizes the imperative for a net-zero transition could spur decisive and transformative action on the part of government and business leaders.

The economic transformation required to achieve net-zero emissions by 2050 will be massive in scale and complex in execution. The transition would bring substantial shifts in demand, capital allocation, costs, and jobs, which will be challenging to a wide range of stakeholders, not least because they will be distributed unevenly. Yet the costs and dislocations that would result from a more disorderly transition to net-zero emissions would likely be far greater, and the transition would prevent the further buildup of physical risks. The findings of this research serve as a clear call for more thoughtful and decisive action, taken with the utmost urgency, to secure a more orderly transition to net zero by 2050. It is important not to view the transition as only onerous; the required economic transformation will not only create immediate economic opportunities but also open up the prospect of a fundamentally transformed global economy with lower energy costs, and numerous other benefits—for example, improved health outcomes and enhanced conservation of natural capital. Actions by individual companies and governments, along with coordinated action to support more vulnerable sectors, geographies, and communities, could help support the needed economic and societal adjustments. Moreover, the level of global cooperation that such a transition will ultimately require could serve as both a model and a basis for solving a broader array of global challenges. Daunting as the task may seem, it is fair to assume that human ingenuity would ultimately rise to the challenge of achieving net zero, just as it has solved other seemingly intractable problems over the past 10,000 years. The key issue is whether the world can muster the requisite boldness and resolve to broaden its response during the upcoming decade, which will, in all likelihood, decide the nature of the transition.

It is important not to view the transition as only onerous; the required economic transformation will not only create immediate economic opportunities but also open up the prospect of a fundamentally transformed global economy with lower energy costs, and numerous other benefits.


The net-zero transition:


*What it would cost, what it
could bring by McKinsey*

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