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The energy transition: A region-by-region agenda for near-term action

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Preface

The Sharm El-Sheikh Climate Change Conference (COP27) concluded last month with an initial agreement to create a “Loss and Damage” fund that would help the world’s most vulnerable nations address the adverse consequences of climate change. Although the fund has yet to be capitalized and its operating rules must still be defined, its creation has been hailed as a milestone in the effort to ensure a just transition. For all the progress achieved in November, including a landmark partnership announced at the G-20 summit to accelerate the energy transition in Indonesia, among other agreements, global commitments to reduce emissions remain largely at the same level as a year ago. At the same time, the path to achieving those commitments has been complicated by the war in Ukraine, which has heightened geopolitical tensions and deepened the global, post-pandemic macroeconomic challenges.

Indeed, the events of the past year have brought into sharp focus renewed concerns about energy resilience and affordability for almost every country in the world. These concerns have led some to question the feasibility, or even the advisability, of a net-zero transition by 2050. There is no doubt that short-term risks and challenges to energy systems have to be squarely addressed. But this response must also be balanced with an equal focus on the longer-term risks of unabated climate changes. Compromising either of these objectives will likely result in major setbacks in addressing the looming climate (and natural capital) crisis, and represent unacceptable risks to global prosperity and stability.

Central to the efforts to mitigate the risk of unabated and possibly catastrophic climate change is a transformation of the energy sector, as energy-related emissions contribute to more than 80 percent of total greenhouse-gas emissions. Such a transformation will be both massive and complex. It will require a rework of the energy mix across countries and changes in end-use of energy, while minimizing disruption to the global economy.

In this report, which builds on a body of McKinsey research on climate risk and the net-zero transition, we aim to focus on practical, near-term actions that could help countries advance the energy transition while pursuing in parallel shorter-term energy resilience and affordability Given important differences among countries and regions with respect to their starting point for the energy transition, we take a region-by-region view highlighting both challenges and opportunities. The actions suggested amount to a nuanced global agenda to accelerate the energy transition and ensure that it proceeds in a more orderly and resilient fashion.

Underlying the research are insights into the energy transition developed by our McKinsey colleagues worldwide. Our findings and suggestions are not exhaustive and, in attempting a region-by-region approach to such a complex global topic, we acknowledge that there are gaps in our findings. By focusing on regions and archetypes, we may have omitted some of the specificity needed for individual countries. Nonetheless, we hope the research will contribute to the worldwide debate about the energy transition and spur action to accelerate its implementation.

The report is joint research by McKinsey's Global Energy and Materials Practice and McKinsey Sustainability. 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 report includes the publications *The net-zero transition: What it would cost, what it could bring* (January 2022) and *Solving the net-zero equation: Nine requirements for a more orderly transition* (October 2021), as well as McKinsey's annual *Global Energy Perspective*.

The research was led by Humayun Tai, Hamid Samandari, and Daniel Pacthod, McKinsey senior partners in New York; Evan Polymeneas, a partner in Chicago; and Alex Bolano, an associate partner in San Francisco.

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In brief

As 2022 comes to a close, the energy transition seems more disorderly than ever. A world economy shaken by a global pandemic and the surging inflation that has accompanied the subsequent recovery has had to contend with a tragic conflict in Ukraine and its aftermath of human suffering, rising energy costs, and declining energy security. The immediate response has meant more short-term reliance on fossil fuels and less available resources for the transition, not to mention additional challenges to regional and global coordination, As we look toward 2023 and COP28, the dual imperatives of ensuring energy resilience and affordability and of reducing emissions appear equally inescapable. Instead of delaying action, we believe these imperatives emphasize the importance of accelerating coordinated, long-term action, at the same time as taking short-term measures. This report, which builds on our prior work identifying requirements for the net-zero transition, highlights a range of near-term actions that countries and regions around the world could take to ensure they transition their energy system while maintaining focus on the immediate needs of energy resilience and affordability (a less disorderly, and hence "more orderly," transition). The key findings:

The need for accelerated and sustained action is pressing, as physical climate risk and its visible manifestations continue to grow. To bridge a gap between the current emissions trajectory and a path that would limit global warming to 1.7°C by 2030, annual solar and wind installed capacity would need to almost triple over the coming decade, to more than 520 gigawatts (GW) average yearly installed capacity, from an average of about 180 GW from 2016 to 2021.

As the world seeks to move toward cleaner energy, a nuanced view of the role of fossil fuels and of the path to reducing their use is needed. Even though renewable energy production doubled in the past decade, fossil fuels still represent about 82 percent of primary energy consumption in 2021. Moreover, residual reliance on fossil fuels is assumed in all net-zero scenarios by and beyond 2050. As further investments in fossil-fuel production will likely be needed to meet current or future residual needs and demand, it will be critical to aim for lower-emissions, high-efficiency, and highly flexible sources and production approaches. A key concern should be to avoid an accumulation of stranded assets. At the same time, the transition means that fossil fuel producers will need to adjust to an environment of declining volumes of output. The retirement of emissions-intensive fossil-fuel extraction and power generation operations, such as coal plants, will also need to be accelerated.

Three main factors influence each country's ability to achieve a more orderly energy transition. Two are linked with energy resilience and the third with affordability. Opportunities, challenges, and risks from the transition are unevenly distributed because of three principal factors. On the dimension of energy resilience, the two factors are a) the presence (or lack) of natural resources, such as the potential for wind and solar generation as well as the availability of transition critical minerals; and b) a country's economic reliance on energy imports and emissions intensive industries. On the dimension of affordability, a country's disposable financial resources and its ability to leverage capital to support the energy transition are critical.

For the transition, countries can be grouped into five principal archetypes, with differing prospects:

1. **Affluent, energy-secure countries,** including Australia, Saudi Arabia, and the United States, which have abundant domestic production of energy and high GDP per capita. As the energy transition unfolds, they are likely to remain energy exporters but will need to reconsider energy sources to meet emissions targets.

2. **Affluent, energy-exposed countries,** including Germany, Italy, and Japan, which face energy-security challenges. The transition could represent an opportunity for them to pivot toward domestic clean-energy production, reducing dependence on fossil fuel imports.

3. **Large, emissions-intensive economies,** including China, India, and South Africa, which are faced with the challenge of meeting growing energy demand with cleaner resources, at the same time as addressing their reliance on high-emissions fuels, particularly coal.

4. **Developing, naturally endowed economies,** including Brazil, Mexico, and Indonesia, which have significant power potential from solar or wind sources and critical natural resources such as rare metals. Their natural priority will be to set up the framework to develop these resources and move to a sustainable mode of production.

5. **Developing, at-risk economies,** which include parts of Africa and Southeast Asia, along with several island nations. These economies are mainly agricultural and have a disproportionate exposure to climate risk. Some have limited potential for renewables development, either because of financial constraints or because of limited natural endowments. Their transition will need to be coupled with the establishment of basic infrastructure services and investment in climate adaptation.

All countries, irrespective of archetype, need to take actions that meaningfully advance decarbonization while ensuring energy security and affordability. There is, therefore, a premium on actions that take into account the current position, momentum, and constraints of each region, and that are relatively easier to implement (even though nothing is truly easy). This is precisely the focus of this report, with the full awareness that the actions it suggests are only a step in the transition journey. In addition to these regional actions, eight actions are globally applicable and would need to be accelerated: (1) streamlining access to land, accelerating permitting, and simplifying processes to accelerate time-to-deployment for renewables and cleantech; (2) modernizing and repurposing grid and other legacy infrastructure and developing new assets to accelerate the integration of renewables and cleantech into the energy system; (3) strengthening global supply chains to secure critical raw materials, components, and labor competencies; (4) decarbonizing the industry and transportation sectors by investing in new technologies such as hydrogen and carbon capture, utilization, and storage, alongside electrification and energy efficiency; (5) limiting and mitigating emissions-intensive generation, to reduce the carbon footprint of fossil fuels and lower the risks of stranded assets; (6) managing economic dislocations to promote energy affordability and create fair opportunities for affected and at-risk communities; (7) developing stable and attractive remuneration frameworks, market designs, and offtake structures to encourage investments in renewables and cleantech; and (8) scaling frameworks and standards to measure the carbon intensity of energy and final products and develop a global, new carbon economy.

Key stakeholders will need to accelerate action to promote a more orderly energy transition by 2030. The risk of a disorderly transition, which has always been high, has become even more so over the past year. This makes greater public and private collaboration, as well as genuine cross-regional and global cooperation, even more critical. Governments and multilateral institutions have a central role in implementing policies and measures to encourage carbon standards and promote investment in renewables, as well as managing dislocations and affordability issues. Financial institutions are instrumental in rethinking investment horizons and risk-return profiles, disclosing and measuring their portfolio exposure in the near term, and quickly deploying capital to clean energy projects, while ensuring appropriate support for traditional energy sources to support redundancy and resilience. Companies would gain from focusing on developing net-zero strategies and action plans, prioritizing innovation in green business models and technologies, and securing a sustainable supply chain. Energy providers, including utilities and transmission and distribution companies, could focus on managing stranded risks for their carbon intensive assets, securing the supply chain, prioritizing innovation in business models and technologies, and developing manufacturing for clean technologies. Companies in energy-intensive industries such as mining, cement, and oil and gas extraction could consider setting time-bound initiatives for decarbonization, investing in energy supply and developments, transitioning assets and operations toward a net-zero world, and developing a procurement and energy-risk management strategy to mitigate energy-security and volatility risks. Individuals, too, have a role to play. To manage a transition that combines emissions reductions with energy security and affordability, they have the ability to participate in the climate-change conversation, make informed trade-offs, and demand increased transparency and accountability from their leaders.

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Executive summary

Energy represents 83 percent of global emissions of carbon dioxide (CO_2).[1] No wonder, then, that the sector has long been recognized as being at the very heart of the transition to net-zero greenhouse-gas emissions.

The conclusion of COP27 has brought renewed uncertainty on the path to this transition. While progress was made in pursuing global co-operation, through the establishment of “Loss and Damage” funding arrangements for particularly vulnerable countries, progress on emissions mitigation remained largely elusive. Emission mitigation commitments remained essentially the same as before COP27, despite some hopeful developments such as the expansion of the global methane pledge to 150 countries and the G-20 Summit’s announcement of a $20 billion plan to support Indonesia’s transition from coal to renewables.[2] According to our analysis, achieving national commitments could lead to significant progress toward a 1.5°C pathway. However, after COP27 it is less obvious whether these critical targets will be met. Finally, there is an increasing recognition that the current emissions trajectory would lead to an increase of 2.4°C to 3.5°C in average global temperatures by 2100, which would have significant and potentially catastrophic consequences.[3]

COP27 came at a time of global macroeconomic and geopolitical turbulence, which has led many to doubt whether a 1.5°C pathway is feasible (or, according to some, even advisable). Industry observers remark that the energy transition is already “disorderly.” It will be made even more so if the imperatives of energy resilience and affordability are not addressed in parallel to bringing about the net-zero transition. It is important to recognize that while these two imperatives appear in contention with each other in the short term, they are highly self-reinforcing in the longer term.

There is therefore no case for slowing down the transition but rather for accelerating action and developing nuanced, near-term plans to address these challenges. Such plans need to balance the pace of the necessary phasing down of fossil fuels with the ramping up of renewables, remove obstacles such as land constraints and financing hurdles, and manage the fallouts, such as stranded assets, employment consequences, and potential cost increases. Such plans must also encompass careful consideration of both shorter- and longer-term risks, such as the economic impact on emissions-intensive industries, the (regressive) burdens placed on certain countries and populations, and fair allocation of opportunities and burdens.

Despite the evident challenges, we believe that bold and decisive action can make a difference in bringing about this transition. In fact, undertaking a carefully thought and calibrated set of actions today can avoid mounting risks in the future. In this report, we focus on near-term and enabling actions for countries and regions that would be the foundations of any transition plan and that would help these countries progress along a path toward an affordable, resilient, and timely energy transition.[4]

We look at these actions through three different lenses. First, we describe eight actions that apply across countries and regions and, when taken, will guide the world toward a more orderly transition. Second, we consider ten regions that together represent a total of 86 percent

[1] Insights on Sustainability, 2022, McKinsey; EMIT database of Insights on Sustainability; *Global Energy Perspective 2022,* McKinsey, April 26, 2022; *The net-zero transition: What it would cost, what it could bring,* McKinsey, January 2022; International Energy Agency (IEA) data for 2019.
[2] “COP27 reaches breakthrough agreement on new ‘Loss and Damage’ fund for vulnerable countries,” United Nations Climate Change press release, November 20, 2022; “The EU and international partners launch ground-breaking Just Energy Transition Partnership with Indonesia,” European Commission, November 15, 2022.
[3] Intergovernmental Panel on Climate Change (IPCC). The warming estimate is an indication of a global rise in temperature linked to the emissions levels expected by 2100 versus preindustrial levels, based on IPCC assessments.
[4] While we believe that climate adaptation will prove increasingly critical around the world, and particularly for the most vulnerable countries and communities, adaptation (whether for energy systems or more broadly) is not a focus of this report.

of the world's population and 86 percent of global emissions.[5] For each of these regions, we identify the specific actions that apply, by bringing to bear local needs and nuances on the global actions. We are aware that an ideal analysis would be on a country-by-country level but believe that the focus on these ten regions allows us to do a more manageable analysis (while enabling us to make distinctions among countries in each region as well). Third, we look at taking action from the perspective of various stakeholders and specifically what governments, institutions, companies, and individuals could do to find a path to a more orderly transition.

For this report, we use 2030 as the time horizon. We are aiming to describe neither a longer-term (hypothetical) path with its implications (we have done so in a previous report[6]) nor what the current momentum may imply (as we do in our energy insights report[7]). Our focus is on near-term, critical action. Three factors motivate this choice. First, the need to move from commitments to clear plans and actions. Second, the recognition that transitioning our energy system is a slow-moving process and that actions taken now could take years to have the desired consequences. And third, the sense that time is running out.

Momentum toward renewables is growing but without a corresponding decrease in global emissions

The world's progress toward cleaner energy has been accelerating. Over the past decade, the production of renewable energy has more than doubled globally, and its share of total primary energy consumption has grown from 9 percent in 2011 to 13 percent in 2021.[8] While renewables broadly defined include a range of energies including hydropower and geothermal energy, we focus in this report mainly on solar and wind energy.

Despite the growth in renewable energy, the use of fossil fuels is also expanding to meet growing demand for energy. Global energy demand grew by 14 percent from 2011 to 2021, driven mainly by emissions-intensive sources. As a result, global energy-related emissions have increased in the past decade by about 5 percent, or 1.7 gigatons (Gt) of CO_2,[9] and the current share of primary energy from fossil fuels remains preponderant, at 82 percent.

Prescriptions for the role of fossil fuels cannot be overly simplistic, given this continued reliance. The net-zero transition requires steep and decisive declines in fossil fuel consumption by 2050. At the same time, in one scenario of our analysis, global demand for natural gas could be higher in 2030 than 2021, while oil consumption would decline by less than 5 percent in the same timeframe. Securing this supply would require judicious investments in fossil fuels to secure energy resilience and affordability (in parallel to much larger investments in renewables and electrification). Achieving a more orderly transition will likely require balancing the accelerated decommissioning of inefficient and highly polluting assets such as coal or oil power generation with incremental investments in lower-emissions fuel production. To the extent that fossil fuel investments are made, they should be directed towards lower emissions options and flexible assets that can rapidly adjust their production as demand decreases to meet net zero goals (see Box E1, "Reducing the use of fossil fuels"). Investments and action to reduce the carbon intensity of fossil fuels, such as addressing methane emissions and electrifying oil and gas operations, will also be needed.

The socioeconomic context has become at once more precarious and more receptive to the energy transition. The war in Ukraine has, beyond its incalculable human cost, significantly increased energy and food costs and exacerbated the inflationary trends that were already

[5] Namely Africa, Australia, China, the European Union, India, Japan, Latin America, the Middle East, Southeast Asia, and the United States.
[6] *The net-zero transition: What it would cost, what it could bring,* McKinsey, January 2022.
[7] *Global Energy Perspective 2022,* April 26, 2022.
[8] *BP energy outlook: 2022 edition,* BP, 2022.
[9] *Global Energy Review 2021,* International Energy Agency (IEA), April 2021.

manifest in the post-pandemic recovery. It has also made energy resilience and affordability a much more pressing concern. In addition, the COVID-19 pandemic disrupted global supply chains and inflated, among others, the costs of energy-project construction. These challenges have heightened awareness and spurred new actions toward an energy transition, particularly in Europe.

Physical climate risk and its visible manifestations are also continuing to grow. Specifically, according to the United Nations' Intergovernmental Panel on Climate Change (IPCC) sixth assessment report, extrapolation of current policies would lead to a median global warming of 2.4°C to 3.5°C by 2100 and put limiting global warming to 1.5°C beyond reach. Past McKinsey analysis indicates that there could be an annual 2.4 Gt carbon dioxide equivalent (CO_2e) gap (7 percent of 2021 energy-related emissions) between the current trajectory and the trajectory of an "achieved commitments" scenario. To bridge this gap, the annual solar and wind installed capacity would need to nearly triple, from approximately 180 gigawatts (GW) of average yearly installed capacity from 2016 to 2021 to more than 520 GW over the coming decade, with different accelerations required across global regions.[10]

[10] *Renewable energy capacity statistics,* International Renewable Energy Agency (IRENA), 2022; *Global Energy Perspective 2022,* McKinsey, 2022, data for Achieved Commitments scenario, 2030.

Box E1

Reducing the use of fossil fuels

The use of fossil fuels for energy production will decline sharply if the world advances along the path of the net-zero transition. Our estimates indicate that in an "achieved commitments" scenario, oil demand for primary energy would more than halve, from about 30 billion barrels in 2021 to about 12 billion in 2050, while gas demand would fall by about 35 percent, from about 3,800 billion cubic meters (bcm) in 2021 to about 2,500 bcm in 2050.[1] Oil and gas producers will need to adjust to a world of declining oil and gas output and, eventually, to a reduction of capital invested in upstream assets.

However, demand for oil and gas would continue to exist for the next few decades, including for uses beyond energy production. For example, under an "achieved commitments" scenario, demand in 2030 could be about 28 billion barrels of oil and about 4,000 bcm of gas. It would thus be important to assess and minimize the emissions associated with oil and gas production. Investments in fossil fuels will be needed, but they will have to be carefully managed with the right incentives (for example, natural gas replacing more intensive fuels like coal).[2]

Given the gradual nature of the transition from fossil fuels, an optimal solution would be to produce from basins that are cheaper, carry lower emissions, and can more flexibly ramp production up or down, thereby minimizing the risk of stranded assets. The most attractive and least carbon-intensive regions might need capital investments to counteract the natural declines in the rate of production, modernize operations, and continue to mitigate emissions. Conversely, higher cost and emission basins would need to be retired. In the end state, production would naturally fall even in the most carbon-efficient basins.

One natural area of focus to achieve this outcome would be to establish mechanisms that reward oil and gas that is sourced from lower-emissions operations and, conversely, discourage operations that have a heavier emissions intensity. Another focus area would entail payment mechanisms that reward upstream operators for investing in flexible production capacity rather than reward them for the volume of their fossil fuel output.

[1] See *Global Energy Perspective 2022*, "achieved commitments" scenario, McKinsey, April 26, 2022.
[2] Such coal for natural-gas replacements might not always be prudent or economical.

Countries fall into five main archetypes with respect to their opportunities and priorities for a more orderly energy transition

The opportunities, challenges, and risks associated with a more orderly energy transition are not distributed evenly around the globe. Some countries can count on higher financial or natural resources, and not all economies are equally equipped to address the challenge of transforming their energy mix. It is therefore useful to identify the primary archetypes, or groupings, into which countries would fall in the context of the energy transition and the corresponding opportunities and challenges.

Considerations of affordability and resilience will shape each country's ability to achieve a more orderly transition. The following three factors are critical in understanding each country's ability to make the transition:

Related to energy resilience

1. **The country's short-term economic reliance on energy imports and emissions-intensive industries.** Some countries rely on imported energy, frequently fossil fuels, for energy security. These include several European countries such as Germany, which are exposed because of their high level of dependence on imported fuels, and countries like India and China, which represent the world's largest population centers and have both high energy needs and carbon-intensive energy-consumption profiles.

2. **The country's access to favorable natural resources.** Some countries have limited natural domestic potential for the development of clean energy, such as the required levels of sunshine or wind, suitable land for new projects, or abundant reserves of minerals such as copper and nickel that are critical to the energy transition.

Related to affordability

The country's disposable financial resources and ability to leverage capital to support the energy transition. The net-zero transition would require an additional $1 trillion to $3.5 trillion in average annual capital investment globally through 2050, according to our estimates.[11] Renewable energy and grid improvements require up-front capital investment. These capital investments pay off over various time horizons in the form of reduced operating expenses and improved energy resilience and cost. The transition would also require addressing, where necessary, the risk of stranded costs in fossil-fuel assets, conducting at-scale R&D, retraining the workforce, offering safety nets to vulnerable groups, and funding early-stage infrastructure deployment to initiate "learning-curve" effects. Both more and less affluent countries find themselves under budget constraints these days, but the former have many more resources and face fewer trade-offs than the latter in making these investments.

The examination of these three dimensions leads us to define five main archetypes of countries, each grouping with similar challenges and opportunities in the net-zero transition (Exhibits E1 and E2). While each country is different, we believe these archetypes naturally lend themselves to a similar or comparable set of actions and priorities for a more orderly energy transition. This categorization of countries reveals that the burdens of the energy transition, and each region's ability to meet the challenges of adaptation and mitigation, will not be evenly distributed. Moreover, global cooperation and coordinated collective action beyond current levels will be needed: for example, while significant progress has been made in mobilizing public and private financing for developing countries, OECD analysis indicates that the $100 billion target for 2020, set at COP15 in Copenhagen, was likely not met.[12]

The pathway to mobilizing global financial flows from more affluent to more at-risk countries is still unknown, but our analysis indicates that developing countries can benefit from readily

[11] Estimates are based on the "net zero 2050" scenario of the Network for Greening the Financial System (NGFS). Our research is not a projection or prediction and does not claim to be exhaustive. See *The net-zero transition: What it would cost, what it could bring,* January 2022.
[12] *Aggregate trends of climate finance provided and mobilised by developed countries in 2013-2020,* OECD, 2022.

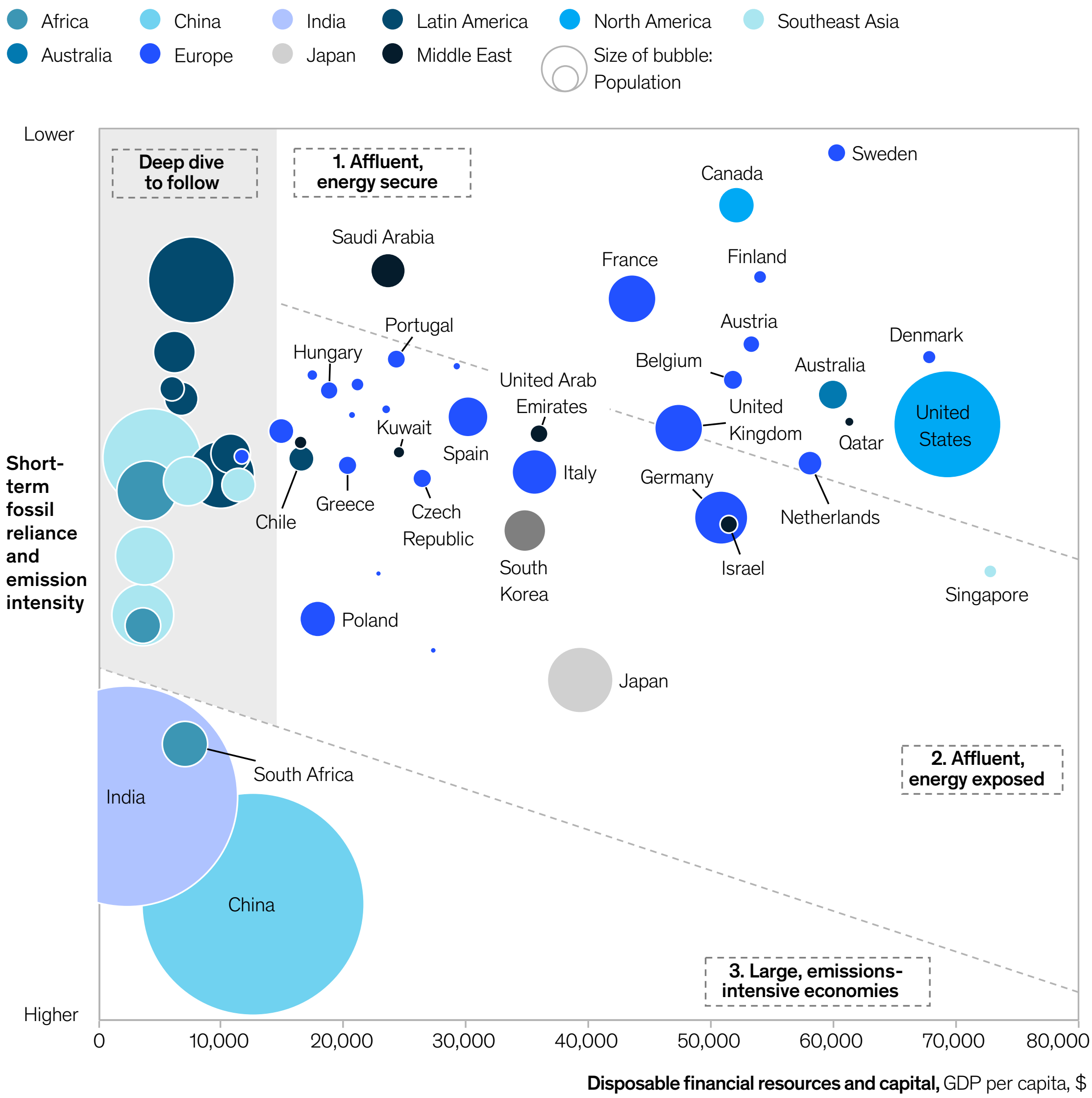
available solutions such as abatement and avoidance of coal expansion or methane emissions, which increased financing flows can catalyze. Similarly, affluent countries would benefit from greater availability of critical natural resources from developing countries, which would require investment in the sustainable extraction and processing of these resources.[13] The Just Energy Transition Partnership between Indonesia and a number of developed countries, announced in November, is an example of positive efforts in this direction that will need to be replicated and multiplied at scale.[14]

[13] See, for example, Marcelo Azevedo, Nicolas Goffaux, and Ken Hoffman, "How clean can the nickel industry become?," McKinsey, September 11, 2020; and Henry Legge, Clemens Müller-Falcke, Tomas Nauclér, and Erik Östgren, "Creating the zero-carbine mine," McKinsey, June 29, 2021.
[14] "The EU and international partners launch ground-breaking Just Energy Transition Partnership with Indonesia," European Commission, November 15, 2022.

Exhibit E1

Countries can be divided into five main archetypes based on key energy transition characteristics.

Short-term risk: Relative energy security; CO_2 intensity

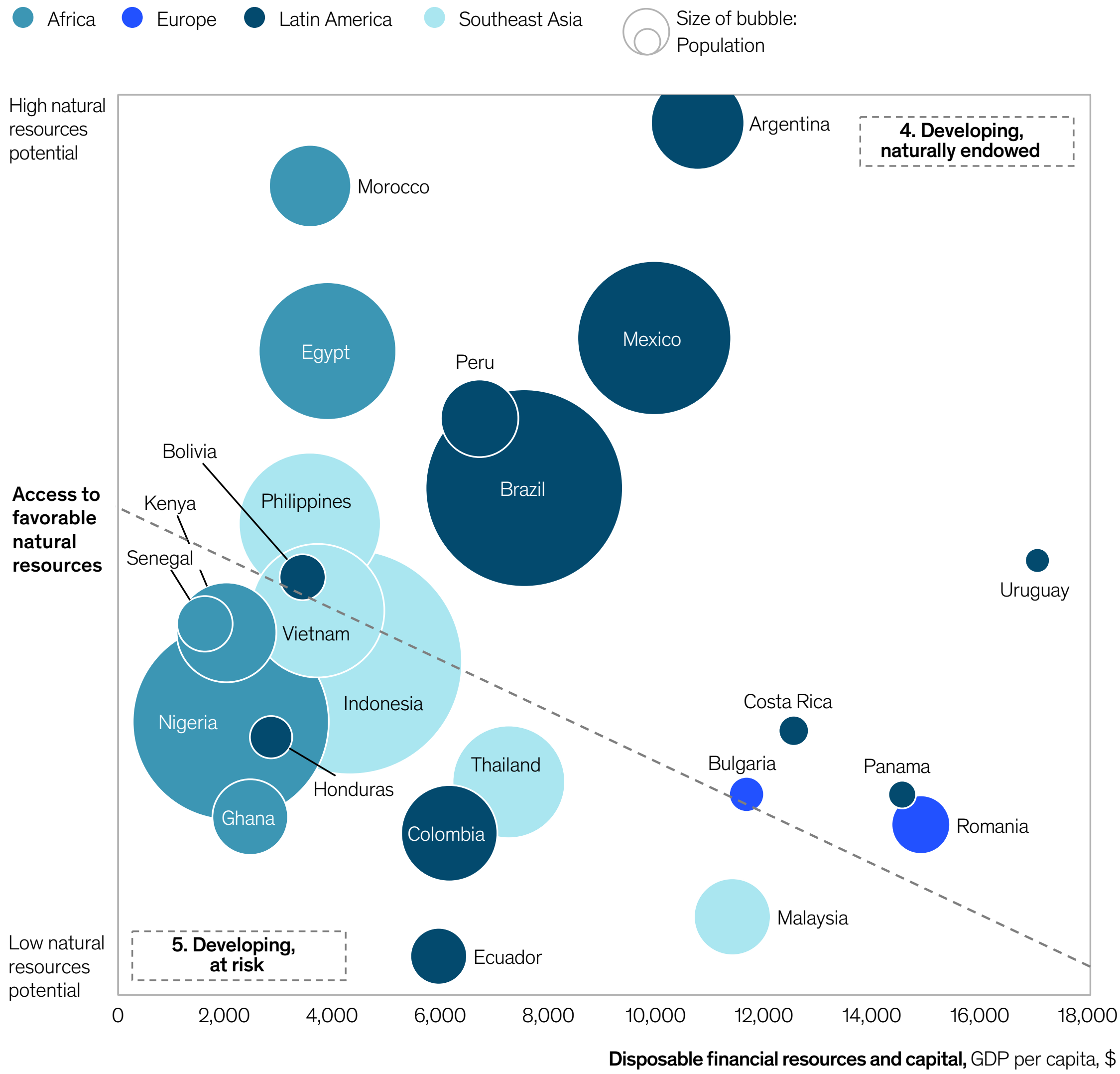


Source: McKinsey analysis

Exhibit E2

Countries can be divided into five main archetypes based on key energy transition characteristics.

Long-term opportunity: Relative potential from wind and solar; presence of critical materials



Source: McKinsey analysis

The five archetypes are:

1. **Affluent, energy-secure countries.** These countries—which include Australia, Saudi Arabia, and the United States—together have 8 percent of the global population and account for 22 percent of global greenhouse-gas (GHG) emissions. They have abundant domestic production of energy and high GDP per capita (as a proxy for the amount of available financial resources and capital). They are likely to remain energy exporters in the near term, as long as fossil fuel consumption remains relevant, but could reconsider their energy sources to meet emissions targets.

2. **Affluent, energy-exposed countries.** These countries—which include Germany, Italy, and Japan—represent 7 percent of the global population and 13 percent of global emissions. They have high GDP per capita but are exposed to energy-security concerns. The transition could represent an opportunity for them to pivot to domestic clean-energy production; some of the more manufacturing-intensive countries could incorporate more green manufacturing practices.

3. **Large, emissions-intensive economies.** China, India, and South Africa are among the countries with large, emissions-intensive economies. Altogether, they are home to 37 percent of the global population and generate 40 percent of global emissions. For these economies, a net-zero transition would naturally focus on finding a balance between meeting growing energy demand with cleaner resources, on the one hand, and addressing the reliance on the most emissions-intensive fuel, which has historically been relatively low-cost, domestically produced coal, on the other.

4. **Developing, naturally endowed economies.** Brazil, Indonesia, and Mexico are among the countries with developing, naturally endowed economies. Altogether, they represent 9 percent of the global population and 5 percent of global emissions. These countries have significant potential for power from solar or wind sources or critical natural resources, such as rare metals, to support the energy transition. A natural priority for these countries would be setting up the framework to develop these resources and attract domestic and international capital.

5. **Developing, at-risk economies.** The countries with developing, at-risk economies include parts of Africa, Southeast Asia, and Latin America, as well as several island nations. Altogether, they are home to 11 percent of the global population and generate 5 percent of global emissions. They are characterized largely by agricultural economies, a disproportionate exposure to climate risk. Some have limited potential for renewables development, either because of financial constraints or because of limited natural endowments. Their transition would likely be coupled with the establishment of basic infrastructure services and investment in climate adaptation, and likely possible only with foreign support.

Globally, eight sets of common actions are needed for a more orderly transition

All countries have the opportunity to take eight sets of actions that are necessary in the near term to make the energy transition more orderly. The extent to which these actions are relevant to a given country, and the specifics of their implementation, would of course vary. We have prioritized these actions based on two criteria. One is relative ease of implementation. The second is the need to ensure energy resilience and affordability along the way. We recognize that any such articulation would fall short of the ideal that would be pursued in the absence of constraints.

While these actions address the entirety of the global energy system, most of them focus on energy production rather than consumption. Indeed, while promoting the adoption of green technology on the demand side will be important, we believe that many of the actions to be taken in the near term will interest the supply side, where addressing the scalability of assets and infrastructure and moving energy production toward a smaller carbon footprint will likely be priorities.

This analysis builds on a previous article outlining nine requirements for a more orderly transition, which are grouped into three categories: physical building blocks; economic and societal adjustments; and governance, institutions, and commitments.[15] We note that these actions are well known in many cases. We believe it is possible and critical to make meaningful progress on all of them within the 86 months remaining in this decade.

Physical building blocks

1. **Streamlining access to land, accelerating permitting and simplifying processes to accelerate time to deployment for renewables and cleantech.**[16] Streamlining the permit process and limiting the number of required project-approving entities could accelerate project execution. Access to land could be simplified by advancing projects that benefit local communities and by developing land-efficient solutions such as offshore wind. The use of alternative lands—for example, wastelands, which is land degraded by human activities, or agrivoltaic land, land used for both agriculture and solar photovoltaic energy generation—and out-of-the-box solutions like floating solar photovoltaics (PVs), could help expand the area suitable for renewable installation.

2. **Modernizing and repurposing legacy infrastructure and creating new assets to accelerate the integration of renewables and cleantech into the energy system.** Investing in developing and modernizing the power grid will be crucial to ensuring that areas with high potential for renewables generation are integrated and connected with demand centers. Also important would be the development of new flexibility solutions such as batteries and better-matching supply and demand through demand-response programs—that is, incentives and technology solutions to adjust distributed energy demand and generation whenever the grid needs support. Conventional assets such as gas plants or pipelines might still be important to ensure an adequate supply, but they would need to be adjusted to decreasing utilization or repurposed to use a cleaner fuel mix, such as hydrogen.

3. **Strengthening global supply chains to secure critical raw materials, components, and labor competencies.** Countries will need to develop a resource strategy to match their needs for components and materials with the supply that is either available or could be made available. This could include investing in product redesign to promote the substitution of constrained or at-risk materials. Promoting recycling and reuse could help limit the demand for critical resources. The selective adoption of reshoring could promote the development of local supply chains. Setting up long-term agreements and partnerships with suppliers can be a hedge against variations in critical supply.

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[15] Mekala Krishnan, Tomas Nauclér, Daniel Pacthod, Dickon Pinner, Hamid Samandari, Sven Smit, and Humayun Tai, “Solving the net-zero equation: Nine requirements for a more orderly transition,” McKinsey, October 27, 2021.
[16] Cleantech refers to clean climate and energy-related technology solutions, including advanced building technologies, biopower, grid analytics, next-generation vehicles, solar photovoltaics (PVs), unconventional natural gas, wind, advanced biofuels and bio-based chemicals, carbon capture and storage, grid-scale storage, and intelligent transport.

4. **Decarbonizing the industry and transportation sectors by investing in new technologies such as hydrogen and carbon capture, utilization, and storage (CCUS), alongside electrification and energy efficiency.** Incentivizing investments in hydrogen and CCUS solutions could help increase demand in hard-to-abate sectors and, in turn, promote the growth of a green-product industry. Investing in electrification and energy efficiency could boost the decarbonization of light industry.[17] The transportation sector could address its carbon footprint through incentives for the uptake of light-duty transportation. Technological acceleration could reduce the cost difference between fuel-cell electric vehicles and conventional internal-combustion-engine vehicles for heavy-duty transportation.

Economic and societal adjustments

5. **Limiting and mitigating emissions-intensive generation, to reduce the carbon footprint of fossil fuels and lower the risk of stranded assets.** Measures to limit the addition of new fossil assets could be introduced to avoid the further expansion of fossil plants, particularly highly intensive assets such as coal. Fossil-fuel generation would progressively shift toward balancing intermittent renewables while storage systems are brought to scale. Mechanisms to value flexibility and capacity of "firm" power generation assets—that is, sources that provide controllable and reliable energy—could be introduced, even as the utilization rates of some of these assets decline. To the extent that fossil-fuel extraction is necessary, basins with the lowest carbon intensity could be prioritized (see Box E1, "Reducing the use of fossil fuels").

6. **Managing economic dislocations to promote energy affordability and create fair opportunities for affected and at-risk communities.** The introduction of compensation mechanisms such as subsidies would likely be required to ensure energy affordability for most vulnerable consumers. Regions, especially those more dependent on fossil fuels, would need to accelerate diversification of their GDP and industrial footprints. Workers in at-risk industries such as fossil mining would need safety nets. Skills programs could be developed to create a new generation of competencies that can respond to the needs of the energy transition.

Governance, institutions, and commitments

7. **Developing stable and attractive remuneration frameworks, market designs, and offtake structures to encourage investments in renewables and cleantech.** Lower-risk frameworks for offtake, such as virtual power purchase agreements (PPAs), could be applied on a global scale to renewables and to an even broader universe of technologies.[18] In addition, establishing and scaling capacity markets could be a measure to reward flexibility and contribute to attracting investments in storage solutions like batteries and hydrogen.

8. **Scaling frameworks and standards to measure carbon intensity of energy and final products and develop a global, new carbon economy.** Developing the right carbon standards, incentives, and markets will be important to accelerating the transition. Further, beyond voluntary carbon markets, setting the right carbon pricing could play an essential role in driving the fossil-to-green switch and promoting the viability of business cases for low-carbon technologies. Carbon transparency could ultimately lead to the pricing of carbon contents and the creation of low-carbon or green premiums for various fuels like hydrogen and commodities like steel and cement.

In parallel to these actions, immediate and sustained efforts toward energy efficiency can help ease the burden of this transformation.

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[17] Based on the IEA definition, light industry describes a range of sectors with lower absolute energy use than heavy industry such as steel and cement. Light industry includes, among other industries, consumer goods, food, and construction. See Alexandre Gouy and David Hodgson, *Light industry,* IEA, September 2022.
[18] Virtual-power purchase agreements do not involve the physical delivery of energy.

Region-specific actions will be needed to address local characteristics and socioeconomic differences

The just-discussed global actions will play out differently across regions and countries and will need to be combined with region-specific actions to enable a more orderly transition. We provide here a brief overview for each of the ten regions, recognizing that there are differences among the countries (and different archetypes) in each region and, therefore, additional nuances. These are addressed in greater detail in chapters of the full report. Each region is presented here under its dominant archetype. As we consider these region-specific actions, it is important to bear in mind that securing energy resilience and affordability remains a key priority of governments across the world. This report focuses therefore on more feasible actions that could materially advance the energy transition. We recognize that further innovation and cost declines in clean technologies are needed to bring down the cost of meeting net-zero goals, but we believe the actions outlined here are mostly possible with the technologies available today.

Affluent, energy-secure regions

United States. The United States has a highly developed economy, with a relatively high penetration of renewables and resources to scale green solutions. The country could move closer to a having more orderly energy transition by committing to six high-priority measures: (1) designing and deploying a capital-efficient and affordable energy system; (2) strengthening supply chains to provide stable access to raw materials, components, and skilled labor (for example, developing resilience plans to maintain access to critical materials and technologies); (3) securing access to land with strong renewables potential and proximity to transmission lines for the deployment of renewables (through better valuation, technological innovation, and strategic site selection, for example); (4) reforming transmission development to include proactive planning, fast-track permitting, and systematic consideration of transmission alternatives (for example, deploying distributed energy resources like rooftop solar panels, behind-the-meter storage, and demand-side management); (5) creating market mechanisms for expanding firm capacity to ensure a reliable and adequate clean energy supply; and (6) accelerating technological innovation to ensure timely deployment of new clean technologies.

Australia. With its significant renewables potential and large-scale reserves of critical materials, Australia could prosper in the energy transition. It could, for example, export green fuels and critical minerals to support the transition beyond its borders. As a fossil-intensive economy, Australia has a significant abatement opportunity and could focus on: (1) expanding firm capacity and transmission to accelerate coal retirements (for example, taking a sector-wide approach to managing the exit of coal capacity) and investing in green alternatives; (2) securing power supply by strengthening natural gas supply capacity; (3) building infrastructure and implementing incentives to spur investments aimed at decarbonizing industry; (4) mitigating economic and social impacts on local communities affected by the energy transition (for example by developing sector- and region-specific economic transition plans for workforces and communities).

The Middle East. The Middle East accounts for the largest share of global oil production today, but it has the potential to become an exporter of clean, sustainable energy such as hydrogen and green products. Key priority actions to do so include: (1) promoting investments to scale the supply of CCUS, low-carbon hydrogen and ammonia while stimulating demand domestically and internationally; (2) boosting renewables development and facilitating renewable integration by upgrading supporting infrastructure (for example, transmission grids and long-duration storage); (3) incentivizing electrification and energy efficiency in buildings, industry, and the transportation sector; and (4) promoting green businesses that are building new energy solutions in order to diversify the local economy and capture new economic opportunities from the transition.

Affluent, energy-exposed regions

Europe. Europe has invested significantly in decarbonization efforts. However, given its heavy reliance on fuel imports and recent energy-security disruption, it would need to further accelerate its adoption of renewables. A successful energy transition would require: (1) Creating resilient, at-scale supply chains for key decarbonization technologies (for example, by diversifying the supplier base or securing long-term partnerships); (2) Building out energy grid infrastructure to support resilience and reduce barriers to in-region renewables (for example, increasing the regasification capacity of liquefied natural gas); (3) Overcoming land-use, societal, and regulatory constraints to accelerate development of renewables (for example, by simplifying and streamlining permitting processes to shorten time lines); (4) Redesigning power markets in line with decarbonization and affordability objectives (which could include tapping into the market for PPAs and negotiating contracts directly with renewable energy sources); (5) Ensuring affordability of clean technologies to foster their adoption and accelerate the energy transition (for example, by subsidizing the adoption of clean technologies that are not yet cost competitive, such as EVs and heat pumps).

Japan. Although Japan relies largely on imported fossil fuels, it has a strong technological and innovation base for developing new green technologies. To accelerate its energy transition, Japan could prioritize: (1) developing solutions to overcome land constraints, such as offshore wind and rooftop solar, to maximize renewables penetration; (2) scaling infrastructure and the supply chain (including developing infrastructure to transport liquefied hydrogen) to enable hydrogen and ammonia imports that can help meet total energy demand; (3) establishing the value chain for CCUS, including developing equipment and facilities (for example, by finalizing the research and selection of carbon-storage sites); (4) enhancing transmission capacity and grid resilience through improved developer economics and power sharing by regions; and (5) enhancing the current carbon pricing and trading scheme (for example, considering standards and rules for heavy emitters to incent the power and industry sectors more effectively).

Large, emissions-intensive economies

China. Although China accounts for the largest share of global emissions, it also leads in the development of renewable capacity. To accelerate its transition, China could consider the following priorities: (1) limiting and mitigating coal emissions in the power and industry sectors and substituting coal with renewables; (2) enabling and scaling grid connectivity between demand centers and renewable capacity, which would involve streamlining permitting and cooperation across regions to promote the coordinated development of transmission systems; (3) promoting development of renewables and flexibility solutions while considering enhancements to market structures (for example, companies could be enabled to sign green-power deals quickly and efficiently through flexible PPAs); (4) scaling up hydrogen-based fuels and carbon capture, utilization, and storage, which would amount to a transition of the existing hydrogen production from gray to green; and (5) enabling greater carbon transparency and incentivizing the private sector to pursue more ambitious targets (for example, China may consider extending its emissions-trading system to nonpower sectors).

India. India's projected rapid demographic and economic growth will increase energy demand significantly, heightening the importance of an affordable, renewable energy supply. Key opportunities for India are: (1) expanding land availability and reducing acquisition barriers for renewable deployment (for example, the country could use geospatial technology to identify sites suitable for renewables development and prioritize wasteland and other readily available land); (2) streamlining the contracting process through state utility buy-in to facilitate state and corporate PPAs; (3) creating new financial mechanisms to de-risk projects and improving the financial and operational health of distribution companies, including through green bonds and sustainability funds; (4) accelerating the development of green manufacturing capacity and promoting access to raw materials and local supply-chain opportunities; and (5) reducing the carbon intensity of high-emissions power and industrial sites (for example, by setting up hydrogen targets in preidentified sectors and providing gap funding to encourage green hydrogen expansion).

Developing, naturally endowed economies

Latin America. This region holds significant potential to drive the energy transition given its high availability of natural resources, which can contribute to the energy transition globally. Latin American countries have a few opportunities to consider: (1) streamlining, accelerating, and increasing certainty of project permitting, and promoting simpler frameworks for public-private collaboration; (2) improving and stabilizing pricing schemes, market designs, and guarantees to de-risk energy transition investments and improve access to domestic and international capital; (3) introducing demand-side measures to promote the switch from fossil to electric and other energy-efficient alternatives in transportation; (4) developing regulated carbon tracking mechanisms and markets, and driving green incentives to decarbonize industry footprints; (5) promoting local manufacturing of parts and equipment, and exporting clean energy commodities and products; and (6) developing a qualified regional workforce to support the transition and create socioeconomic benefits.

Developing, at-risk economies

Africa. The African continent is hugely diverse, and while several countries are vulnerable to energy risks, the energy transition creates an opportunity to accelerate economic growth, expand access to energy and clean cooking, create jobs, and improve health and quality of life. African countries would benefit from: (1) ensuring attractive returns on green development projects to mobilize capital (for example, setting up electricity tariffs that reflect costs and implementing managerial reforms could improve the financial viability of utilities); (2) deploying green off-grid solutions at scale to provide universal access to energy (for example, by supporting commercial players to build regional isolated grid projects called "metrogrids" in Africa) to improve energy access and affordability; (3) establishing infrastructure, supporting environment, and regulations, to build green industries and realize export opportunities (for example, African nations could consider implementing environmental, social, and governance standards and creating special economic zones); and (4) expanding gas pipeline capacity and downstream infrastructure to shift to clean cooking and balance the grid.

Southeast Asia. A rapidly developing region with slow deployment of renewables and a strong reliance on coal, Southeast Asia faces many obstacles in the energy transition. To manage rapid development and a large emissions footprint, the region might prioritize several steps: (1) creating the conditions for bankable renewables projects and advancing national and regional plans to minimize new coal development, and improving efficiency of the existing coal fleet (for example, rethinking subsidies and regulatory frameworks to close the cost gap between coal and renewables); (2) electrifying and improving efficiency across sectors to temper growing demand (for example, private financing could be encouraged to invest in the energy-efficiency value chain); (3) adapting local economies to take full advantage of the transition, driving employment and socioeconomic growth across the region; and (4) developing standards and practices for emissions transparency to enable carbon tracking for multinational manufacturers in the region (which could include, for example, establishing region-wide carbon markets).

As we consider the actions listed here, it is important to recognize that the burdens of the transition will not be felt evenly. Developing countries face unique challenges related to transitioning their energy systems. Three stand out: difficulty accessing private capital markets; constraints on public spending (particularly if government tax revenues from emissions-intensive industries fall); and challenges related to bearing any impact of rising energy costs, given the limited safety nets and the imperative in these regions to expand energy access and enable development.

A more orderly transition will therefore need to be a just transition, one that recognizes the specific challenges that developing countries experience and that responds with collective, global, and unified action. This could take various forms, including the expansion of North-South financial transfers, measures to de-risk lending to developing countries (for instance, via a greater role for multilateral development banks), and broader capital-market access.

Key stakeholders can accelerate the action to promote a more orderly transition by 2030

Meeting the moment of global orderly energy transition will require decisive, coordinated action by all global stakeholders. It will also require global coordination to ensure an equitable and affordable transition, while not compromising the need for energy security. Recent events have set the world on the path to an even more disorderly transition than was expected in early 2022. Global stakeholders will need to consider several key priorities:

Governments and multilateral institutions have a central role to play in implementing policies and measures to encourage carbon standards and promote investment in renewables, with the objective of translating net-zero goals into an integrated energy plan that combines emissions reductions, resilience, affordability, and energy security and mitigates uneven impacts on communities at risk. Governments will need to work together with the private sector to promote measures that accelerate green technologies and mobilize key resources, such as the domestic labor force and supply chain.

Financial institutions are instrumental in rethinking investment horizons and risk-return profiles (for example, derisking lending to drive demand for net-zero technologies), disclosing and measuring their portfolio exposure in the near term and quickly deploying capital toward clean energy projects while supporting broader energy resilience. Financial institutions can further contribute “beyond money,” by lending their expertise and guidance to drive the success of green initiatives.

Companies would gain from focusing on developing net-zero strategies and action plans, prioritizing innovation in green business models and technologies, deploying energy efficiency solutions to limit demand, and securing a sustainable supply chain. For energy providers such as utilities and transmission and distribution companies, priorities will be defining a strategy for carbon intensive assets to manage stranded-asset risks without compromising energy security; derisking and securing the supply chain for raw materials, labor and components; prioritizing innovation in business models and technologies; and developing the manufacturing footprint for clean technologies. Companies in energy-intensive industries, such as mining, cement, and oil and gas extraction, could consider setting targets for energy decarbonization, linked to specific, time-bound initiatives such as power-purchase agreements and energy-efficiency programs, which would also improve their resilience to commodity market fluctuations; investing in energy supply and developments, usually with partners; creating an asset transition strategy to promote a transition of portfolio and operations toward a net-zero world; and developing a procurement and energy risk management strategy to mitigate energy security and volatility risks.

Individuals could participate in the climate change dialogue, make informed tradeoffs and behavioral changes that may be required, and demand increased transparency and accountability from their leaders to manage a transition that combines emissions reductions with energy security and affordability.


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1 The current state

The growth of renewable energy production has been strong in the past decade, and a growing number of governments and companies are committing to meet net-zero targets. At the same time, demand for energy continues to rise and fossil-fuel production has also risen to meet that demand. Fossil fuels still account for more than 80 percent of the world's primary energy.

Momentum toward renewables is growing but without a corresponding decrease in global emissions

The world's progress toward cleaner energy has been accelerating. Over the past decade, the global production of renewable energy such as wind, solar, and hydro has more than doubled, and its share of total primary energy consumption has increased from 9 percent in 2011 to 13 percent in 2021.[19] Installed wind and solar capacity has risen fourfold in the same period (Exhibit 1).[20] Recent public- and private-sector commitments, particularly after the 26th UN Climate Change Conference of the Parties (COP26) in Glasgow in 2021, suggest investment in renewables will continue. As of June 2022, economies that have set national net-zero targets in domestic legislation or public policy documents accounted for 65 percent of global greenhouse gas (GHG) emissions, up from 10 percent in December 2020.[21] In the private sector, more than 1,800 companies had put in place science-based targets, up from the just more than 1,000 companies that had done so at the end of 2021.[22]

At the same time, the need to meet growing energy demand continues to drive the expansion of fossil fuel use. Global energy demand grew by 14 percent in the decade from 2011 to 2021, driven in large part by growth in both population and economic activity. The demand was fueled mainly by emissions-intensive sources, which have in turn hindered progress on emissions reduction: of the incremental 74 exajoules (EJ) of growth in energy demand over the past decade, 61 percent was met by an increase in carbon-emitting fuels. As a result, while energy efficiency has improved, global energy-related emissions have nonetheless increased in the past decade by about 5 percent, or by 1.7 gigatons (Gt) of carbon dioxide (CO_2).[23]

The current share of primary energy from fossil fuels remains predominant and has dropped only slightly, to 82 percent from 85 percent. For example, coal production in India and China alone has grown by 600 million tons since 2011, as growing energy needs in the two countries have led to an increase in coal production of 10 percent in China and nearly 30 percent in India. Indonesia, meanwhile, has produced an additional 260 million tons of coal in the past decade.[24]

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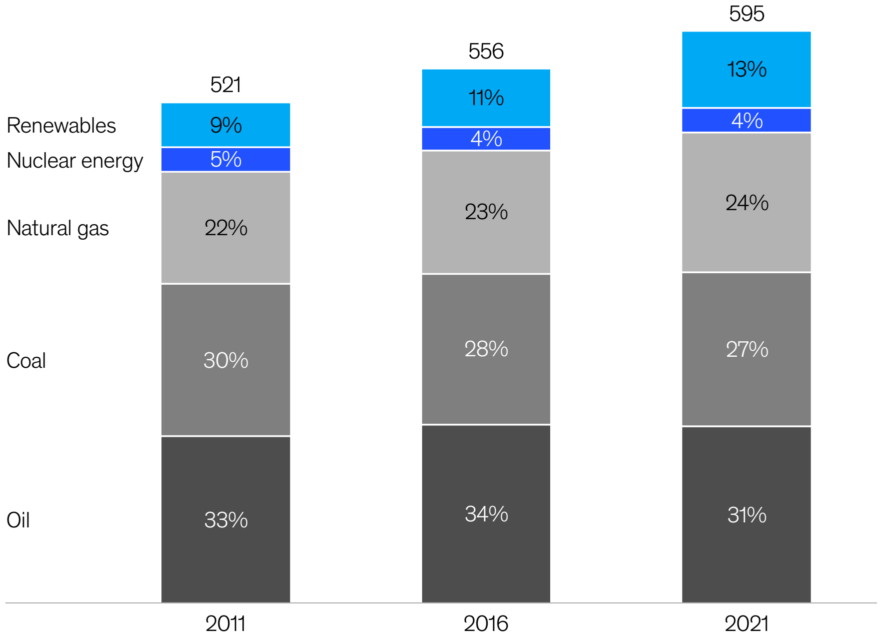
[19] *BP energy outlook,* 2022.
[20] *Renewable energy capacity,* 2022.
[21] "Net Zero Tracker," Energy and Climate Intelligence Unit, Data-Driven EnviroLab, NewClimate Institute, Oxford Net Zero, 2022.
[22] *Science Based Targets initiative (SBTi),* data as of September 2022.
[23] *Global Energy Review 2021,* IEA.
[24] *BP energy outlook*, 2022.

Exhibit 1

The share of renewables in primary energy consumption has risen, but fossil fuels still predominate.

Primary energy consumption, exajoules



Installed capacity, gigawatts

	2011	2016	2021
Total renewable[1]	**1,330**	**2,010**	**3,064**
Solar and wind	**294 (22%)**	**767 (38%)**	**1,674 (55%)**

Note: Figures may not sum to 100%, because of rounding.
[1]Includes wind, solar, hydropower, marine, bioenergy, and geothermal energy.
Source: BP Global Energy Outlook, 2022; International Renewable Energy Agency (IRENA) Renewable Capacity Statistics, 2022

The current renewables development rate may not suffice to meet global warming-reduction targets

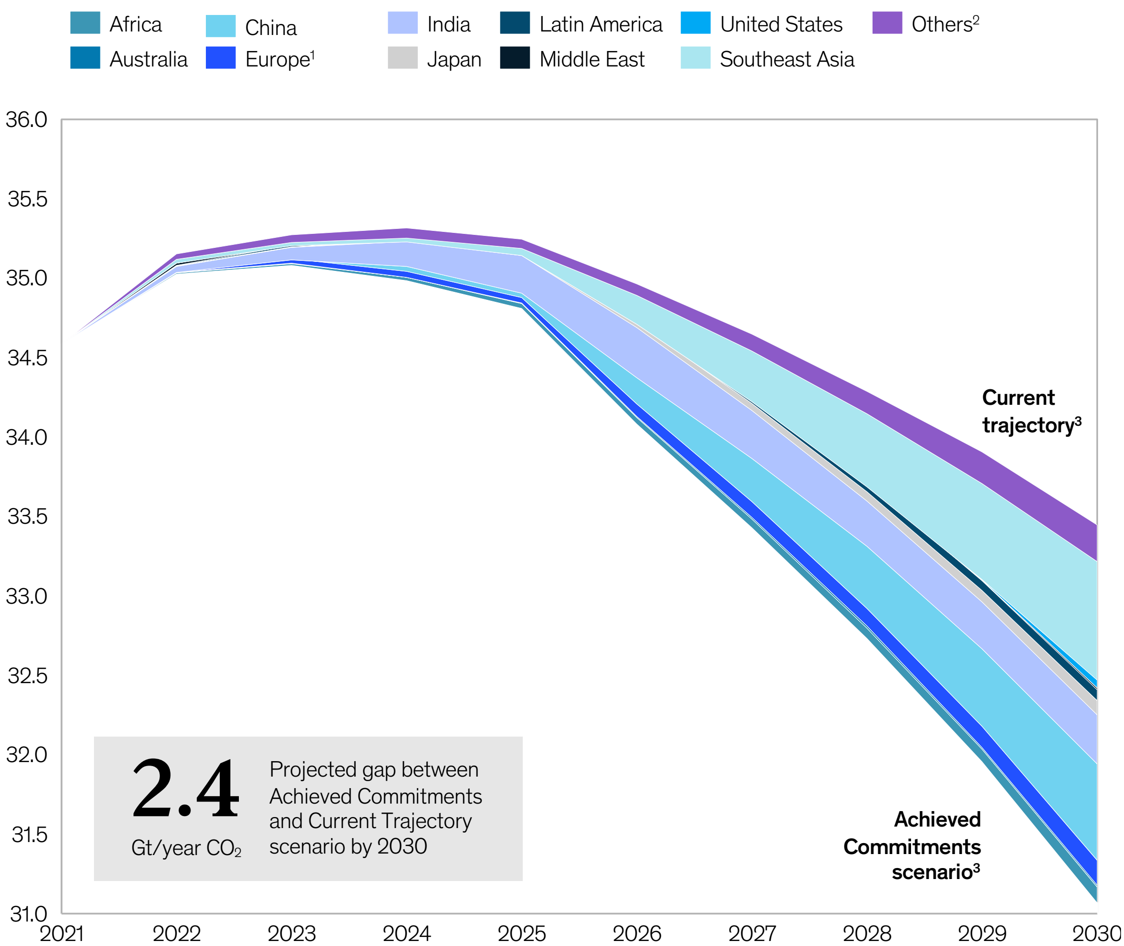
As a result, a major gap remains between renewables on one hand and fossil fuel production and consumption on the other—and the need for bold, decisive, and carefully considered climate action is stronger than ever. Despite the planned growth in renewables, the world is not on track to meet net-zero requirements. According to McKinsey's Global Energy Perspective 2022, the current rate of renewable development would not be sufficient to maintain global warming within the worldwide targets set by the Paris Agreement adopted at COP21 in 2015 (see Box 1, "Scenarios exploring technological progress and policy enforcement").[25]

[25] *Global Energy Perspective,* April 26, 2022; the report was developed as a collaboration between McKinsey Sustainability and McKinsey's Global Energy and Materials and Advanced Industries practices.

Exhibit 2

The world needs to 'bend the curve' to achieve net-zero emissions.

Net energy-related annual emissions by scenario,
Metric gigatons (Gt) of CO_2 equivalent per year, 2022–30



[1]Includes members of the EU27 only; other European countries have been included in Other.
[2]Includes Commonwealth of Independent States (CIS) and other countries in Europe and Asia.
[3]The Current Trajectory would imply a 2.4°C rise in global temperatures by 2100, while an Achieved Commitments scenario would lead to a rise in global temperatures of 1.7°C by 2100 (see Exhibit 3 for more details on our scenarios).
Source: McKinsey Global Energy Perspective 2022

According to the sixth assessment report of the United Nations' Intergovernmental Panel on Climate Change (IPCC), extrapolation of current policies would lead to median global warming of 2.4°C to 3.5°C by 2100. Limiting global warming to 1.5°C by 2100 would be beyond reach, absent scenarios in which immediate action is taken.[26] Indeed, past McKinsey analysis indicates that the world would need to "bend the curve" for energy emissions to, by 2030, bridge a yearly gap of 2.4 Gt carbon dioxide equivalent (CO_2e) (7 percent of 2021 energy-related emissions) that exists between our "current trajectory" scenario and our "achieved commitments" scenario (Exhibit 2).

[26] *Climate Change 2022: Impacts, Adaptation and Vulnerability,* the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC), February 2022.

Box 1

Scenarios exploring technological progress and policy enforcement

In our Global Energy Perspective 2022, we explore different scenarios for the pace of technological progress and the level of policy enforcement, including the "current trajectory" scenario and the "achieved commitments" scenario, both referred to in this report. Exhibit 3 describes all five scenarios.

In the "current trajectory" scenario, the global median rise in temperature by 2100 is forecast to be about 2.4°C,[1] and the cost of renewables continues to decline. However, policies that are active in this scenario are insufficient to close the gap to the net-zero goal.

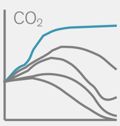
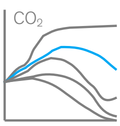
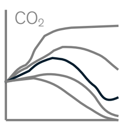
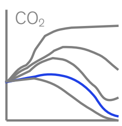
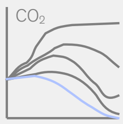
In the "achieved commitments" scenario, the global median rise in temperature by 2100 is expected to be about 1.7°C, because of more aggressive policies, including a higher carbon price. Leading countries would achieve their net-zero commitments through purposeful policies, while other countries would make the transition at a slower pace.

[1] Warming estimates are an indication of global rise in temperature by 2100 versus pre-industrial levels (median - 17th/83rd percentile), based on IPCC assessments, given the respective emission levels and assuming continuation of trends after 2050 but no net-negative emissions.

Exhibit 3

The speed of the energy transition will differ based on which scenario is realized.

Scenarios focus on the pace of technological progress and level of policy enforcement

	Slower		Modeled from the bottom up as part of GEP 2022		Faster
Speed of energy transition					
Scenario description	**Fading Momentum**	**Current Trajectory**	**Further Acceleration**	**Achieved Commitments**	**1.5° Pathway**
	Fading momentum in cost reductions, climate policies, and public sentiment will lead to prolonged dominance of fossil fuels	Current trajectory of declining cost of renewables continues, though active policies currently remain insufficient to close gap to ambition	Further acceleration of transition driven by country-specific commitments, though financial and technological restraints remain	Net-zero commitments achieved by leading countries through purposeful policies; followers transition at slower pace	A 1.5° pathway is adopted globally, driving rapid decarbonization investment and behavioral shifts
Required CO_2 price[1] €/metric ton CO_2, 2030–50	**<€50**	**€55–130**	**€75–140**	**€100–180**	**>€200+**
Median global temperature increase linked to expected emission levels[2]	**>2.4°C**	**2.4°C** (1.9–2.9°C)	**1.9°C** (1.6–2.4°C)	**1.7°C** (1.4–2.1°C)	**<1.5°C**

[1]Global average CO_2 prices required in 2030 and 2050 to trigger decarbonization investments sufficient to fulfill the scenario. Prices are weighted by country and sector emissions and are holistic in that they include both explicit costs (eg, carbon tax or emission trading system) and implicit costs (eg, subsidies or feed-in tariffs) to incentivize abatement.
[2]Warming estimate is an indication of the global rise in temperature by 2100 versus preindustrial levels (median, 17th and 83rd percentile) based on Intergovernmental Panel on Climate Change (IPCC) assessments given the respective emission levels and assuming a continuation of trends after 2050 but no net-negative emissions.
Source: McKinsey Energy Insights; McKinsey Global Energy Perspective 2022

Amid these conflicting trends, the socioeconomic context has become at once more precarious and more receptive to the energy transition. Today's macroeconomic conditions are further highlighting the importance of a functioning energy system. The disruption in global supply chains has increased concerns about energy security, inflated the costs of energy-project construction, and sharply increased the cost of energy globally. The same challenges have spurred renewed awareness and actions toward a more orderly energy transition, particularly in Europe.

Nonetheless, the potential to reach net-zero GHG emissions and a feasible pathway do exist. As shown in Exhibit 4, there are significant naturally endowed areas across the globe where solar and wind potential could be exploited for a transition to a renewable system.

What will be needed to bridge the gap?

To bridge this gap, significant changes will be needed to a variety of factors, which are explored more in depth throughout this report. For example, development of renewable energy will require significant acceleration. We estimate that the average yearly installed capacity will need to nearly triple in both wind and solar energy, from 181 gigawatts (GW) of average yearly installed capacity between 2016 and 2021 to 524 GW over the next decade, to meet an "achieved commitments" scenario (a 1.7°C average global temperature rise by 2100). For example, that will require the Middle East, Africa, and India to increase solar and wind deployment by a factor of eight (Exhibit 5).

Ultimately, a successful transition would require significant rebalancing. It would require new investments, including in grids that connect remote locations to demand and storage centers. Such centers would allow consumers to use energy from renewables and excess generated energy to be stored or released in storage solutions that would balance and stabilize the system. Some countries would become exporters and others would become importers of raw materials as well as energy. The transition would affect traditional jobs and create new ones where new skills are required.

To avoid extreme impacts on economies and societies, such as growth impairment, public resentment, and political challenges, the transition would need to be balanced and avoid becoming disorderly. In a more orderly transition, access to energy would be secure, resilient, and affordable and would consider the current macroeconomic conditions, such as high inflationary pressure, supply-chain bottlenecks, and growing economic disparities.

A major gap remains between renewables on one hand and fossil fuel production and consumption on the other—and the need for bold, decisive, and carefully considered climate action is stronger than ever.

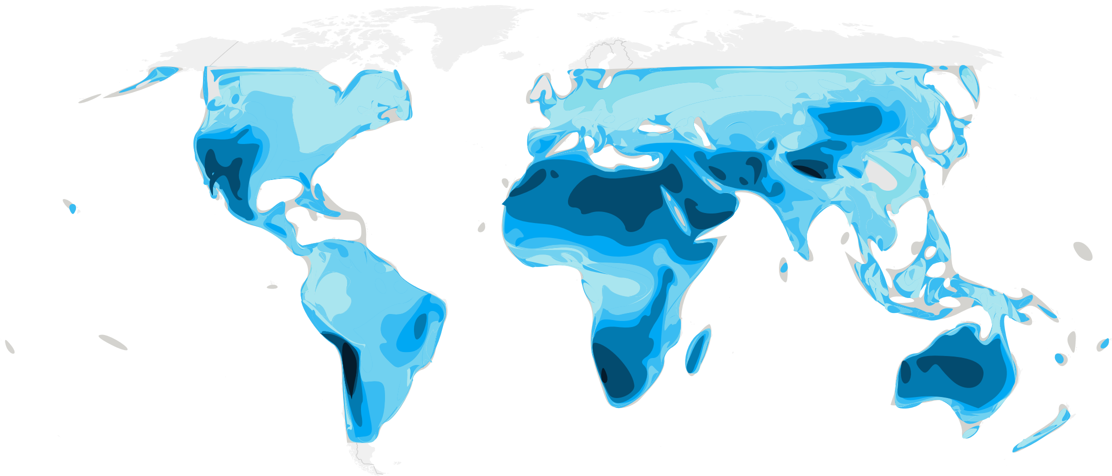
Exhibit 4

There are various areas around the world where solar and wind potential could accelerate a transition to a renewable-energy system.

Photovoltaic power potential, kWh/kWp

Long-term average photovoltaic power potential (PVOUT[1])

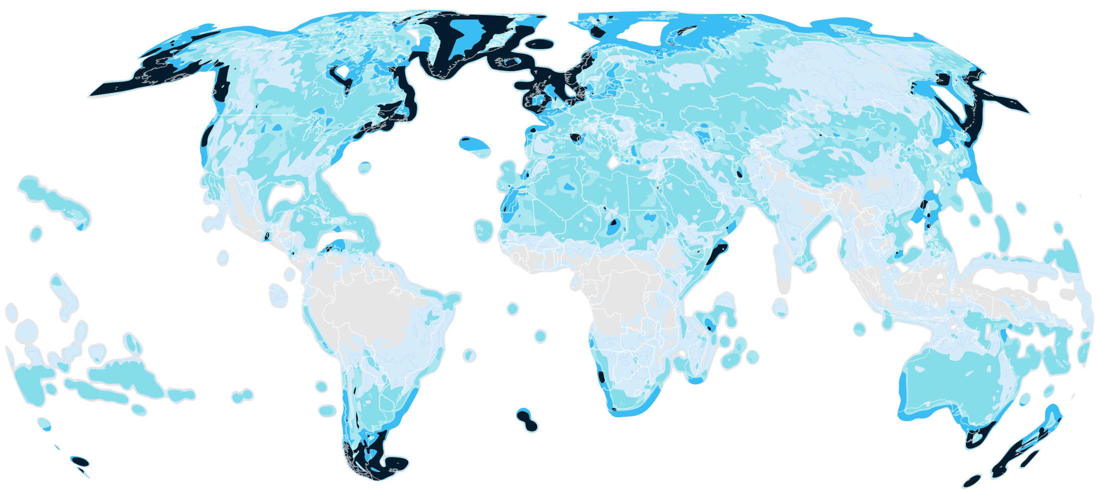
Daily totals: ≤2.4 | 2.8 | 3.2 | 3.6 | 4.0 | 4.4 | 4.8 | 5.2 | 5.6 | ≥6.0 kWh/kWp[2]



Wind power density potential, watts per square meter

Wind power density at 100 meters, watts per square meter (W/m²)

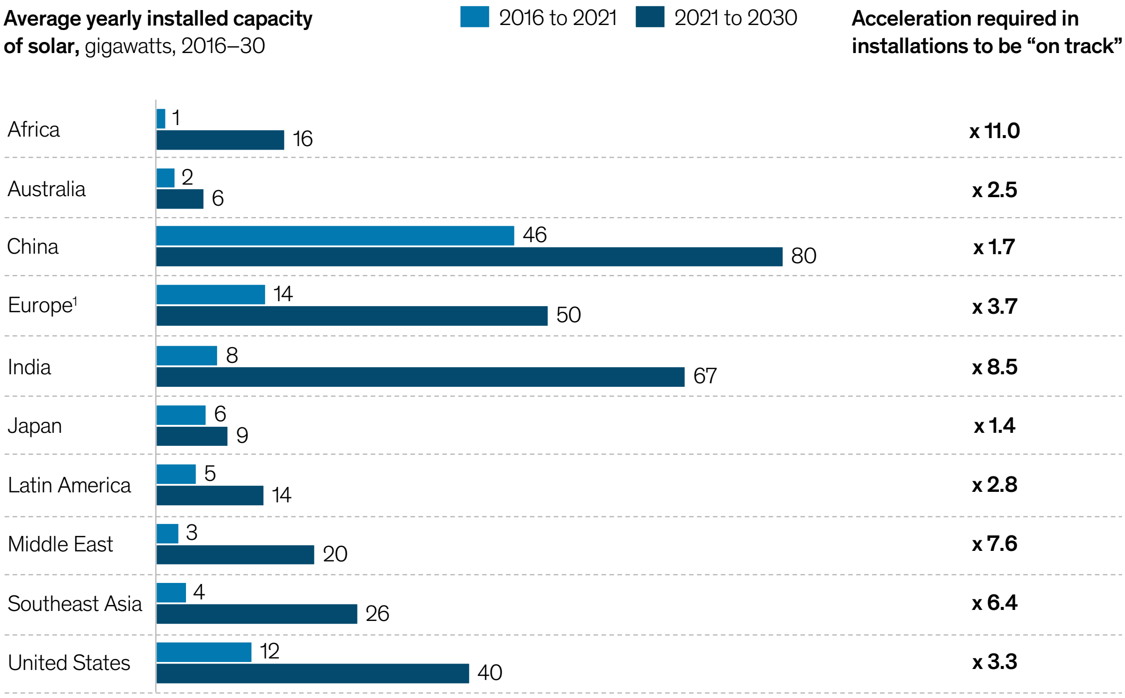
≤100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | ≥1,000

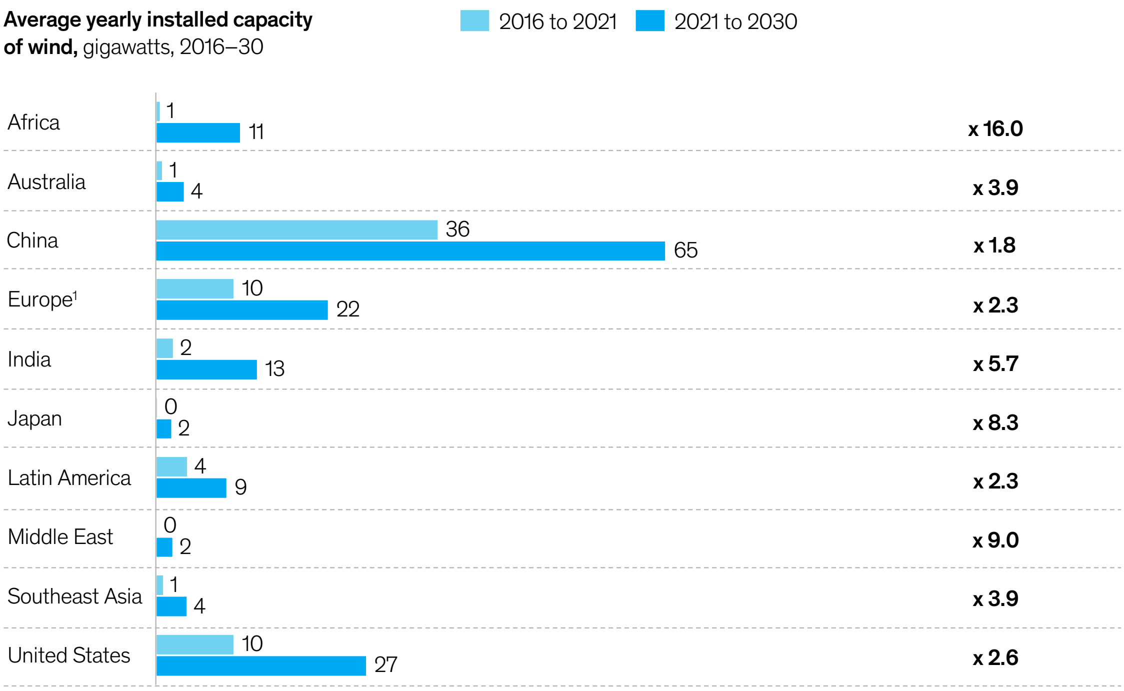


Note: The boundaries shown on maps do not imply official endorsement or acceptance by McKinsey & Company.
[1]Photovoltaic power output.
[2]Kilowatt-hours/kilowatt peak.
Source: The Global Solar Atlas; The Global Wind Atlas

Exhibit 5

The acceleration in renewable-energy installations required to achieve commitments varies among regions.





[1]Includes members of the EU27 only.

Source: McKinsey Global Energy Perspective 2022 (Achieved Commitment scenario); International Renewable Energy Agency (IRENA) Renewable Capacity Statistics, 2022

2 Countries fall into five main archetypes with respect to their opportunities and priorities for a more orderly energy transition

The opportunities, challenges, and risks associated with a more orderly energy transition are not distributed evenly throughout the world. Some countries can count on greater financial or natural resources than others, and not all economies are equally equipped to address the challenge of transforming their energy mix. It is therefore useful to identify the primary archetypes, or groupings, into which countries fall in the context of the energy transition and the corresponding opportunities and challenges.

Three dimensions will likely shape each country's ability to achieve a more orderly transition

Geography will affect how the energy transition plays out from country to country and from region to region. While our perspectives can be synthesized in several ways, organizing insights into geographical clusters helps us assess unique energy opportunities based on the intrinsic characteristics of countries (such as natural endowment) and overall geopolitical profiles. We identify three main dimensions that we believe will influence each country's ability to achieve a more orderly transition: long-term risk and potential, relating to the presence of or lack of favorable natural resources; short-term risk and potential, driven by the economic reliance on energy imports and emissions-intensive industries; and disposable financial resources and the ability to mobilize capital to support the energy transition.

Long-term risk and potential, relating to the presence of (or lack of) favorable natural resources
Some countries have limited natural domestic potential for developing clean energy, such as abundant sunshine or wind, suitable land for new projects, or abundant reserves of minerals critical to the energy transition, such as copper and nickel. Naturally endowed countries are those with significant potential for solar and wind development as well as opportunities to establish a role in new-materials trading and the related manufacturing supply chains.

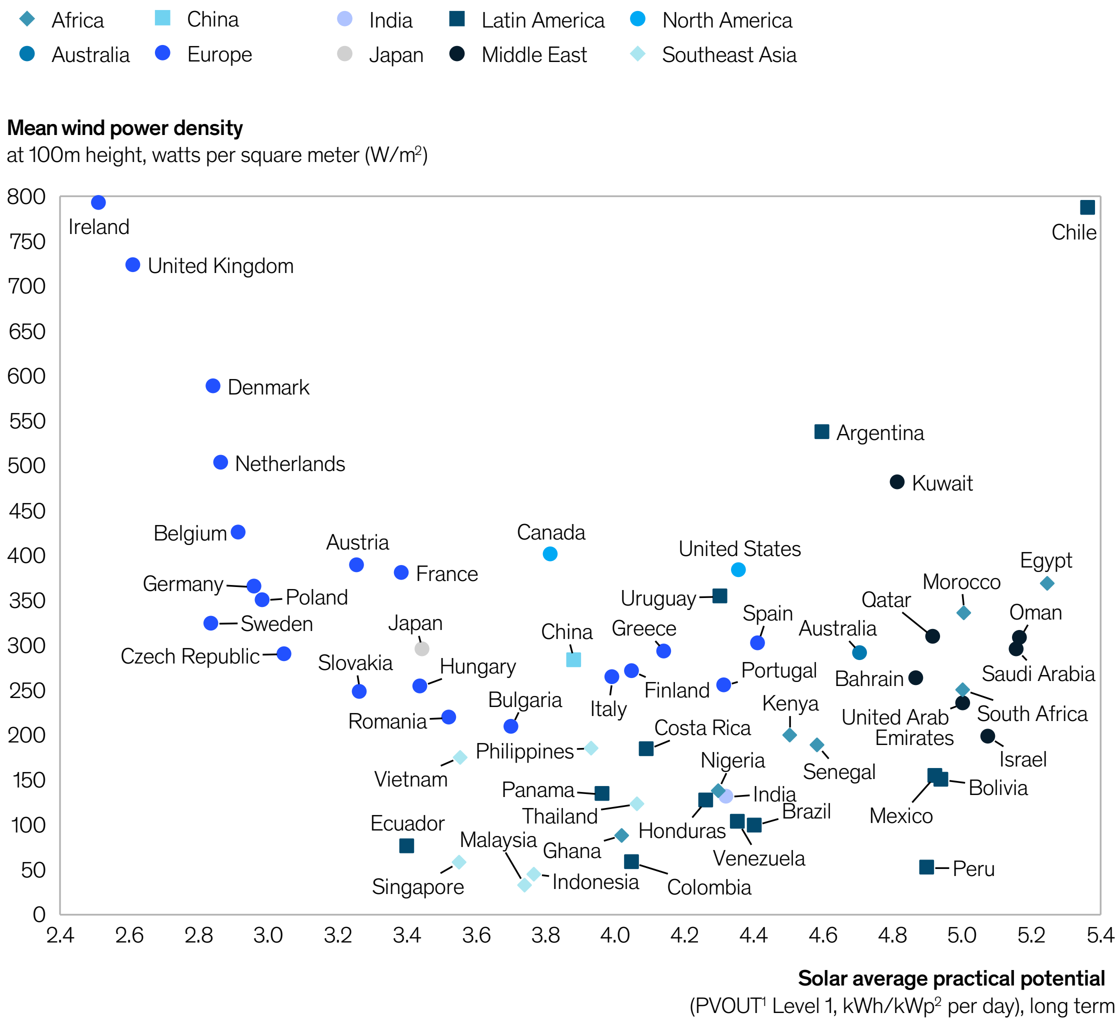
In our analysis, long-term opportunity comes primarily from a combination of potential for renewable generation and the availability of materials that are critical to the transition.

Potential for renewables generation. Wind and solar power potential vary across the globe. For example, Africa, Australia, and the Middle East have significant solar-generation opportunities, while North and South America and northern Europe have strong wind-power density (Exhibit 6). The shift toward renewables will, in all likelihood, favor naturally endowed countries, provided that the countries will be able to build on their potential—by, for example, developing attractive remuneration frameworks or power purchase agreements (PPAs), setting tariffs, and streamlining permitting and grid interconnection processes.

Exhibit 6

Countries have significant differences in the potential for renewable power.

Renewable-power potential by country



[1]Photovoltaic power output.
[2]Kilowatt-hours/kilowatt peak.
Source: Global Solar Atlas; Global Wind Atlas

Availability of raw materials. The energy transition is expected to lead to a significant increase in the "material intensity" of energy resources. For example, a solar plant is about four times as material-intensive as a gas-fired plant producing the same amount of energy.[27] Materials critical for the transition include cobalt, nickel, and lithium, which are used in batteries and electric vehicles; copper, used in the grid and transformers; and rare-earth elements, which are critical for wind-turbine generators. Reserves of these materials are typically concentrated in a handful of countries around the world (Exhibit 7).[28]

These producing countries are typically not the final users for critical materials (Exhibit 8). For instance, the Democratic Republic of the Congo produces 75 percent of today's cobalt, while 78 percent of the demand comes from China. Indonesia produces almost 30 percent of nickel today but is not among its top ten users. We also estimate how some of these markets are or will be short on supplies. For example, the current demand for copper and nickel is larger than the actual production, and this is expected to hold true also for the 2030 scenario. Tight markets will put further pressure on final-destination countries to secure key materials, even as they strengthen the role of producing countries in commodity trading.

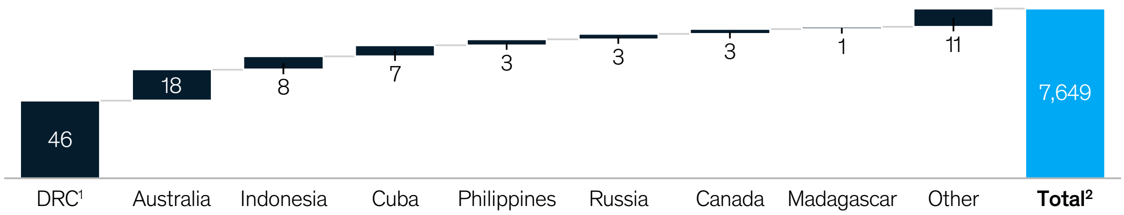
The opportunities, challenges, and risks associated with a more orderly energy transition are not distributed evenly throughout the world. Some countries can count on greater financial or natural resources than others, and not all economies are equally equipped to address the challenge of transforming their energy mix.

[27] Information is in tons of copper equivalent per terawatt hour. See Marcelo Azevedo, Magdalena Baczynska, Patricia Bingoto, Greg Callaway, Ken Hoffman, and Oliver Ramsbotto, "The raw materials challenge: How the metals and mining sector will be at the core of enabling the energy transition," McKinsey, January 10, 2022.
[28] *Mineral commodity summaries 2022,* US Geological Survey (USGS), 2022.

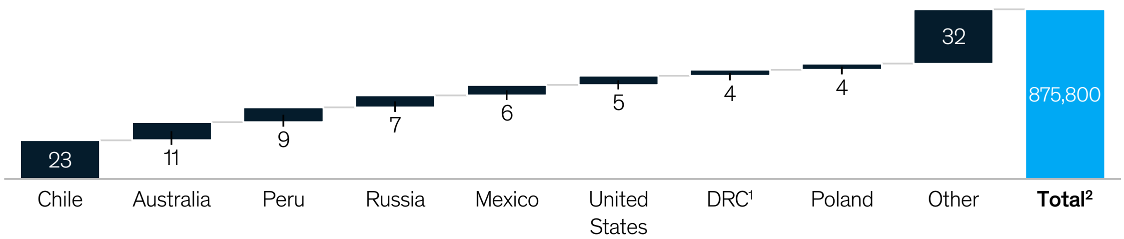
Exhibit 7

Reserves of key commodities for the energy transition are highly concentrated in a few countries.

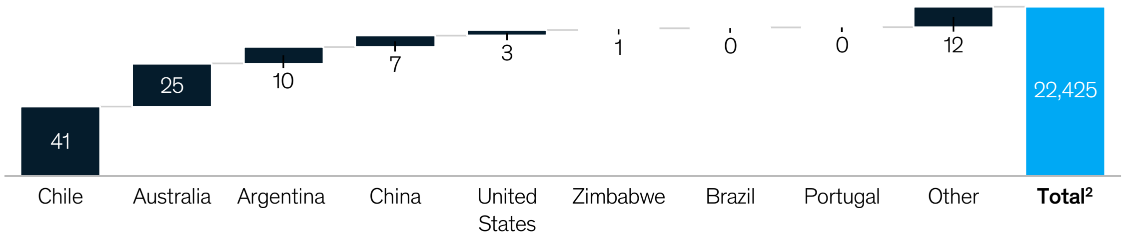
Cobalt (Co) reserves, % of Co contained



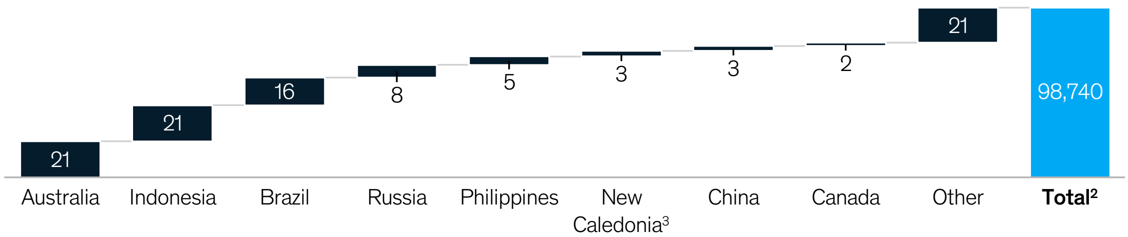
Copper (Cu) reserves, % of Cu contained



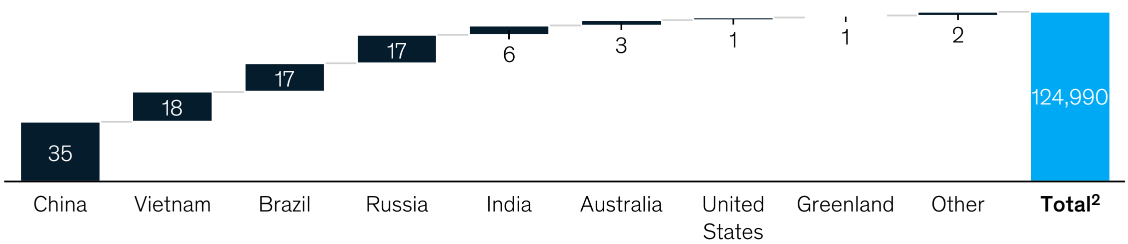
Lithium (Li) reserves, % of Li contained



Nickel (Ni) reserves, % of Ni contained



Rare earth elements (REE) reserves, % of REO[4] equivalent



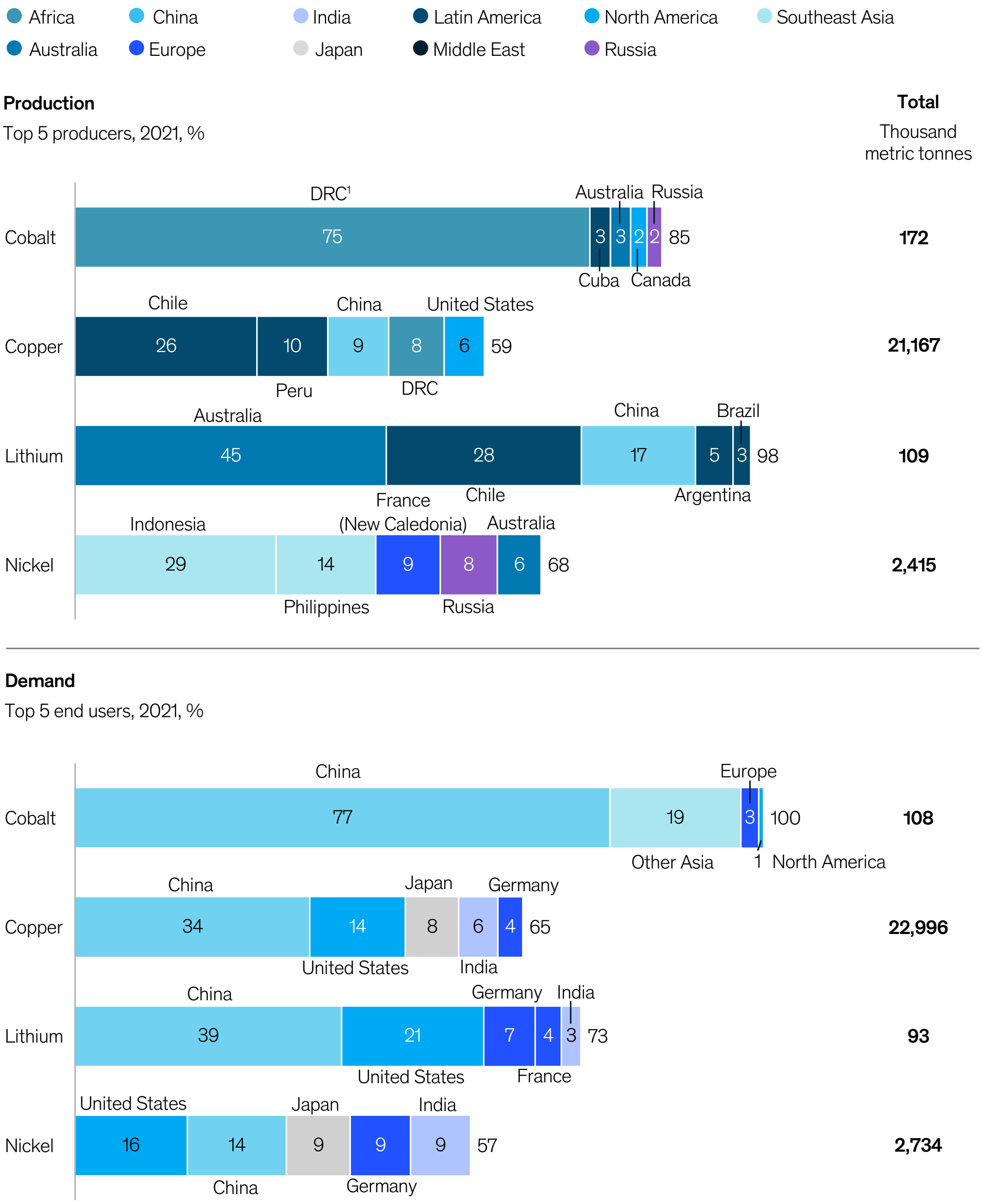
Note: Figures may not sum to 100%, because of rounding.

[1]Democratic Republic of the Congo.
[2]Total expressed in thousand metric tonnes.
[3]New Caledonia (France).
[4]Rare earth oxide.

Source: *Mineral commodity summaries,* US Geological Survey (USGS), 2022

Exhibit 8

Countries that produce critical materials for the energy transition are, for the most part, not the final users.



Note: Figures may not sum, because of rounding.
[1]Democratic Republic of the Congo.
Source: McKinsey MineSpans

Short-term risk and potential, driven by the economic reliance on energy imports and emissions-intensive industries

In our analysis, short-term risk is driven primarily by a combination of energy security and carbon intensity. Energy security—that is, the relationship between internal energy production and consumption—expresses the exposure of countries to current market instabilities such as commodity-price volatility and the state of global markets for fossil fuel. The greater this dependence, the more pressing the need is for domestic fossil-to-renewable substitution to limit exposure to imports. Carbon intensity is a proxy for the level of complexity in today's decarbonization efforts: the higher the intensity, the more likely a country is to have a fossil-fuel-oriented energy mix and a low deployment of energy-efficiency measures.

Some countries rely on energy imports, frequently of fossil fuels, for energy security. These include several European countries, such as Germany, which are exposed due to high dependence on imported fuels. Countries like India and China, which are the world's largest population centers, have high energy needs and carbon-intensive energy consumption profiles.

The interplay of energy security and carbon intensity could play out differently for different countries.

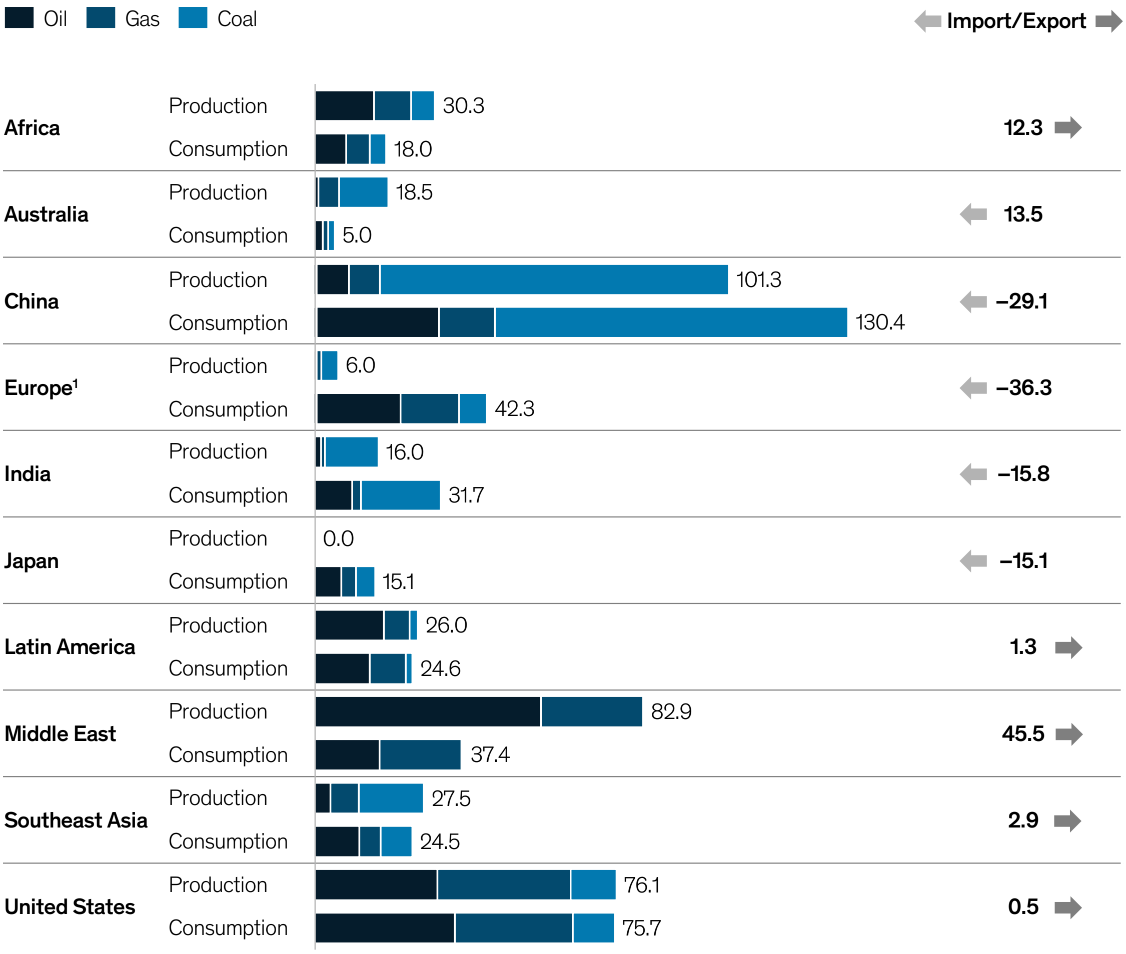
For heavy importers of fossil fuel, including Europe and Japan, the deployment of renewables is not only a matter of decarbonization but also of energy security. The use of renewable sources could protect against global commodity market swings and uncertainties in fossil fuel supplies. Renewables could therefore help to narrow the gap between imports and exports. However, the energy gap to be filled is significant and would require multiples of today's renewable generation to fully bridge the import-export gap—with the multiple being as high as 33 in Japan and 27 in India (Exhibit 9). A massive increase in deployment would thus be needed if renewables are to propel import-dependent regions toward energy security.

As noted, the share of fossil fuels in primary energy consumption averages 82 percent across regions, rising to as much as 99 percent in the Middle East and 90 percent in Africa, India, and Southeast Asia (Exhibit 10). The higher the dependence, the higher the bar for decarbonization—and the more complicated it will be to push for renewables substitution and reduce the fossil fuel footprint.

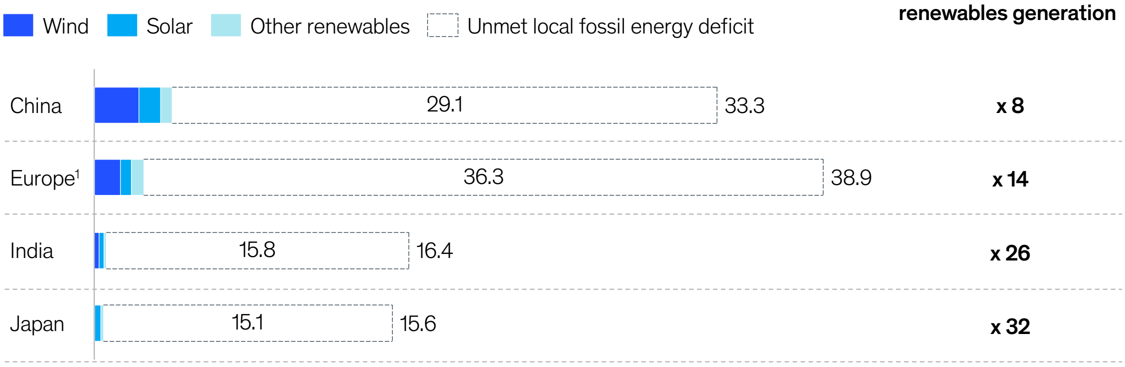
Exhibit 9

A massive increase in deployment of renewable energies will be needed to fill gaps between energy production and consumption.

Production vs consumption for key commodities, exajoules per year, 2021



Renewables generation by source today vs fossil fuel deficit, exajoules per year, 2021

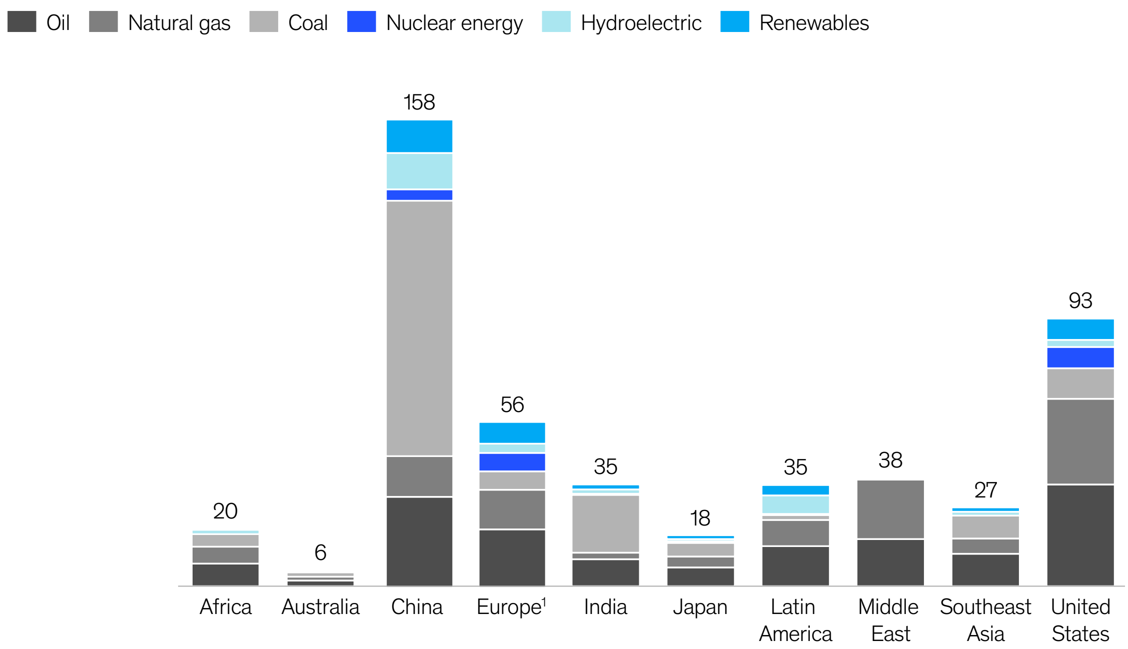


Note: For regions that are dependent on fossil imports, such as China, Europe, India, and Japan, the development of renewables can provide increased energy resiliency, but significant acceleration is required to fill the fossil dependency gap.
[1]Includes members of the EU27 only.
Source: *BP statistical review of world energy 2022,* BP, 2022

Exhibit 10

The energy mix of regions differs substantially, although fossil fuels remain the prevalent source of primary energy.

Primary energy consumption by fuel, exajoules, 2021



	Africa	Australia	China	Europe[1]	India	Japan	Latin America	Middle East	Southeast Asia	United States
Fossil fuel share, %	**90**	**87**	**83**	**70**	**90**	**85**	**70**	**99**	**90**	**81**
Emissions per GDP, tCO_2e/$[2]	**0.36**	**0.24**	**0.59**	**0.16**	**0.80**	**0.21**	**0.27**	**0.85**	**0.51**	**0.20**

[1]Includes members of the EU27 only.
[2]Metric tons of carbon dioxide equivalent per dollar.

Source: *BP statistical review of world energy 2022,* BP, 2022; McKinsey Energy Insights; McKinsey Global Energy Perspective 2022; McKinsey analysis

Disposable financial resources and the ability to leverage capital to support the energy transition

The availability of capital to finance the transition will affect the extent to which countries could mobilize capital toward cleaner energy sources. The net-zero transition would require an additional $1 trillion to $3.5 trillion in average annual capital investment globally through 2050, according to our estimates.[29] Renewable energy and grid improvements require up-front capital and pay off over various time horizons in the form of reduced operating expenses and fuel costs.

The transition will also require investments to address stranded costs in fossil fuel assets, conduct at-scale R&D, retrain the workforce, and fund early-stage infrastructure deployment. Many countries find themselves under budget constraints these days, but more affluent ones have more resources and face fewer trade-offs than poorer ones. We use GDP per capita as an indicator of access to financial resources. To make these investments effectively, countries would need to address stranded costs, find ways to prevent or mitigate the premature obsolescence of technologies, rethink fossil subsidies, and potentially create new incentives for clean tech. For all countries, whether affluent or not, the path will be demanding.

[29] Estimates based on the Net Zero 2050 scenario from the Network for Greening the Financial System (NGFS). Our research is not a projection or prediction and does not claim to be exhaustive. See *The net-zero transition: What it could cost, what it could bring,* McKinsey, January 2022.

Five country archetypes highlight different opportunities and priorities for a more orderly transition

The examination of these three dimensions leads us to define five main archetypes of countries that face similar challenges and have analogous opportunities in the net-zero transition (Exhibits 11 and 12). While each country is different, we believe these archetypes naturally lend themselves to a similar set of actions and priorities for the energy transition. Each of these archetypes will have a different set of actions to take to accelerate the transition toward a pathway that leads to net zero. We touch on these potential actions only briefly and at a high level here, as we describe them in detail in the individual country and region sections in Chapter 4 of this report. The five archetypes follow.

1. Affluent, energy-secure countries

The countries that fall into the affluent, energy-secure archetype have 8 percent of the global population and account for 22 percent of global emissions. These countries, which include Australia, Saudi Arabia, and the United States, have abundant domestic production of energy and high GDP per capita. Typically, we find here countries that are net fossil fuel exporters, including Australia, Qatar, and the United States, and can use domestic production to cover demand against market volatility. Some countries that fall into this archetype are net importers but have high levels of domestic security through nuclear power (France and Belgium, for example) or fossil fuels (the Netherlands and the United Kingdom, for example). This archetype's countries are affluent, with substantial purchasing power and investment resources. They are likely to remain energy exporters as the energy transition unfolds but will need to reconsider their energy sources to meet emission targets.

These countries likely will focus during the transition on accelerating the deployment of clean resources. Key priority measures could be to scale proven clean solutions for such renewables and storage by ensuring that their transmission capacity and market structures are adequate. Countries with this archetype could also promote a strong local supply chain—as the United States is doing to re-shore domestic silicon-wafer production for solar photovoltaics (PVs), for example—and work to develop and retrain their workforce. Other potential actions include creating a new supply chain and bankable returns for new energy innovations—for example, for hydrogen in Australia and CCUS in the Middle East—to tackle hard-to-abate sectors and promoting opportunities to diversify their economies away from fossil fuels. The latter is especially pertinent in the Middle East, where one-quarter to one-half of GDP is linked to fossil fuel sectors like oil exploration.

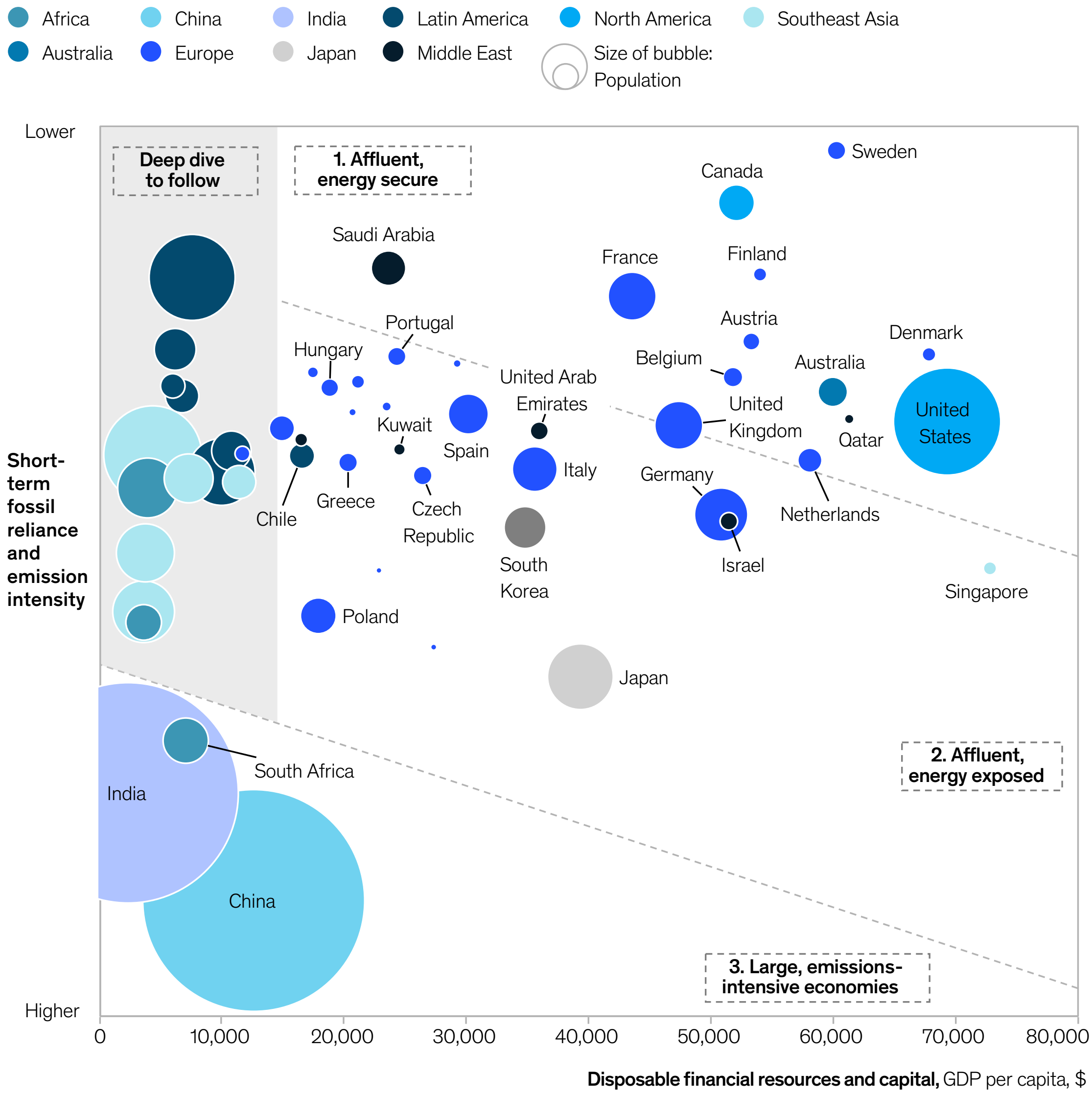
2. Affluent, energy-exposed countries

Germany, Italy, and Japan are among the countries that fall into the affluent, energy-exposed archetype, which account for 7 percent of the global population and 13 percent of emissions. These countries are also affluent, as measured by GDP per capita, but will be increasingly exposed to energy security concerns as the transition unfolds. Several European countries, especially the ones more exposed to fossil imports—for example, Germany and Italy—as well as Japan, are included in this archetype because of their high volume of energy imports and the risk that implies for their energy security. Some Middle Eastern countries, including Oman and Kuwait, belong to this archetype because of the risks they face from carbon intensity. For these countries, the transition could represent an opportunity to pivot toward domestic clean-energy production. For the more manufacturing-intensive countries, the transition could also represent an opportunity to incorporate more green manufacturing practices.

Exhibit 11

Countries can be divided into five main archetypes based on key energy transition characteristics.

Short-term risk: Relative energy security; CO_2 intensity



Source: McKinsey analysis

The near-term focus for these countries will likely be on energy security. Key actions could include deploying green technologies at an accelerated rate and streamlining land availability; ensuring grid efficiency; rethinking the demand side, where energy efficiency will be hugely important for net importers' reduction of demand needs; and promoting mitigation of the industrial footprint with greater electrification and a shift toward green commodities. Finally, these countries may look to improve carbon markets and standards to boost the competitiveness of low-carbon solutions.

3. Large, emissions-intensive economies

This archetype includes three large countries: China, India, and South Africa. They are home to 37 percent of the global population and account for 40 percent of global emissions. These countries have a relatively low GDP per capita and significant exposure to short-term risks. Typically, these are the result of a combination of large fossil fuel imports and carbon-intensive economies. These countries typically have a significant coal or other fossil fuel presence in power generation and industry, and they have all started taking action in the realm of clean energy. As they transition to a low-emissions economy, they will need to balance meeting growing energy demand with cleaner resources while addressing their reliance on the most emissions-intensive fuels—historically, relatively low-cost, domestically produced coal.

Near-term solutions for these countries will likely focus on reducing the carbon intensity of fossil fuels while ensuring the sufficient and continued presence of resources to propel local growth. Key actions could include rapidly scaling up renewables to outpace the need for new fossil plants; deploying an energy grid at the same pace in order to link high-potential renewable areas with demand centers; and innovating in new technologies to reduce the footprint of their current fossil fuel base while ensuring the required baseload.

The other two archetypes are in the mid-to-low range for GDP per capita and mid-to-low short-term risk area (see Exhibit 12).

4. Developing, naturally endowed economies

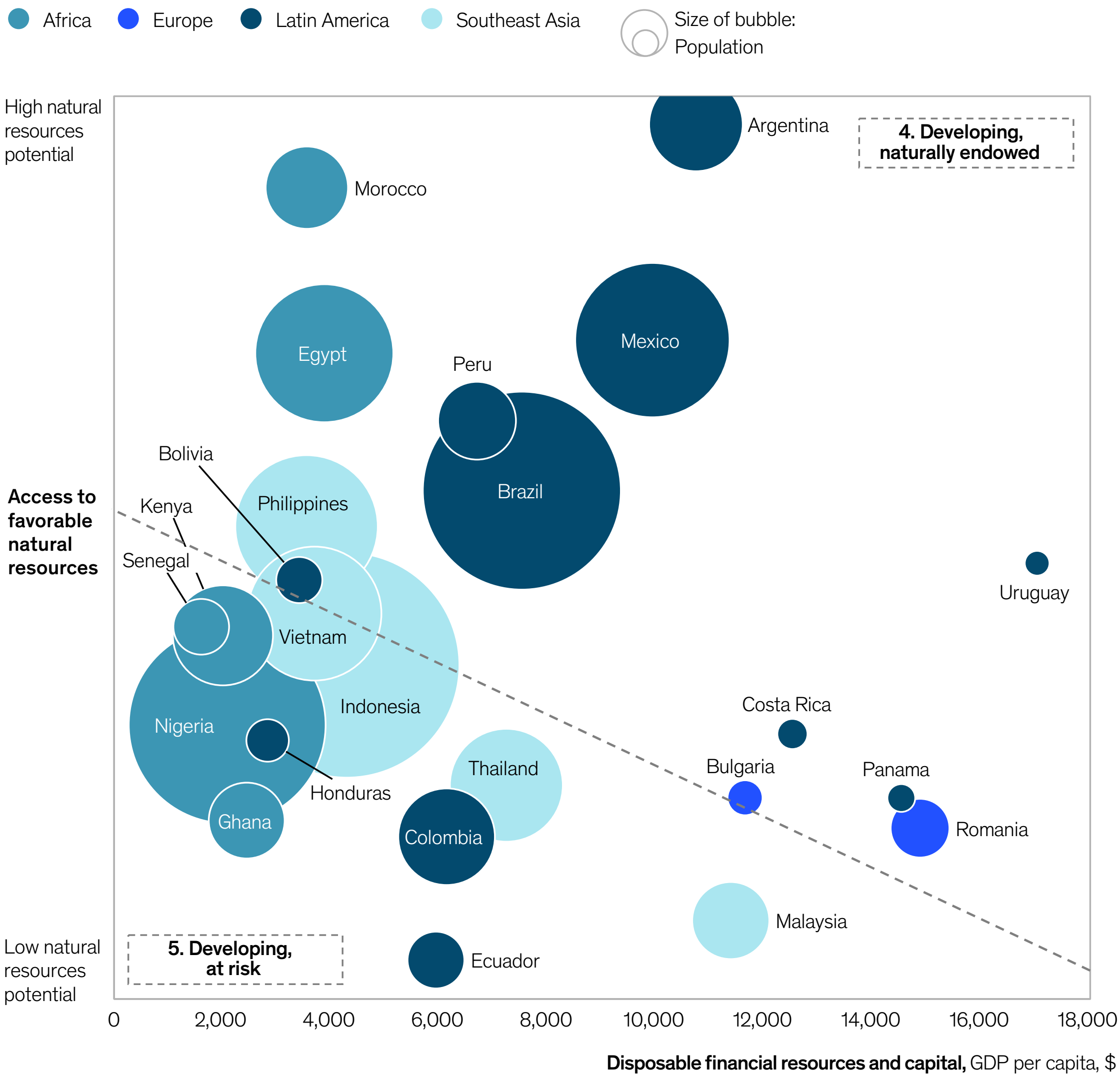
Brazil, Mexico, and Indonesia are among the countries with developing, naturally endowed economies. This archetype accounts for 9 percent of the global population and 5 percent of global emissions. The countries it covers have significant potential power from solar or wind sources as well as critical natural resources, such as rare metals, to support the energy transition. These attributes put these countries in a position to treat the energy transition as a strategic advantage: they could use their domestic resources to promote opportunities for economic and social growth. Their natural focus would be setting up a framework to develop their resources and move to a sustainable mode of production.

The near-term focus for these countries will likely be strengthening their basis for deployment of renewable energy. That could include developing solid frameworks and standards to attract local and international investments—for example, PPA risk-sharing mechanisms and sustained and attractive feed-in tariffs—as well as promoting the full exploitation of their local solar and wind potential. Some countries would be able to leverage their rich material endowments to promote local economic growth. Congo, for example, has about half of the global cobalt reserves, and Indonesia has about a quarter of the nickel reserves.

Exhibit 12

Countries can be divided into five main archetypes based on key energy transition characteristics.

Long-term opportunity: Relative potential from wind and solar; presence of critical materials



Source: McKinsey analysis

5. Developing, at-risk economies

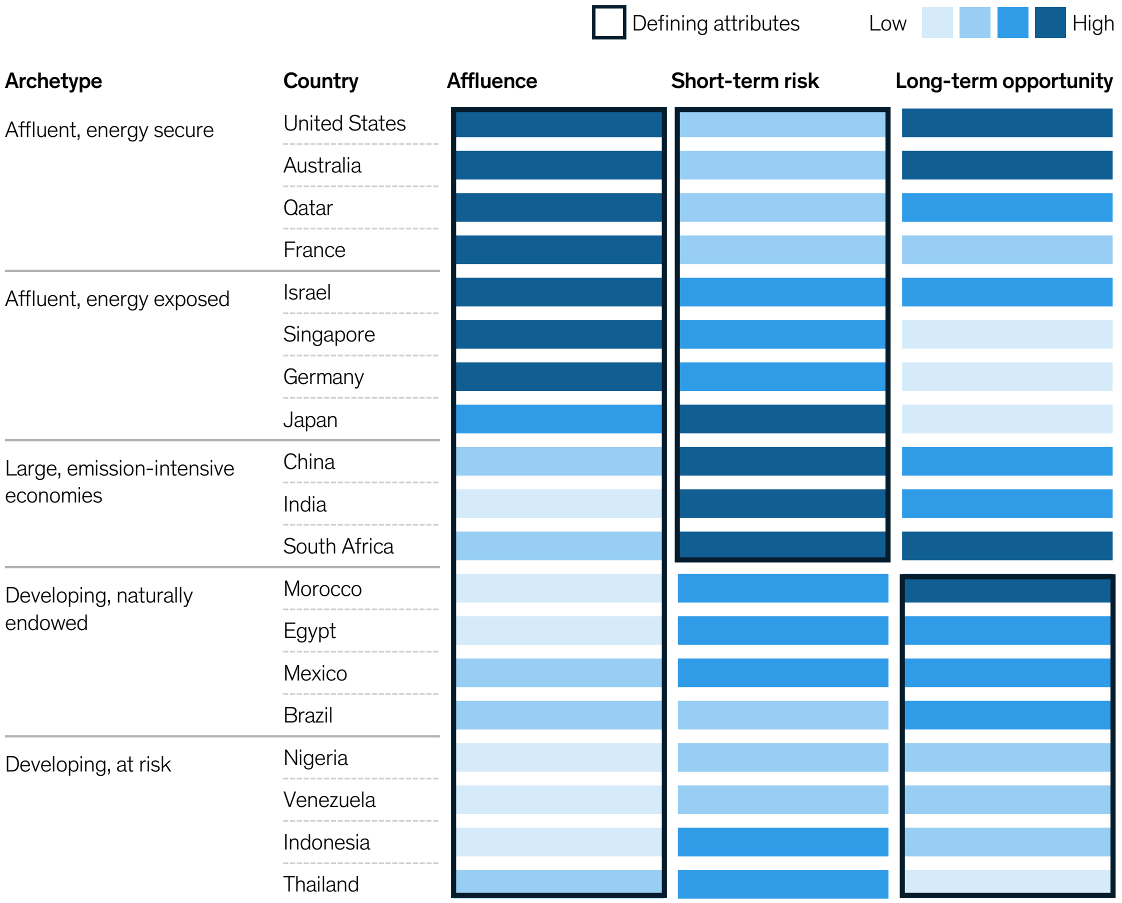
Developing, at-risk economies represent 11 percent of the global population and generate 5 percent of global emissions. These countries, mainly in Africa, Latin America, and Southeast Asia, have mostly agricultural economies. They are disproportionately exposed to climate risk and have limited potential for renewables development. Their transition would need to be coupled with the build-out of basic infrastructure services and investment in climate adaptation—likely to be possible only with foreign support. Significant effort from local leaders and global support would be needed to (1) minimize the impacts on society that could stem from the energy transition and (2) investigate ways in which the countries in this archetype could benefit from a future with cleaner energy.

The near-term focus of these countries would likely be on finding opportunities to compensate for the limited availability of both an existing infrastructure and abundant natural endowments that support clean resource development. Key near-term actions include fostering global cooperation to enhance electrification and access to basic resources. Innovating or importing clean and resilient technologies such as mini- and micro-grids would help address these countries' natural constraints and needs for resilience.

Exhibit 13 also shows a few country examples in each archetype and displays their differences in an alternative way.

Exhibit 13

Countries can be ranked by three dimensions of the energy transition: affluence, short-term risk, and long-term opportunity.



Source: McKinsey analysis

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3 Globally, eight sets of common actions are needed for a more orderly energy transition

Despite differences across regions, a number of common global actions appear to apply across all archetypes and countries.

In a previous article, we introduced the nine requirements for a more orderly transition.[30] We grouped these requirements into three categories: physical building blocks, economic and societal adjustments, and governance, institutions, and commitments. Building on that analysis, here we identify eight sets of actions that are universally necessary in the near term to enable a more orderly transition—and group them into the same three categories. The extent to which these actions are relevant to a given country, or the specifics of their implementation, will of course vary.

While these actions address the entirety of the global energy system, most of them focus on energy production rather than energy consumption. Indeed, while promoting the adoption of green technology on the demand side will be important, we believe that many of the actions required to reduce energy production's footprint in the near term would need to address the scalability of assets and infrastructure.

These actions, in many cases, are well known. We believe that it is possible—and critical—to make meaningful progress on all of them within the 86 months that remain in this decade.

[30] "Solving the net-zero equation: Nine requirements for a more orderly transition," McKinsey, October 27, 2021.

Physical building blocks

Four of the eight sets of actions we identify fit into the category of physical building blocks.

1. Streamlining access to land, accelerating permitting, and simplifying processes to accelerate time-to-deployment for renewables and cleantech[31]

The large-scale deployment of renewables will require the dedication of large land areas to solar and wind installations. For instance, our estimates[32] indicate that if the goals set by the US government—that is, a 50 to 52 percent reduction from 2005 levels in net GHG emissions by 2030—are to be met, about 75 percent of all land with strong renewable potential and proximity[33] to transmission lines would need to be developed for either solar or onshore wind power generation. In India, land access represents a significant issue, as the country is densely populated and uses approximately 60 percent of its land for agriculture alone.[34] Indeed, the country would need 65,000 to 95,000 square kilometers of land by 2050 to help meet its officially declared 2050 emissions target.[35] This could put renewable energy growth into competition with other priority uses of land, such as for urban development and agriculture.

Inefficient processes and unclear regulations and incentives are also hampering the development of new clean-energy projects. For example, US solar and wind project stalled in the second quarter of 2022 because of uncertainties about equipment prices and tax incentives, although the country's more recent Inflation Reduction Act (IRA) has been boosting renewable projects again.[36] In Germany, too, onshore wind expansion has slowed in recent years because of planning and permitting bottlenecks.[37]

Streamlining of permitting and limiting the number of required project-approving entities can accelerate project execution. Access to land can be simplified by advancing projects that benefit local communities and developing land efficiency solutions such as offshore wind. The use of alternative lands—for example, agrivoltaic land that is used for both agriculture and solar energy—and wastelands, along with out-of-the-box solutions, including floating solar PVs, can help expand the suitable area for renewables installation while minimizing disruption to other land uses.

2. Modernizing and repurposing legacy infrastructure and creating new assets to accelerate the integration of renewables and cleantech into the energy system

Policy makers and the private sector have focused on improving the economics of novel clean technologies. However, their deployment can be limited by legacy systems such as an aging and rigid electric grid or a fuel transportation infrastructure that has been designed for hydrocarbons but not hydrogen. This legacy infrastructure has been designed for the needs of the past 100 years. New investment, operating norms, and processes are now needed to integrate clean-energy resources into these systems. This includes repurposing gas pipelines for hydrogen and reforming processes and procedures surrounding the interconnection of renewable energy resources in the electricity grid.

[31] *Cleantech* refers to clean climate and energy-related technology solutions, including advanced building technologies, biopower, grid analytics, next-generation vehicles, solar PVs (photovoltaics), unconventional natural gas, wind, advanced biofuels and bio-based chemicals, carbon capture and storage, grid-scale storage, and intelligent transport.
[32] "Six action areas for a more orderly US energy transition," McKinsey, forthcoming.
[33] The large-scale deployment of renewables will require large land areas to be dedicated to solar and wind installations. For instance, our estimates indicate that if the 2030 goals set by the US government are to be met, about 75 percent of all land with strong renewable potential and proximity to transmission lines would need to be developed for either solar or onshore wind power generation.
[34] *World Development Indicators, Agricultural land* (percentage of land area), World Bank, 2020.
[35] Institute for Energy Economics and Financial Analysis, September 5, 2021.
[36] Shel Evergreen, "US solar and wind projects stalled in Q2. What happened?" *Canary Media,* August 1, 2022.
[37] See, for example, "New German government to speed up wind energy expansion," WindEurope, December 10, 2021.

For instance, in the United States, 1 terawatt (TW) of renewable energy capacity (of which 700 GW is solar PV) is estimated to be active at interconnection queues.[38] Connection times to the power grid are more than three years.[39]

Investing in developing and modernizing the power grid will be crucial to ensure that areas with high potential for renewables generation are integrated and connected with demand centers. Development of new flexibility solutions, such as batteries and demand response, and integrating them with more conventional assets, will be key to ensuring a balanced energy system. For gas, assets could be repurposed to serve new low-carbon molecules such as hydrogen.

3. Strengthening global supply chains to secure critical raw materials, components, and labor competencies

Our research indicates that the energy transition will lead to an increase in the material intensity of energy production. That means it will be critical to extract materials such as nickel, lithium, and copper and to ensure the supply-chain capacity is sufficient for them. The transition will also considerably expand the need for skilled technicians, construction workers, and engineers—but many countries have yet to develop this skilled labor force.

One example is a global shortage of cobalt, which is strongly affecting the electric vehicle (EV) industry, which could need more than 280,000 tons of cobalt per year by 2025. That is double the 2020 mine production of 140,000 tons.[40] This has prompted many battery makers to pursue research in nickel- and cobalt-free chemistries.[41] The price of battery-grade lithium carbonate has nearly doubled in 2022.[42]

Demand for these critical materials is expected to increase significantly by 2030. In fact, according to McKinsey analysis, demand for lithium would grow to 576,000 tons, six times more than current demand; for cobalt and nickel, it would nearly double.[43] The talent shortage is also critical. In the European Union, the shortage of workers affects speed of deployment of renewables, and the number of people working in wind and solar energy would need to double in the next eight years, according to trade associations SolarPower Europe and WindEurope.[44]

Governments and the private sector would need to collaborate to enhance available capacity and create supply chains that accommodate the sharp increases in demand. Countries (or broader regions such as Europe) would benefit from developing a national or regional resource strategy to match their needs with the natural resources available; this could involve building a local manufacturing industry. Countries would also need to better assess import needs and export opportunities. Investing in R&D to promote substitution and promoting recycling and reuse could help limit demand for critical resources. The selective adoption of reshoring would promote the development of local supply chains and competence building. Setting up long-term agreements and partnerships with suppliers could help hedge against variations in critical supply.

[38] Joseph Rand, Ryan Wiser, Will Gorman, et al., "Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection," Lawrence Berkeley National Laboratory, April 2022 (as of end of 2021).
[39] "FERC Proposes Interconnection Reforms to Address Queue Backlogs," Federal Energy Regulatory Commission (FERC), June 16, 2022.
[40] See Peter Keusgen, "How would a cobalt shortage impact these three Aussie mining shares?" IG Bank Market Insight, August 10, 2022.
[41] "National Blueprint for Lithium Batteries 2021–2030," The Federal Consortium for Advanced Batteries (FCAB), June 2021.
[42] Lithium carbonate price, Trading Economics, last accessed October 10, 2022.
[43] MineSpans.
[44] "Insight Weekly: Loan growth picks up; US-China PE deals fall: France faces winter energy crunch," S&P Market Intelligence, September 6, 2022.

4. Decarbonizing the industry and transportation sectors by investing in new technologies, electrification, and energy efficiency
Industry and transportation are the end-use sectors that account for most energy-related CO_2 emissions, through their consumption of fuels for combustion. Industry is also among the sectors that face the most challenges to becoming less emissions-intensive, particularly in hard-to-abate industries such as steel and cement.

For example, China, which accounts for nearly half of CO_2 emissions from industry, is facing obstacles in its path to net-carbon neutrality in the industrial sector because of its heavy reliance on coal. In the transportation sector, North America is the largest contributor of CO_2 emissions. It is looking into multiple avenues to increase the uptake of EVs; 45 US states and the District of Columbia provide incentives to promote ownership of EVs, including tax credits and other benefits.[45]

On the industry side, incentivizing investments in hydrogen and carbon capture, utilization, and storage (CCUS) solutions could help promote the growth of a green-product industry in hard-to-abate sectors, while investing in electrification and energy efficiency could help the decarbonization of light industry.[46] On the transportation side, incentives for uptake of light-duty transportation and technological acceleration toward cost parity between fuel-cell electric vehicles and conventional internal-combustion-engine vehicles for heavy-duty transportation could help address the sector's carbon footprint.

Economic and societal adjustments

Two of the sets of potential actions are in the category of economic and societal adjustments.

5. Limiting and mitigating emissions-intensive generation, to reduce the carbon footprint of fossil fuels and lower the risks for stranded assets
The world is expected to expand its energy consumption by about 8 percent (50 EJ) by 2030, according to our analysis. New growth in demand would need to be met by cleaner resources to avoid the expansion of high-impact fossil-fuel-based combustion, such as that from coal, oil, and wood. However, while oil subsidies have recently decreased, oil remains the most subsidized fuel, according to the International Energy Agency (IEA).[47]

Measures may be required to limit the additions of new fossil fuel assets, so as to avoid the further expansion of all but the most essential fossil plants. This would have to be balanced with shorter-term needs for energy availability and the ongoing need to have a reasonable level of capacity redundancy in the system. More longer-term planning and orientation in investment decisions would also be needed to minimize the risk that new developments could be quickly abandoned. Additionally, rethinking fossil subsidies and progressively eliminating them could also be considered. Fossil production would progressively shift toward balancing intermittent renewables, while storage systems are brought to scale. Mechanisms to value flexibility and capacity of fossil assets could be introduced, while at the same time driving their lower utilization. To the extent that fossil production is necessary, basins with the lowest carbon intensity could be prioritized.

[45] Austin Igleheart, "State Policies Promoting Hybrid and Electric Vehicles," National Conference of State Legislatures (NCSL), April 26, 2022.
[46] Based on the IEA definition, *light industry* describes a range of sectors with lower absolute energy use than steel, cement, and other heavy industry. Light industry includes, among other industries, consumer goods, food, and construction. See *Light industry: More efforts needed,* IEA Tracking Report, September 2022.
[47] Fossil Fuel Subsidies Database: Energy subsidies: Tracking the impact of fossil fuel subsidies, International Energy Agency (IEA), June 2021 (data as of 2020).

6. Managing economic dislocations to promote energy affordability and create fair opportunities for affected and at-risk communities

More expensive energy and economic dislocation could severely affect at-risk communities and further increase the divide between socioeconomic groups. The energy transition could increase the risk of economic dislocation of vulnerable communities, particularly those relying on fossil fuels. At the same time, low-income communities may lack the capital required to transition their energy use. For example, they may not have the up-front capital to buy relatively expensive EVs or retrofit their homes to reduce emissions from heating and cooking. The transition may also lead to particular challenges for people in some regions in which industrial activities and profit pools are rebalanced; regions that are more dependent on fossil fuels will need to accelerate the diversification of their GDP and industrial footprint.

Governments and institutions might need to explore ways to alleviate burdens and maximize opportunities to turn the energy transition into an economic opportunity. The introduction of compensation mechanisms, including subsidies, would likely be required to ensure energy affordability for most vulnerable consumers. There would also be a need for investment in reskilling and creating economic development opportunities in these areas through local project development and clean manufacturing. Safety nets would be needed for workers in at-risk industries such as fossil mining, while retraining programs could be developed to create a new generation with the skills needed for the energy transition. Countries reliant on fossil fuels will need a broader diversification of their economies. For example, many Middle Eastern countries are diversifying their economies by moving toward clean resource production such as clean hydrogen.[48]

Governance, institutions, and commitments

The final two sets of possible actions are in the category of governance, institutions, and commitments.

7. Developing stable and attractive remuneration frameworks, market designs and offtake structures to encourage investments in renewables and cleantech

Market structures, long-term planning approaches, and industry value chains have been designed for a world of fossil fuels. As a result, countries are experiencing multiple challenges when it comes to offtake structures.

For example, without investments in a reliable and secure power supply, Australia could face reliability and resource adequacy issues as renewable power scales up.[49] Price spikes in Germany have recorded up to €1,050 per megawatt hour (MWh) in intraday power markets.[50] On the market side, the ability of large energy users to enter into bilateral PPAs has proved effective for accelerating renewable development, particularly in the United States and Europe. For example, approximately a quarter of Europe's new renewable energy installations in 2020 signed a PPA.[51]

A more orderly transition would require faster implementation of new market mechanisms that are aligned with the policy direction. For example, new capacity markets for energy storage would be needed, as would compensation mechanisms for low-utilization fuel-based sources that are critical for system reliability. Such market designs would need to keep pace with policies and ownership models.

[48] "Economic Diversification in Oil-Exporting Arab Countries," International Monetary Fund, April 2016.
[49] Clyde Russell, "Australia's timing problem with moving from coal to renewables," Reuters, September 1, 2022.
[50] Lars Paulsson, "Europe's benchmark power price breaks 1,000 Euros for first time," Bloomberg News, August 29, 2022.
[51] "European power purchase agreement (PPA) energy market grows in Europe despite COVID-19," IHS Markit.

Predictable and de-risked mechanisms and flexible frameworks for offtake, such as virtual PPAs, could be applied on a global scale to renewables and to a broader universe of technologies. For instance, introducing credit guarantees and insurance could help reduce capital risks and increase the appeal to investors. Establishing and scaling capacity markets could be a measure to reward flexibility and help attract investments in storage solutions like batteries and hydrogen.

8. Scaling frameworks and standards to measure carbon intensity of energy and final products and develop a global, new carbon economy

Countless opportunities beckon, particularly in developing countries, to achieve significant emissions reductions. These could include retrofitting and upgrading carbon intensive energy resources (those derived from traditional resources such as coal, oil, and natural gas), which might include abating methane leaks along the value chain, achieving energy efficiency in high-emissions sectors, and transitioning to lower-intensity fuels.

For now, however, there are no universal, clear, standardized ways to track emissions intensity and quantify the impact of new clean-energy solutions. Appropriate frameworks to inform a new "carbon economy" are also limited.

A few countries have started implementing carbon markets. For example, China's introduction of an energy trading scheme for power emissions will create the largest carbon market in the world, three times the size of Europe's energy trading scheme in terms of covered CO_2 emissions.[52]

Developing the right carbon standards, incentives, and markets will be important to accelerating the transition. It would require a commitment by the public and private sectors to embrace, develop, and enforce rigorous carbon-intensity frameworks globally and make investment and growth decisions based on them. And it would need to be combined with the development of a new carbon economy that includes carbon monitoring, voluntary carbon markets, and carbon capture and removal. Further, the right carbon pricing and incentives could be key to the viability of business cases for low-carbon technologies. Carbon transparency could ultimately lead to the pricing of carbon contents and the creation of low-carbon, or "green," premiums.

Policy makers could support these services by aligning on standards and helping secure access to stable financing. The establishment of energy-trading schemes could accelerate accountability and catalyze action. From different company investment decisions to new consumer habits, changes in mentalities and ways of working will likely be required to embed carbon consciousness in day-by-day operations.

[52] "China's Emissions Trading Scheme," IEA, June 2020.

Investing in developing and modernizing the power grid will be crucial to ensure that areas with high potential for renewables generation are integrated and connected with demand centers.

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4 Region-specific actions needed to address local characteristics and socioeconomic differences

The global actions discussed in Chapter 3 play out differently across regions and countries. To enable the global energy transition to be orderly, they will need to be combined with region-specific actions that take into account local characteristics and socioeconomic variations.

To ensure a global perspective, we have analyzed 10 major regions of the globe: the United States, Australia, the Middle East, Europe, Japan, China, India, Africa, Latin America, and Southeast Asia. Together, these regions account for nearly 90 percent of the world's total GHG emissions. In this chapter, we discuss each in turn, looking first at their starting point and their so-called nationally determined contributions—essentially, commitments to reduce emissions that governments made at the COP26 conference in 2021. We then discuss in detail potential actions countries could consider taking in the near term to accelerate their energy transition.

As we consider these actions, it is important to recognize that the burdens of the transition would not be felt evenly. Developing countries face unique challenges in transitioning their energy systems. Three challenges in particular stand out. First, the difficulty of accessing private capital markets. Second, constraints on public spending, particularly if government tax revenues from emissions-intensive industries were to fall. And third, challenges from the impact of rising energy costs, given limited safety nets and the imperative in these regions to expand energy access and enable development.

A more orderly transition will therefore also need to be a just transition, one that recognizes the specific challenges of developing countries and to which collective, global, and unified action finds responses. This action could take various forms, including an expansion of North-South financial transfers, measures to de-risk lending to developing countries—for instance, via a greater role for multilateral development banks—and a broadening of capital market access.

Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

The United States

The United States exhibits the main characteristics of the archetype for “affluent, energy-secure” regions. As the world’s largest economy and with abundant renewable energy resources, the United States has the opportunity to build a secure and reliable energy system on the foundation of renewable energy. However, the current trajectory is not at the pace and scale the global pathway requires to limit warming to 1.5°C. There are six high-priority measures that could be taken to help the United States embark on a more orderly energy transition:

- Designing and deploying a capital-efficient and affordable energy system
- Strengthening supply chains to provide stable access to raw materials, components, and skilled labor
- Securing access to adequate land with high load factors for the deployment of renewables
- Reforming transmission development to include proactive planning, fast-track permitting, and systematic consideration of transmission alternatives
- Creating market mechanisms for expanding firm capacity to ensure reliable and adequate clean-energy supply
- Accelerating technological innovation to ensure timely deployment of new clean technologies

The United States' starting point

13%

Renewable energy accounts for just 13 percent of US energy production

25%

The United States is responsible for about a quarter of global, cumulative CO_2 emissions

With natural gas, petroleum, and coal accounting for nearly 80 percent of US energy production, fossil fuels represent the majority of the energy mix in the country.[53] Renewable energy represents 13 percent of energy production, mainly by wind and solar production. The share of wind and solar nearly quadrupled from 2011 to 2020, to more than 228 GW of installed capacity today.[54] And yet the United States' potential for renewable energy remains largely untapped, as it has 100 times the renewable resources needed to meet its annual electricity needs.[55]

Nuclear power accounts for about 8 percent of US energy production; it could play an important role in stabilizing the grid as the proportion of intermittent renewable energy sources increases.[56]

The United States has emitted more GHGs than any other country to date. It is responsible for approximately 25 percent of cumulative CO_2 emissions.[57] Today the country emits more than 13 percent of global CO_2 emissions despite being home to less than 5 percent of the world population.[58] Three sectors generate more than three-quarters of its GHG emissions: transportation (27 percent), electric power (25 percent), and industry (24 percent).[59]

Nationally determined contributions

In the United States, public policy has begun to shift, and momentum is accelerating for public- and private-sector efforts to limit the effects of climate change. On February 19, 2021, the country rejoined the Paris Agreement after temporarily exiting on November 4, 2020.[60] That same year, President Joe Biden announced targets for achieving a 50 to 52 percent reduction from 2005 levels of net GHG emissions by 2030 and 100 percent carbon-free electricity by 2035. Recent actions, such as the passage of the Inflation Reduction Act (IRA), built momentum toward achieving commitments.[61] At the same time, government policies such as those put in place by the 25 states that have set their own economy-wide emissions-reduction targets continue to accelerate US decarbonization.[62]

Priority measures that could accelerate a more orderly energy transition

The accelerating momentum toward the energy transition at long last puts the United States on a path to achieve needed decarbonization. With careful planning and execution, the country could make marked progress toward a more orderly energy transition. However, six challenges could stand in the way: (1) significant investments are required in the energy sector that could result in higher energy costs for end users—costs that may be disproportionally borne by low-income households; (2) supply-chain bottlenecks and labor shortages risk limiting the development of clean energy or increasing its cost and causing delays; (3) expanding transmission capacity and developing new renewables frequently runs into land-access restrictions, inhibiting new development; (4) developing of new transmission capacity to enable renewables deployment could be slowed by reactive planning, barriers to siting and permitting, cumbersome regulatory frameworks, and lengthy interconnection processes; (5) firming capacity may be insufficient to accommodate growing adoption of intermittent renewable energy sources, and (6) long timelines for the development and deployment of innovative technologies.

[53] *US primary energy consumption by energy source,* 2021, US Energy Information Administration, 2021.
[54] Ibid; *Renewable energy capacity,* 2022.
[55] "Renewable Energy Resource Assessment Information for the United States," US Department of Energy, March 2022.
[56] "Nuclear Explained: U.S. Nuclear Industry," EIA, April 18, 2022.
[57] The United States has emitted around 400 million tons of CO_2 since 1751, according to "Who has contributed most to global CO_2 emissions?" Our World in Data, October 1, 2019.
[58] In 2020, the United States was responsible for 13.54 percent of global CO_2 emissions, and its share of the world population was 4.28 percent, according to "Who emits more than their share of CO_2 emissions?" Our World in Data, 2020.
[59] *Sources of Greenhouse Gas Emissions,* US Environmental Protection Agency, 2020.
[60] Antony Blinken, "The United States Officially Rejoins the Paris Agreement," US Department of State press statement, February 19, 2021.
[61] "By the Numbers: The Inflation Reduction Act," White House briefing statement, August 15, 2022.
[62] *US State Greenhouse Gas Emissions Targets,* Center for Climate and Energy Solutions.

To overcome these challenges and make sufficient progress toward meeting the 2030 and 2035 emissions targets, stakeholders could consider the following six measures.

1

Designing and deploying a capital-efficient and affordable energy system

$500 billion

$500 billion in additional capital is required for generation, transmission, and distribution through 2030 in the United States

Unlike deploying fossil fuel plants, deploying wind and solar energy has zero fuel costs. As the energy system shifts toward renewables, capital spending—on building renewable-energy facilities and boosting electric-grid capacity, for example—will be more front-loaded. Our analysis suggests that the energy transition could require potentially more than $500 billion in additional capital for generation, transmission, and distribution through 2030 in the United States. This amount does not include the potential costs of stranded assets—that is, assets not used as long as originally planned, such as thermal plants that are retired early. These additional investments, however, could help avert the even more costly consequences of delayed action and could result in a system that would cost less to operate in the long term.

Nevertheless, spending on the energy transition—coupled with the significant investment in the grid needed for reliability and resilience under any scenario—could increase the cost of the US energy system, thereby increasing expenses for households and businesses. If not carefully managed and mitigated to the extent possible, these cost increases could hamper economic activity and create customer backlash, which would in turn delay needed action and result in a less orderly energy transition. Businesses and policy makers will need to target capital expenses with a laser focus to mitigate the affordability challenges that some customers will face.

Proactively planning the system for long-term decarbonization. Given the long lifetime of power infrastructure, customers would bear the costs over many decades. Planning today for the long term will therefore be critical to managing costs for the duration of the transition. Utilities could identify and plan the right portfolio of assets to deliver the energy transition at lower cost by today incorporating new asset types, such as hydrogen-related assets and carbon capture, as well as engaging in integrated cross-sector planning by centrally assessing and prioritizing grid changes. For example, electric and gas utilities could work with regulators and communities to reach alignment about areas where full electrification and gas pipeline decommissioning could be feasible.

Investments in fossil fuel assets could be made based on their anticipated useful life, and alternatives to large-scale reinvestments in these assets could be explored without affecting safety. Asset owners might look for ways to repurpose assets that are no longer used and useful—for example, leveraging brownfield coal sites to build new nuclear plants or upgrading gas pipelines to transport hydrogen.

Improving capital efficiency for energy companies through technology, operational best practices, and proper incentives. Capital efficiency is more critical than ever today, especially in the context of steep inflation and supply-chain challenges. Private-sector players could implement best practices in capital productivity and operational excellence to reduce overall costs. Renewables developers, for example, have lowered capital expenditures by 10 to 20 percent through measures such as design-to-cost analysis, clean-sheet-based negotiation, schedule optimization, and lean and digitized construction.[63] To encourage these

[63] Tom Brinded, Erikhans Kok, Lucas Ponbauer, and Bevan Watson, "How capital expenditure management can drive performance," McKinsey, June 29, 2022.

and other cost-saving measures, government and regulators could adjust incentives for utilities—for example, through performance-based measures or an evaluation of a utility's total expenditure including both capital and operations spending.

Revising electricity-rate designs and empowering end users, particularly low-income users, to adopt new solutions for their energy. Utilities and other energy companies could put in place programs to help their customers understand, prepare for, and adapt to potential changes. Rate designs could be revised to incentivize reductions in energy demand when energy production from solar and wind is low. Customers could benefit from smaller energy bills while contributing to the flexibility of the grid. For example, rates could be proportional to the spread between demand and renewable production. In this way, customers could lower their bills by using less electricity during times when the system is most constrained. This arrangement could be accompanied by tools to educate customers to shift loads and understand rate options. To further reduce costs specifically for lower-income customers, utilities could offer discounted rates or provide financing options, such as on-bill financing, to assist with the electrification of the consumers' households and vehicles.

Where sensible for the system and the customer, companies could also develop tools that encourage cost-effective, demand-side management and distributed energy resources (DER).

2

Strengthening supply chains to provide stable access to raw materials, components, and skilled labor

95%

Nearly all solar polysilicon, ingot, and wafer production occurs in China

Already-challenged supply chains will likely be stretched further as the demand for materials, manufacturing, and labor increases globally and many countries ratchet up their commitments to reach net zero. Volume shortages, long lead times and unreliable quality of raw materials and components could result in supply shortages of clean fuels and technologies, while price volatility could steeply increase costs. Geographic sourcing dependence also creates supply-chain vulnerabilities. For example, 95 percent of solar polysilicon, ingot, and wafer production is concentrated in China.[64] Any domestic disruption in China or in the trade flows between China and the United States thus poses real risk to the solar supply chain.

550k

More than a half million new jobs may be needed in 2030 to deploy solar, wind, and natural gas in the United States

The energy transition will also require significant labor. Our analysis suggests that deployment of solar, wind, and natural gas in the United States could require more than 550,000 direct and indirect jobs in 2030. This would be in addition to the jobs needed to develop other technologies, perform grid build-out and management, and deploy electrified equipment and vehicles.

Potential labor constraints and supply-chain bottlenecks could result in costly delays in the deployment of technologies needed for a more orderly energy transition. The following three key actions could be taken by business leaders and policy makers to mitigate their impact.

Building resilience through partnerships with raw material suppliers and demand reduction of scarce inputs. To ensure the steady availability of raw materials and other resources that are critical to the energy transition, private-sector players could commit to long-term supply agreements and diversify suppliers across geographies. Suppliers and miners of critical materials could increase output—by, for example, using machine learning to discover new reserves of critical materials.

[64] "Solar PV Global Supply Chains," IEA, July 2022.

Where these measures are insufficient, companies could innovate to reduce material constraints by applying advanced analytics in mining and processing; developing alternative materials that are more readily available; boosting efficiency without increasing material usage; and developing recycling processes and capacity.

Investing in and incentivizing domestic sources of raw materials and manufacturing where possible. To scale up resilient manufacturing, companies could focus research and development on innovation for domestic production capabilities and leverage artificial intelligence to create optimized, flexible sourcing plans. Policy makers could incentivize domestic manufacturing by increasing tax credits for locally produced components and increasing domestic content requirements in clean energy, as the Inflation Reduction Act does. Private and public players could also collaborate to invest in building clean-technology hubs.

10%

Less than 10 percent of the more than half million new jobs needed could be filled by talent pools from fossil fuels industries

Reskilling and upskilling the workforce to ensure an adequate labor supply to scale clean technologies. Of the 550,000 new job needs that we identified through our analysis, fewer than 10 percent could be filled by talent pools from fossil fuel industries, which in many other instances have skills that are transferable to the jobs required for the energy transition. Companies could tap these talent pools using targeted recruitment programs. To fill the remaining gap, companies could adopt more inclusive hiring practices, such as shifting from credentials-based hiring to skills-based hiring. Companies could also facilitate upskilling and reskilling through vocational schools and on-the-job training programs. The government could support the programs by providing dedicated funding. Furthermore, policy makers could support the attraction of talent through incentives—by, for example, providing credits to businesses that offer jobs that pay above a certain wage threshold.

3

Securing access to land with strong renewables potential and proximity to transmission lines for the deployment of renewables

75%

Three-quarters of land with strong renewables potential and proximity to transmission lines needs to be developed for solar or onshore wind

About 75 percent of all land with strong renewables potential[65] and proximity[66] to transmission lines would need to be developed for either solar or onshore wind power generation to achieve the climate goals the US government has set to reduce levels of net greenhouse-gas emissions by 50 to 52 percent from 2005 levels by 2030.[67]

Challenges to siting and permitting, including community pushback and competition with uses like farming and grazing, could obstruct access to the land. In addition, high costs and elongated project timelines associated with transmission interconnection could impact project viability. The following three actions could be taken to overcome these obstacles:

Increasing the amount of high-quality land available by expanding transmission capacity and the adoption of alternative clean-energy technologies. Many of the highest-quality renewables land areas are far from demand centers. Expanding transmission to connect high-quality land to population centers could increase the amount of potential land available for cost-effective renewables development. Alternatively, deploying clean-energy technologies, such as offshore wind, that could be built closer to population centers creates opportunities. The National Renewable Energy Laboratory estimates that the United States has 4,200 GW

[65] Land is considered as having a strong renewable potential if the capacity factor of solar or wind is in the 95th percentile of all land in the United States.
[66] For the purpose of this analysis, high-quality land is defined as land with a capacity factor in the 95th percentile and above and within 1.5 miles of an existing transmission line. Note that beyond proximity to transmission, capacity of transmission lines also plays a role. Existing transmission lines could already be congested based on existing demand. This analysis only considers proximity to transmission lines and does not account for the congestion of existing transmission lines.
[67] "Six action areas for a more orderly US energy transition," McKinsey, forthcoming.

140 GW

The United States needs to reach 140 GW of offshore wind by 2050 for an orderly energy transition

of offshore wind potential.[68] Our modeling of a more orderly energy transition forecasts 30 GW of offshore wind in 2030 and 140 GW in 2050.

Use available land more efficiently through technological innovation and the rejuvenation of brownfield sites. Improving the efficiency of solar and wind could reduce renewables' overall land needs per unit of output. For example, solar arrays that track the sun throughout the day require less than half the land of solar projects built ten years ago.[69] As further technological advancements occur, existing solar and wind sites could be repurposed with new technologies to increase solar output without the need for new-site development.

Build community support to mitigate siting challenges through improved valuation and strategic site selection. The land that is optimal for wind and solar projects may be limited, but it is also very valuable. For example, the land with the highest solar capacity factor (the 100th percentile) could be valued ten times higher than land in the 70th or 80th percentile. It could lead to a lower levelized cost of electricity because of higher irradiation levels (approximately $14 per MWh, compared with $16 per MWh).[70] If a developer is willing to pay a premium on land with a high capacity factor, that value could be shared by multiple developers, landowners, and communities—for example, through financial compensation to property owners near developments. While there is already a long history of Midwest farmers and ranchers benefiting from wind farms built on their property, so-called good-neighbor payments could help spread the benefit to other communities.

Developers could also identify community sites with recent economic downturns that could benefit from a new source of sustainable, well-paying jobs. Moreover, co-siting farmland and wind turbines, innovative agriculture practices in use alongside solar farms, or creating public-use lands in transmission corridors could represent further opportunities to develop equitable and socially accepted energy transition projects.

4

Reforming transmission development to include proactive planning, fast-track permitting, and systematic consideration of transmission alternatives

Transmission is critical to achieving a more orderly transition, given the role it plays in connecting renewable power to the grid. However, investments needed for transmission expansion are underestimated due to reactive planning processes with short time horizons and misalignment between cost and benefit allocation. For projects that have received funding, timelines are often elongated—a result of complicated siting and permitting that could, according to our research, delay projects by ten years or more. In addition, lengthy interconnection wait times cause project withdrawals, hefty backlogs, low completion rates, and cost overruns. Long wait times are a result of high demand, low bandwidth for processing applications, limited standardization, coordination issues among stakeholders, and limited innovation in considering solutions such as bundling projects.[71]

[68] Anthony Lopez, Rebecca Green, Travis Williams, et al., *"Offshore Wind Energy Technical Potential for the Contiguous United States,"* National Renewable Energy Laboratory (NREL), August 15, 2022.
[69] "Land-use requirements for solar power plants in the United States," National Renewable Energy Laboratory, June 2013.
[70] This analysis assumes the lifetime of solar is 25 years and that of wind is 30 years. Capacity factor assumes solar is for fixed-tilt panels with CSI technology and wind is for Vestas V112 3-MW turbine at 120-m hub height. The analysis assumes renewables capital spending costs for renewables. Over time, land costs are likely to increase, while other factors driving renewables capital spending are likely to decrease. For example, the cost of panels after current supply-chain challenges have been mitigated. As these cost dynamics shift, the high value of optimal land will decline.
[71] "Transmission Planning for the 21st Century: Proven Practices that Increase Value and Reduce Costs," The Brattle Group and Grid Strategies, October 2021.

Two actions could be taken to support the continuation and acceleration of transmission buildout and to plan for alternatives should transmission gridlock go unresolved:

Enabling transmission development through better transmission planning and the resolution of site challenges. System planners could plan transmission to account for the comprehensive range of benefits that transmission could enable. For example, transmission is often planned "one line at a time," rather than with a portfolio approach. Furthermore, business cases supporting the buildout of transmission lines typically value only either the reliability benefit of the line or the benefit of enabling lower cost fuels, but often they do not value access to cleaner energy sources.

Important national conversations aimed at devising solutions are under way to shrink the decade it currently takes to permit, site, and plan large transmission lines from start to construction. Regional examples, such as the New Mexico Renewable Energy Transmission Authority (RETA), have been created to facilitate the development of electric transmission and storage projects by providing input on project impacts and ensuring that landowners are treated fairly and equitably. One report identified at least 22 additional shovel-ready projects that could potentially benefit from similar efforts and enable a 50 percent increase from current levels of wind and solar generation.[72]

Develop alternatives to transmission, including scaling distributed energy resources and leveraging the existing gas infrastructure. To create local capacity, companies, system planners, and policy makers could facilitate the deployment of distributed energy resources (DERs), which are small renewable generation units on the consumer-end of the meter, including distributed solar and storage as well as demand-side management and energy efficiency. This effort could reduce the need for transmission-capacity buildout, which is particularly important in densely populated areas. Scaling rooftop solar is attractive in regions with high solar irradiation. For example, Los Angeles could achieve its renewable-energy target of 100 percent by installing rooftop solar on up to one-third of LA's existing homes by 2045.[73]

100%

By installing rooftop solar on up to one-third of LA's existing homes by 2045, the city could reach its renewable-energy target of 100 percent

System planners and utilities could use the existing gas network to manage winter peaks in cold regions and lower transmission-capacity needs while reducing overall throughput and transitioning to zero-carbon molecules.

Where transmission build-out to connect renewables to population centers does not materialize, system planners and companies could transition to dispatchable zero-carbon resources that could be sited closer to population centers. Examples of such resources include offshore wind, combustion of zero-carbon fuels such as renewable natural gas, synthetic natural gas, or hydrogen, nuclear power, and long-duration energy storage.

[72] Michael Goggin, Rob Gramlich, and Michael Skelly, "Transmission Projects Ready to Go: Plugging into America's Untapped Renewable Resources," Americans for a Clean Energy Grid, April 2021.
[73] Jaquelin Cochran, et al., *LA100: The Los Angeles 100% Renewable Energy Study,* Los Angeles Department of Water and Power, National Renewable Energy Laboratory, March 2021.

5

Creating market mechanisms for expanding firm capacity to ensure a reliable and adequate clean-energy supply

80%

More than 80 percent of today's US power system consists of flexible power sources

More than 80 percent of today's US power system consists of flexible power sources such as natural-gas plants that could ramp up and down quickly to meet sudden shifts in supply or demand.[74] As more renewables come online, the power system would benefit from more flexible power sources to mitigate the intermittent nature of renewable power—for example, to provide power when the sun goes down. But as penetration of intermittent renewables increases, the lack of flexible resources will put system reliability at risk. To mitigate the risk, system planners, utilities, generators, and policy makers could collaborate through data sharing, simulation planning, and stakeholder engagement to establish and implement the market mechanisms that are needed.

Regulators and system planners could evolve market mechanisms to create incentives for the development of sufficient flexible resources in the following three ways:

Adjusting capacity credits to reflect intermittence of renewables. Most capacity markets allow some share of a renewable plant's power to count as firm power that could be called on when the system is in need. However, the intermittence of renewables introduces unreliability to the objective of delivering firming capacity at every moment in time. In most capacity markets, renewables' stated flexibility could be adjusted to reflect this reality. System operators could use a more conservative calculation to revise capacity credits for intermittent renewables and other resources—basing projections on forecasts of future resource availability in addition to taking a more stringent view of what constitutes reliable output based on historical performance.

This issue is not limited to renewables; system planners could also carefully assess other resources to reduce the risk of overstating firm capacity. For example, gas plants that are not fully weatherized may be unable to dispatch at full capacity during extreme events. Similarly, hydropower and pumped hydro-storage may not be able to dispatch at full capacity during drought years.

Evolving resource planning to factor in electrification and the impacts of climate change on energy demand. As electrification increases and the climate shifts, system operators would need to adjust forecasting to account for changing supply and demand. More frequent extreme weather events could disrupt energy imports and reduce power generation—for example, reducing the efficiency of solar panels as temperature increases. In addition, demand could spike from increased use of air conditioning, on top of the increase in demand from electrification. These shifts would require system planners to forecast more conservatively rather than relying on historical trends. More unpredictable demand and supply also means that planners would need to include larger margins in their forecasts.

Incentivizing expansion of dispatchable zero-carbon resources, such as nuclear and long-duration storage capacity, to ensure grid resilience. The intermittent nature of renewables requires the uptake of flexible power sources that could generate or store power for long periods. For example, in the northern United States, a week of low wind in February would put the energy system in a bind, given that solar output is low and energy demand is high in February. During such periods, the power system requires resources that don't depend on the weather and do not have limited durations. Regulators could consider policies that avoid incentivizing a single threshold—for example, mechanisms that auction capacity by tranches of duration. These could enable the expansion of dispatchable zero-carbon resources, such as nuclear and long-duration storage capacity.

[74] "Six action areas for a more orderly US energy transition," McKinsey, forthcoming.

6

Accelerating technological innovation to ensure timely deployment of new clean technologies

25 years

It took a quarter century for offshore wind to progress from its first commercial demonstration in Europe to starting to scale in the United States

Historically, clean technologies have come onto the grid over several decades, from initial small-scale deployment to broad commercial deployment. For example, it took offshore wind 25 years to progress from the first commercial demonstration in Europe[75] to starting to scale in the United States.[76] Such a time scale is too slow for the development and deployment of the newer technologies needed to affordably meet 2030 decarbonization goals.

Businesses and policy makers could benefit from focusing on the following high-priority actions to accelerate technological innovation:

Fostering collaboration along the value chain to alleviate early-stage risks and share investments in infrastructure. New technologies that could play a role in the energy transition could benefit from an ecosystem in which upstream producers, midstream players, and downstream consumers could collaborate to develop the value chain. Together, stakeholders could invest in R&D and infrastructure to bring down costs and create scale advantages. This action also helps hedge the risks of making investments in nascent markets. For example, in hydrogen hubs such as HyBuild Los Angeles and the H2Houston Hub private companies, industry coalitions, governments and community groups collaborate to scale up hydrogen production and the transportation infrastructure.[77]

Lowering the cost of capital for new technologies by decreasing technical risks of early-stage technologies. Financial institutions and government entities could develop new ways to provide insurance such as public grants or low-cost loans for technical performance risks for early-stage technologies. These solutions could be designed to lower the cost of capital and thus attract more investment in technology development. This could accelerate technologies' proof of concept and commercialization. For example, the US Department of Energy's Loan Programs Office provides loans and loan guarantees to decarbonization technologies that are technologically mature but have not achieved full acceptance by the market.[78]

Providing long-term market and regulatory clarity to unlock large-scale investments. Investors often seek clarity about the longer term to make the large-scale investments to move from pilot programs to full commercial deployment. Corporate players could help signal the market direction by announcing commitments to transition to new technologies even when those technologies are still in early stages. Policy makers could seek to provide regulatory clarity—for example, by providing technology-neutral credits such as those for zero-carbon electricity. The government could also dedicate funding to new technologies, similar to the $8 billion investment in hydrogen hubs that's part of the Infrastructure Investment and Jobs Act,[79] to give investors and producers a longer time horizon.

[75] "History of Europe's wind industry," WindEurope.
[76] "History of U.S. Wind Energy," Wind Energy Technologies Office.
[77] For HyBuild Los Angeles, see www.ghcoalition.org/hybuild-la. For H2Houston Hub, see www.centerforhoustonsfuture.org/h2houstonhub.
[78] Loan Programs Office, US Department of Energy.
[79] "DOE Launches Bipartisan Infrastructure Law's $8 Billion Program for Clean Hydrogen Hubs Across U.S.," US Department of Energy, June 6, 2022.

Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

Australia

Australia exhibits the main characteristics of the "affluent, energy-secure" regions archetype with established access to critical natural resources and a strong supply-chain infrastructure.

Rich in fossil fuels, an enviable reserve of critical minerals, and renewables potential, the country has the natural endowment needed to prosper from embarking on an energy transition. Australia also has the opportunity to become an exporter of green energy and critical materials to support the energy transitions of neighboring countries. An orderly energy transition could enable Australia to add approximately AUD 55 billion to the economy each year through 2035 and 20,000 direct jobs.[80] In some ways, Australia could be a role model for how a fossil-fuel-rich country successfully transitions with minimal economic and social impacts.

To seize these opportunities and promote a path to a more orderly energy transition, Australia could consider the following priority measures:

- Expanding firm capacity and transmission to accelerate coal retirements, and investing in green alternatives
- Securing power supply by strengthening natural gas supply capacity
- Building infrastructure and implementing incentives to spur investments aimed at decarbonizing industry
- Mitigating economic and social impacts on local communities affected by the energy transition

[80] David Dyer, Simon Kennedy, Vic Selvaraja, and Wesley Walden, "Carbon Light: How Australia can power ahead in a net-zero world," McKinsey, forthcoming.

Australia's starting point

Australia is a fossil-intensive economy, with approximately 67 percent of its current electricity mix driven by coal or gas.[81] Australia, on the western and southern coasts, enjoys high levels of solar irradiation and has among the world's best wind resources.[82] However, this potential is largely untapped today: wind and solar combine for 28 GW of installed capacity.[83] That is less than 1 percent of the country's total renewables potential.[84] Australia also has substantial reserves of critical minerals and raw materials needed to manufacture clean technologies like electric vehicles, batteries, and wind turbines. Australia holds 30 percent of the world's iron-ore reserves, 28 percent of lithium reserves, and 20 percent of cobalt reserves.[85]

Given its resource wealth, Australia is a net energy exporter to growing economies in East Asia, such as China, Japan, and South Korea.[86] From 2020 to 2021, it exported 90 percent of black-coal energy, 75 percent of natural gas, and 83 percent of crude-oil production.[87] Australia is also a major exporter of critical metals and minerals—it is the world's largest producer of lithium (46 percent of global production[88]) and a global top-five producer of gold, iron ore, lead, zinc, and nickel.[89] These existing trade relationships and infrastructure could enable Australia to support future low-carbon-energy and commodities exports.

A breakdown of Australia's total emissions shows that one-third comes from electricity generation, and about 20 percent comes from mining, mainly oil and gas (10 percent of total emissions) and coal (8 percent of total emissions).[90] Agriculture is the third-biggest emitting sector with 18 percent of total emissions, while transportation accounts for 5 percent.[91]

Nationally determined contributions

35%

Australia is on track to reduce emissions by more than one-third by 2030

At COP26, Australia updated its nationally determined contribution (NDC) to include a commitment to achieve net zero by 2050, although it left its 2030 target at an emissions reduction of 26 to 28 percent.[92] Government projections suggest that Australia is on track for an emissions reduction of up to 35 percent by 2030.[93] In June 2022, Australia's newly elected government strengthened its 2030 ambition, committing to a 43 percent emissions reduction, below 2005 levels.[94]

Priority measures that could accelerate a more orderly energy transition

Australia faces a set of barriers that threaten to impede its ability to reach its 43 percent emissions-reduction target by 2030. These obstacles include: (1) a shortage of firm capacity and system strength to accelerate coal retirements; (2) a shift from peak gas demand from summer to midwinter, high price volatility, and reduction of gas supply capacity in the southeastern states; (3) a lack of infrastructure and limited incentives to decarbonize industry; and (4) economic and social effects of coal retirements on concentrated local communities.

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[81] *Clean Energy Australia 2022,* Clean Energy Council.
[82] Global Solar Atlas at globalsolaratlas.info and Global Wind Atlas at globalwindatlas.info.
[83] *BP energy outlook,* 2022.
[84] Total renewables potential is more than 25,000 GW. See *The Australian Renewable Energy Race: Which States Are Winning or Losing?* Climate Council, 2014.
[85] *Iron Ore,* Government of Western Australia; *BP energy outlook,* 2022.
[86] *Resources and Energy Quarterly,* Australian Government Department of Industry, Science and Resources, June 2022.
[87] *Energy Trade,* Australian Government Department of Climate Change, Energy, the Environment and Water, retrieved September 15, 2022.
[88] *Resources and Energy Quarterly,* Australian Government Department of Industry, Science and Resources, June 2022.
[89] *Australia Country Commercial Guide,* Australia Mining, International Trade Administration, July 20, 2022.
[90] *National Inventory by economic sector,* National Greenhouse Gas Inventory, Australian Government Department of Climate Change, Energy, 2020.
[91] *National Inventory by economic sector,* National Greenhouse Gas Inventory, Australian Government Department of Climate Change, Energy, 2020.
[92] Colin Packham, "Australia adopts target of net-zero emissions by 2050 but won't legislate goal," *Reuters,* October 25, 2021.
[93] *Australia's plan to reach our net zero target by 2050,* Ministry for Industry, Energy, and Emissions Reduction, press release, October 26, 2021.
[94] *Australia's Nationally Determined Contribution 2022,* United Nations Framework Convention on Climate Change.

To solve its core challenges and de-risk the path to achieving its NDC, stakeholders could consider taking four near-term priority measures.

83 GW

Electricity from renewables in Australia is expected to reach 83 GW by 2030

5%

Only 5 percent of the 45 GW of battery and pumped hydro stroage projects proposed are committed

1

Expanding firm capacity and transmission to accelerate coal retirements, and investing in green alternatives

By 2030, the electricity from renewables is expected to increase from approximately 28 percent in 2020–21 to 83 percent in 2030–31, while 14 GW of coal-fired generation is expected to retire, but these are not guaranteed to happen, because of concerns about energy reliability.[95] Furthermore, replacement firm capacity has been slow to come online. Of the 45 GW of battery and pumped hydro storage projects proposed, only 2.4 GW (5 percent) are committed.[96] Including committed gas and coal expansion projects, capacity will increase to 3.6 GW, which is still almost 10 GW short compared with confirmed coal retirement.[97]

Transmission deployment will be critical to enable greater penetration of renewable energy by connecting renewables from areas with the highest capacity factor to load centers that have demand. However, transmission projects already face delays because of a variety of factors, including outdated energy systems and market designs, which could slow down Australia's renewables build-out.[98]

There are four actions that could ensure Australia has enough firm capacity and transmission to enable an orderly coal retirement.

Implementing a national road map for an orderly exit of coal capacity. Australia could more closely coordinate coal penetration targets across states and establish a national road map to enable a seamless exit of coal capacity in the power sector. One option would be for the National Electricity Market (NEM) to facilitate an NEM-wide "master plan" across states. This would have the ability to influence retirement schedules and thus ensure coordination and avoid rapid capacity shortfalls without having replacement firm generation scheduled to come online. A coordinated plan would help to ensure Australia does not face capacity gaps caused by timing issues between firm capacity retirements and deployments.

The 2022 Integrated System Plan (ISP) of the Australian Energy Market Operator (AEMO) takes positive steps toward outlining how to exit coal. To ensure firm capacity, further planning, coordination, and incentives are required to coordinate across stakeholders, including storage developers and coal-plant operators.[99]

Designing and implementing capacity compensation mechanisms. Enabling the expansion of firm capacity and de-risking capacity deployment are also important to enabling coal retirement. Regulators could add a capacity market to NEM and design compensation mechanisms to encourage investment in storage. This would give storage developers the opportunity to earn a return that meets their thresholds.[100] Putting an explicit value on capacity could clear up market uncertainty that results from reliance on volatile wholesale market prices. It would provide strong signals for project developers to pair

[95] Step Change Scenario, *2022 Integrated System Plan*, Australian Energy Market Operator, June 2022.
[96] "Existing Generation and New Developments of Storage, Battery Storage and Water," NEM Generation Information, July 2022.
[97] *Existing Generation and New Developments of Storage, Battery Storage and Water,* NEM Generation Information, July 2022,
[98] Andrew Reddaway, "Transition delayed – renewable projects facing obstacles," Renew, April 20th, 2020.
[99] *2022 Integrated System Plan,* Australian Energy Market Operator, June 2022.
[100] Andy Colthorpe, "Australia's capacity mechanism 'shouldn't lock in reliance on aging and polluting generators'," *Energy Storage News*, June 22, 2021.

renewables projects with enough storage to enable an orderly transition from fossil fuels to renewables.

Australia's Energy Security Board has already published a proposal along these lines, which is pending stakeholder review and comments.[101] Accelerating the implementation of such a capacity mechanism could give NEM the head start necessary to stick to retirement goals and potentially accelerate them.

65 GW

Australia needs about 65 GW of firming capacity by 2050

Actively supporting development and early-stage deployment of green technologies. Australia could also support development and early-stage deployment of technologies that provide more flexible capacity. Pumped hydro-energy storage (PHES), long-duration storage, and at-scale electrolyzers could all add firm capacity and enable renewables deployment. Australia already has about 2.6 GW of pumped hydro and is developing additional capacity of 2.2 GW.[102] However, the country needs approximately 65 GW of firming capacity by 2050, with a mix of dispatchable storage and a residual of gas to efficiently operate, along with firm intermittent renewable energy.[103] Policy makers could help fill capacity gaps by using incentives, such as financial support programs and capacity mechanisms, to encourage the development of various storage projects like pumped hydro-electrical storage, long-duration energy storage, and lithium ion.[104]

Perhaps most important to Australia's outcome in the energy transition is to continue to build out hydrogen capacity for internal use—blending or replacing natural gas for residential use, storage, and/or industrial feedstock—and for export. State programs such as New South Wales's $2.2 billion program provide incentives to attract projects, including a 90 percent exemption from power network charges for electrolyzers.[105] Even with these incentives, more help is needed to accelerate the scaling up of hydrogen technologies and to bridge the gap between the capital investment required and customer willingness to pay for green molecules. One potential solution is to revise the safeguard mechanism—for example, with a lower emissions baseline or more stringent requirements for obtaining carbon credits.

Streamlining approval processes and mobilizing investments for transmission expansion projects. Transmission deployment will be critical to enable accelerated coal retirement. It will allow for the increased penetration of renewable energy by connecting renewables from areas with the highest capacity factor to load centers that have demand. However, approximately two-thirds of transmission projects are more than six months past their expected delivery dates.[106]

The Australian Energy Market Operator (AEMO) ISP identified more than 10,000 square kilometers that are necessary to support more than 60 GW of dispatchable assets.[107] Executing on transmission projects will remain a challenge. Governments could play a key role in advancing approvals for these projects by prioritizing those that deliver the greatest impact. Streamlining environmental and planning approvals could also accelerate the process and prevent delays in delivery.

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[101] *Post 2025 Market Design – Capacity mechanism – High-level design consultation paper – June 2022,* Australian Government Department of Climate Change, Energy, Environment and Water, June 20, 2022.
[102] Australia is currently operating pumped hydrostorage across Tumut 3 (1,800 MW), Wivenhoe (570 MW) and Shoalhaven (240 MW), and Kidston (250 MW) and Snowy 2.0 (2,000 MW) are planned to be operational in 2023 and 2028 respectively. See "Pumped Hydro Energy Storage Map of Australia," *Renew Economy.*
[103] *2022 Integrated System Plan,* Australian Energy Market Operator, June 2022.
[104] Alberto Bettoli, Martin Linder, Tomas Nauclér, Jesse Noffsinger, Suvojoy Sengupta, Humayun Tai, and Godart van Gendt, "Net-zero power: Long-duration energy storage for a renewable grid," McKinsey, November 22, 2021.
[105] Sonali Paul, "Australian state offers $2 bln to lure hydrogen projects," Reuters, October 12, 2021.
[106] *Powering Australia – Rewiring the Nation,* Australia Parliamentary Budget Office 2022 Election commitments report: ECR125, 2022.
[107] *2022 Integrated System Plan for the National Electricity Market,* Australian Energy Market Operator, June 2022.

New policies, such as "Rewiring the Nation", are expected to provide substantial concessional funding for transmission projects. However, these projects will still need to pass complex and conservative regulatory tests before construction can begin. Thus, to accelerate investments in new transmission projects, public and private investments may need to be secured in advance of regulatory approvals. Other mechanisms could also de-risk the deployment of transmission, including regulatory framework changes, financial mechanisms to reduce the time gap between costs and payouts, and improved benefit allocations to landowners and communities that own the land where projects are set to be developed.[108]

2

Securing power supply by strengthening natural gas supply capacity

As coal plants retire and the share of renewable power increases, gas increasingly plays a firming role for renewables. This leads to bigger spikes in gas demand linked to the intermittence of renewables generation. Furthermore, the large share of solar has resulted in a shift of peak gas demand from the power sector to mid-winter, driven by peak gas demand from the residential sector and strong demand from industry.

180%

The ratio of peak day to average gas demand in southeastern states reached more than 180 percent in 2021

This has resulted in more volatile gas demand. The ratio of peak day to average gas demand in the southeastern states (Victoria, New South Wales, and South Australia) has increased from less than 160 percent in 2017 to more than 180 percent in 2021.[109] Meanwhile, supply capacity has declined in southeastern states due to field depletion and is expected to decline further, increasing peak-period dependence on long-distance imports from Queensland.[110]

New infrastructure to serve existing and planned generation is needed, because of declining supply and persisting peak gas demand in winter. However, investment in gas infrastructure has been limited, as there is uncertainty about the long-term role of gas. This increases the risk of gas-supply emergencies during winter and higher energy prices. To mitigate these risks, the following two actions could be explored.

Expanding infrastructure to meet peak gas demand. New gas infrastructure could be built in the form of transmission capacity from Queensland, liquefied natural gas (LNG) import capacity, or gas storage. While infrastructure to meet peak day demand could meet all demand, it is needed only a few days each year, making it difficult to recover costs. Australia will likely need to help investors recognize the importance of peak gas supply infrastructure and enable economical cost recovery. These could include a security-of-supply mechanism for gas-fired power or capacity payments for peak storage infrastructure.

Streamlining regulations and procedures for management of gas-supply emergencies. The residential sector relies on gas to heat homes in cold winter months. Lack of gas during peak capacity highlights the need for a coherent plan to prioritize among competing gas users during periods of peak demand to avoid interruptions. However, Australia's gas system is fragmented and inconsistent among states, and AEMO's role in managing emergency situations varies between Victoria and the other eastern states, adding complexity.

Coordination and increased transparency across states is needed for regulators to be prepared to make tough decisions in case of emergencies. For example, AEMO could take on the role of coordinating planning for gas-supply security.

[108] Ibid.
[109] *Peak Day Gas Demand per Region and Average Daily Demand per Region,* Australian Energy Regulator, accessed on October 12, 2022.
[110] Southeastern states refer to Victoria, New South Wales, South Australia, Tasmania, and Australian Capital Territory.

3

Building infrastructure and implementing incentives to spur investments aimed at decarbonizing industry

To mitigate country-wide emissions and achieve a more orderly transition, energy-intensive industries would need to abate their emissions using hydrogen or other green solutions to decarbonize.

AUD 9 billion

Retooling steel plants would require roughly AUD 9 billion to produce five million tons per annum of green steel

All states and territories, as well as the federal government, have developed hydrogen strategies, and many are providing financial support. For example, the federal government committed to investing AUD 1.2 billion into the hydrogen industry, which includes AUD 464 million into seven clean-hydrogen industrial hubs for steel, cement, ammonia, and aluminum.[111] However, more public and private investments are required to reconfigure energy-intensive industrial sectors. For example, retooling steel plants would require an investment of about AUD 9 billion to produce five million tons per annum of green steel.[112]

But there are limited targets, market mechanisms, and standards in place to mobilize more collective and private-sector investments and to incentivize hard-to-abate sectors to decarbonize. Three actions could help to move the needle:

Developing efficient top-down decarbonization incentive programs to drive decarbonization programs in industry. Policy makers could implement incentive programs and mechanisms, such as tax breaks or subsidies, to accelerate the uptake of hydrogen in industry. Piloting and enabling the building of emissions tracking tools in conjunction with sector targets could help ensure that the incentives drive change successfully.

Additionally, government agencies could consider investing in developing sector- and geography-specific decarbonization pathways for Australia's biggest industry emitters. This investment would help companies and investors understand both the potential and the risks of decarbonization technology and potentially drive private-sector capital formation. Increased investment in nascent technologies could further accelerate the learning curve for companies deploying these technologies.

Creating robust certification schemes for high-fidelity negative emissions and renewable energy tracing. Australia could develop certification schemes for negative emissions and stringent emissions disclosure regulations to trace renewable energy—which could attract investments in renewables and technologies for negative emissions. Implementing carbon-emissions disclosure requirements also would allow Australia to participate in a potential international trading system. As a major exporter of clean energy, its participation will be beneficial.

[111] *Australia's Long Term Emissions Reduction Plan*, Australian Government, May 2022.
[112] David Dyer, Simon Kennedy, Vic Selvaraja, and Wesley Walden, "Carbon Light: How Australia can power ahead in a net-zero world," McKinsey, forthcoming.

4

Mitigating economic and social impacts on local communities affected by the energy transition

Today there are 16 coal-fired power plants in Australia, of which seven are scheduled to close by 2035.[113] The retirement of these plants will affect Australia's economy and could result in job losses, including indirect job losses such as those at local coal mines. For example, Eraring—Australia's largest coal-fired power plant, which employs around 400 people—is scheduled to close in 2025.[114] Australia could mitigate the effects on workforces and local communities by taking the following two actions.

Developing sector- and region-specific economic transition plans for workforces and communities. Australia will need to develop proactive sector- and region-specific transition plans to manage the effects of the closure of local coal-fired power plants, as well as the longer-term declines in coal demand from international trade partners. These transition plans would need to be tailored to workforces and local communities that are affected by the shift from coal to renewables.

To scale transmission and distribution regionally, support renewable development, and spur growth of the hydrogen economy, companies could put in place reskilling programs and vocational training, to create labor pools of in-demand skills for their projects. For example, Origin Energy, the owner of Eraring, plans to build a battery at the site of the coal-fired power plant, and its employees potentially could be reskilled for its construction.

120k

New opportunities in Australia could result in 120,000 new jobs

Doing these things well carries enormous implications for Australia. We estimate that the energy transition could add approximately AUD 55 billion of recurring value to the economy annually until 2035.[115] In Australia's key export industries globally, 95 percent of the 30,000 direct jobs may be at risk, while the new opportunities for Australia could result in 120,000 new jobs.[116]

Providing financial support to mitigate most direct impacts of the energy transition. To ease the effects of the transition, Australia may need to provide financial support, such as relief packages, to communities affected by accelerated coal retirements. This support would require tailoring to each region's needs and could create new economic drivers for areas that are most heavily disrupted.

[113] "Australia's biggest coal-fired power plant to shut years ahead of schedule," *Carbon Brief,* February 17, 2022.
[114] Rhiana Whitson and Michael Janda, "Origin Energy to shut Australia's largest coal-fired power plant, Eraring Power Station, by 2025," *ABC News*, February 16, 2022.
[115] David Dyer, Simon Kennedy, Vik Selvaraja, Wesley Walden, and Bevan Watson, "Carbon Light: How Australia can power ahead in a net-zero world," McKinsey, forthcoming.
[116] McKinsey analysis was performed on a selected subset of key export commodities, including alumina, aluminum, beef, copper, iron ore, liquefied natural gas, metallurgical coal, and thermal coal.

Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

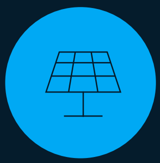
The Middle East

The Middle East encompasses a diverse set of countries, from affluent fossil fuel economies to developing ones, with different energy mixes, emissions trajectories, and levels of affluence. While we evaluated the overall region from a broad perspective, our analysis has focused primarily on the Gulf Cooperation Council (GCC) countries.[117] Exhibiting the main characteristics of the "affluent, energy-secure" regions archetype, the GCC countries pay a prominent role in today's global energy landscape as major fossil fuel producers.

The Middle East accounts for 31 percent of global oil production today. As much as 40 percent of its GDP comes from fossil fuels in some countries.[118] The region could move forward in its energy transition by pivoting to low-carbon upstream technologies such as CCUS, boosting innovation to drive maturity and cost reductions in cleantech, and accelerating the build-out of a policy framework to move toward green alternatives across sectors. The Middle East is positioned to take an important role in the energy transition, potentially as an exporter of clean low-carbon energy (for example, hydrogen and ammonia) and products such as green steel, thanks to a geographic location that connects markets of the West and the East as well as abundant natural resources such as solar.

To seize these opportunities and move toward a path to a more orderly energy transition, the Middle East could consider the following priority measures.

Promoting investments to scale the supply of CCUS, low-carbon hydrogen and ammonia while stimulating demand domestically and internationally



Boosting renewables development and facilitating renewable integration by upgrading supporting infrastructure

Incentivizing electrification and energy efficiency in buildings, industry, and the transportation sector

Promoting green businesses that are building new energy solutions to diversify the local economy and capture new economic opportunities from the transition

[117] Gulf Cooperation Council is a political and economic union comprising Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates.
[118] Nader Kabbani and Nejla Ben Mimoune, *Economic diversification in the Gulf: Time to redouble efforts,* Brookings, January 31, 2021.

The Middle East's starting point

98%

Natural gas and oil account for nearly 100 percent of energy consumption in the Middle East

With a GDP of nearly $2.4 trillion as of 2021, the Middle East represents about 3 percent of the world's GDP.[119] In 2021, it was home to about 3 percent of the global population, more than 230 million people.[120] Natural gas and oil amount to than 98 percent of energy consumption in the Middle East.[121] Electricity generation is mostly powered by gas as well as some oil-fired plants, which add up to 96 percent of electricity generation and 90 percent of the electricity capacity installed in the region in 2020.[122]

Today the Middle East accounts for 1.9 Gt of CO_2e of energy emissions, nearly 5.5 percent of global energy-related emissions.[123] The region is also home to several of the world's top ten per-capita carbon-emitting nations.[124] The power, transportation, and industry sectors are the top CO_2-emitting sectors, accounting for 36 percent, 29 percent, and 24 percent, respectively, of the region's total emissions.[125] Further, GCC countries account for about 55 percent of emissions in the Middle East.

The region is also a major producer of fossil fuels. In 2020, it accounted for 31 percent of global oil production, 18 percent of gas production, 48 percent of proven oil reserves, and 40 percent of proven gas reserves. Exports from the Middle East accounted for 5.8 percent of the total global exports by value, of which 53 percent came from oil and gas alone.[126] The Middle East exported 22 million barrels of oil per day and 127 bcm of gas, representing 34 percent and 26 percent, respectively, of global energy exports in 2020. [127]

One of the region's major advantages is that it has some of the lowest-cost and least carbon-intensive extraction basins in the world. The carbon intensity of upstream operations in Saudi Arabia of 4.6g CO_2e/MJ, for example, is less than half the global average of 10.3g CO_2e/MJ.[128] Capital investments might be needed to counteract the natural declines in rate of production, modernize operations, and continue mitigating emissions as the world's mix of energy demand and supply gradually shifts.

16.5 GW

Middle Eastern countries have deployed 16.5 GW of solar

2 GW

Total wind energy installed in the Middle East

Renewables are gaining momentum in the region because of local green agendas; for example, the United Arab Emirates plans to invest $160 bn in clean, renewable energy sources in the next 30 years.[129] Several countries have announced giga-scale projects (GW-sized), including the Saudi Arabia "Vision 2030" program, which is targeting installation of about 60 GW of renewables by 2030.[130] The GCC also has among the lowest solar bid prices globally.[131] Nonetheless, the investment size and deployment of renewables in the Middle East lags those of many other countries. For example, the Middle East and North Africa (MENA) region receives 22 percent to 26 percent of all solar radiation energy on earth[132], but Middle Eastern countries have deployed only about 16.5 GW of solar.[133] For wind, 75 percent of MENA has average wind speeds that exceed the minimum threshold for utility-scale wind farms.[134] Yet only 2 GW of wind has been installed so far in the Middle East.[135] Large-scale deployment of low-cost renewables could also enable the region to produce green products like aluminum, cement, and steel at a lower cost than other economies.

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[119] World Bank Group data.
[120] Ibid.
[121] *Statistical review of world energy,* BP, 2021.
[122] *Middle East Region Profile,* IEA.
[123] *BP energy outlook,* 2022.
[124] These countries include Qatar, Kuwait, Bahrain, UAE, and Saudi Arabia, *World Development Indicators,* World Bank.
[125] *Global Energy Perspective,* 2022, data for Current Trajectory scenario, 2021.
[126] *Trade Map 2021,* International Trade Center, accessed Oct 10, 2022.
[127] *Statistical review,* 2021.
[128] Mohammad Masnadi, et al., "Global carbon intensity of crude oil production," *Science,* volume 361, issue 6405, August 31, 2018.
[129] "UAE to invest $160bln in clean, renewable energy sources in next 30 years," *Zawya,* May 26, 2022.
[130] "Saudi to produce 60 GW of renewable energy by 2030, says official," *Gulf Business,* January 14, 2019.
[131] "UAE to invest $163 Billion in Renewables by 2050," UNFCCC, January 11, 2017; "New era of climate action diplomacy in the Middle East," World Economic Forum, July 1, 2021.
[132] Global Solar Atlas.
[133] *Renewable energy capacity,* 2022.
[134] Global Wind Atlas.
[135] *Renewable energy capacity,* 2022.

Nationally determined contributions

The Middle East has pledged to embark on an ambitious near-term progress pathway to meet decarbonization targets by 2030.[136] Currently announced NDCs collectively place the region on a more ambitious trajectory than the 1.7° pathway. The NDC submissions to the UN Framework Convention on Climate Change (UNFCCC) to date mainly target economic diversification; GHG emissions avoidance, reduction, and removal; and climate-change mitigation and adaptation actions.[137] One of the frameworks being championed is that of the circular carbon economy. Under this framework, the region would aim to continue producing hydrocarbons while simultaneously seeking to close the carbon cycle and avoid emitting CO_2 into the atmosphere.[138]

Priority measures that could accelerate a more orderly energy transition

The Middle East faces a set of challenges and opportunities unique to the region: (1) currently limited regulation and incentives to scale the supply of CCUS and low-carbon hydrogen; (2) untapped opportunities for renewables development, despite significant progress and a favorable cost structure; (3) a large hydrocarbon production and processing operation, for which carbon-footprint mitigation is still limited; and (4) a large portion of local GDP linked directly or indirectly to the hydrocarbon industry. The energy transition could put this industry at risk as demand for fossil fuel progressively declines.

To solve these challenges and make near-term progress toward meeting the Middle East's emission targets, stakeholders could consider the following set of priority measures.

1

Promoting investments to scale the supply of CCUS as well as low-carbon hydrogen and ammonia, while stimulating demand domestically and internationally

Various hard-to-abate sectors like refining, steel, and cement could use CCUS applications to decarbonize at scale. The untapped potential here is large, because the characteristics of the Middle East sedimentary basin could make the region a global hub for carbon storage.[139] For now, most projects are at the pilot stage and there is not enough financial incentive or regulatory support to advance CCUS applications to meet 2030 targets.

7%

GCC countries currently use about 7 percent of the world total of gray hydroen based on natural gas

GCC countries currently use large quantities of gray hydrogen based on natural gas, about 8.4 megatons (Mt) a year, or approximately 7 percent of the world total.[140] The current pipeline of committed projects to 2030 still has a considerable share of gray-hydrogen projects at 45 to 50 percent capacity, rather than blue-hydrogen projects, which use CCUS to mitigate emissions, or green-hydrogen projects, which use even less carbon.[141] While some of the production facilities could be retrofitted with CCUS, most hydrogen units exist as part of

[136] For example: UAE: reduction in GHG of 23.5 percent compared with business as usual (BAU); Saudi Arabia: reduction in GHG of 278 million tons; Bahrain: GHG reduction targets such as increasing the ratio of renewable energy in peak power-supply capacity to 5 percent by 2025 and 10 percent by 2035 have been set with BAU by 2030; *Global Strategic Studies Institute Monthly Report,* Mitsui & Co., December 2021.
[137] Nationally Determined Contribution Registry, UNFCCC; Climate Watch; *Middle East & North Africa Climate Roadmap (2021–2025),* World Bank, January 25, 2022; *Global Energy Perspective,* April 26, 2022.
[138] *United Nations Nationally Determined Contributions Registry,* United Nations Climate Change.
[139] *Global status of CCS 2021,* Global CCS Institute.
[140] *Hydrogen in the GCC: A Report for the Regional Business Development Team Gulf Region,* Qamar Energy, November 2020.
[141] Hydrogen is tagged as gray, blue, or green based on the production method. Gray hydrogen is produced from fossil fuels; gray hydrogen production with CO_2 capture produces blue hydrogen; green hydrogen is produced from electrolysis using renewable power.

refineries, steel factories, and petrochemical facilities. These have complex integration with the existing facility and cannot be easily retrofitted. Gas-to-liquids represents an estimated 39 percent of hydrogen consumption in the region, followed by oil refining (27 percent) and ammonia production (21 percent).[142] Current costs of hydrogen production vary depending on the technology and region, and carbon-based incentives and regulations to support decarbonization of oil and gas operations are currently limited. The result is a low level of implementation of low-carbon hydrogen technologies.

Following are four actions that the Middle East could consider taking.

Promoting incentives in the production and infrastructure of CCUS and hydrogen. Long-term targets and remuneration mechanisms that create the stable rate of return required by investors could enable successful deployment of CCUS and hydrogen projects. Streamlining ownership structures and optimizing revenue streams and incentives could help CCUS develop successfully, opening up economies of scale from the sharing of common infrastructure by different capture projects and across borders. Developing the appropriate clusters in highly industrialized locations would require collaboration among different sector players—for example, players in upstream oil and gas, refineries, and chemical and fertilizer and metals producers and cement companies. But doing this would likely require the appropriate economic incentives mechanisms.

Capture parties could be incentivized to allow for a return on the carbon, capture, and storage (CCS) investment and a pass-through of transmission and storage fees—through grants, such as the Capital Infrastructure Fund, or through competitively allocated rebates driven by the carbon market price. For example, in the United States and the United Kingdom, government support in the form of incentives and grant funding has been instrumental in expanding the applications and industries where CCS is economically viable.

Launching exploration programs for suitable carbon sequestration sinks in the region. Capturing, transportation, and technology costs are the major cost drivers for scaling the use of captured carbon. The Middle East could form CCUS hubs across the region by mapping high-CO_2-emitting industrial regions to the closest natural carbon sinks. One example is UAE's plans to expand capacity at the Al Reyadah CCS plant of Abi Dhabi National Oil Company (ADNOC). The plan is to sequester up to 0.8 Mt of CO_2 annually, a volume expected to rise to 5 Mt by 2030.[143] The Middle East is a suitable region for carbon storage, with a vast and accessible underground storage potential of about 30 Gt.[144] Suitable sites for basins storage could be further explored. These include sandstone aquifers in Saudi Arabia, carbonate reservoirs in the UAE, and sandstones in Kuwait.[145] Further, driving investments in technology through global partnerships could enable the future use of the captured carbon in applications beyond enhanced oil recovery, such as synthetic fuels, CO_2-enriched concrete, and supercritical CO_2 for power generation.[146]

30 Gt

The Middle East has underground carbon storage potential of about 30 Gt

Strengthening local demand for CCUS and low-carbon hydrogen and ammonia use. Currently, hydrogen liquefaction and transportation are expensive and require large investments in the short term. Ammonia could potentially act as a one-way carrier of hydrogen fuel, as ammonia easily liquefies at –33°C (versus –253°C for hydrogen). Governments could play a leading role in the initial development of the hydrogen economy through hydrogen road maps, including setting targets for national hydrogen and ammonia production and implementing regulations to decarbonize different sectors to spur local demand for hydrogen. Setting up bilateral partnerships could secure demand for local hydrogen exports, thereby

[142] *Hydrogen in the GCC: A Report for the Regional Business Development Team Gulf Region,* Qamar Energy, November 2020.
[143] "ADNOC to Build World-Scale Blue Ammonia Project," ADNOC press release, May 24, 2021.
[144] *Global status of CCS 2021,* Global CCS Institute.
[145] *CCUS deployment challenges and opportunities for the GCC, A report prepared for the Oil and Gas Climate Initiative,* AFRY, January 2022.
[146] Supercritical CO_2 is a fluid state of carbon dioxide where it is held at or above its critical temperature and critical pressure.

developing a perspective on the localization of hydrogen production across the value chain and supporting hydrogen deployment through regulatory support.

A local market for hydrogen in parallel to the development of export corridors could contribute to creating the foundations of a hydrogen ecosystem. Guidelines around compliance requirements for carbon markets could help address demand-side issues for hydrogen, as compliance requirements could raise the demand for carbon trading. Adequate carbon prices could increase viability and financial incentives to switch to blue and green hydrogen. Facilitating long-term offtake agreements between customers like as steel or fertilizer producers and hydrogen producers could drive demand in clean-hydrogen projects through a minimum utilization guarantee.

$2 per kg

GCC countries are among the lowest-cost regions in the world for green hydrogen production, at less than $2 per kilogram of hydrogen

Securing international partnerships for co-development of CCUS and hydrogen projects, as well as export of green commodities and products. As noted, the GCC countries are among the lowest-cost regions in the world for green hydrogen production, given local natural resources, with potential production costs below $2 per kilogram of hydrogen (kgH2).[147] This compares with a global cost range of $2.8 to $6.3 per kgH2 in 2020.[148] For example, the current level of Oman's electrolysis is about $1.8 per kgH2, lower than Saudi Arabia's steam methane reforming with CCS of about $3 to $4 per kgH2.[149] Scaling up both blue and green hydrogen as well as ammonia production could drive international partnerships and investments for hydrogen exports.

These low-cost, low-carbon hydrogen production capabilities could enable the GCC to produce green products such as aluminum, cement, and steel at a lower cost than other economies could. For example, using clean hydrogen instead of natural gas in the refining process of alumina can reduce emissions from aluminum production. As companies across sectors worldwide aim to achieve net zero, these green products have a potential for green premiums,[150] which could give manufacturers an edge among environmentally conscious buyers—and greater pricing power.

2

Boosting renewables development and facilitating renewable integration by upgrading supporting infrastructure

27.3 GW

Saudi Arabia recently increased its 2023 renewables targets from 9.5 GW to 27.3 GW

Middle Eastern energy investments in renewable energies remain lower than those in petrochemicals, oil, or gas. On average, GCC countries lag behind on the path to their 2030 stated targets in terms of the share of renewables in the power-generation mix, even as their announced targets have become more ambitious. For example, Saudi Arabia recently increased its 2023 renewables targets from 9.5 GW to 27.3 GW.[151] Its renewables capacity in 2021 was 0.5 GW.[152]

Market economics remain a challenge, since putting a price on carbon still lacks a strong policy framework: one of the challenges to developing carbon markets is the lower economic incentives of carbon credits compared with very low bidding prices for renewables. Given that

[147] Rashed Albinali, "COVID-19, the GCC and the Race for Renewables," The Euro-Gulf Information Center, January 8, 2021.
[148] "A hydrogen strategy for a climate neutral Europe," European Commission, July 8, 2020; Conversion rate used: $0.877 per euro, as per 2020 exchange rates.
[149] "Middle East refineries set to grow hydrogen capacities faster than distillation to 2025," S&P Global, February 18, 2022.
[150] The green premium is the additional cost of choosing a clean technology over one that emits a greater amount of GHG.
[151] National Renewable Energy Program (NREP), Enerdata; *BP statistical review of world energy,* BP, 2022.
[152] *Renewable energy capacity,* 2022.

power in the region is relatively inexpensive and the carbon price is low, companies have little incentive to adopt renewables. Renewables in the Middle East are among the cheapest in the world[153]: our analysis suggests, for example, that solar bid prices are as low as $14 to $17 per MWh.

Large-scale renewable deployment would require local supply chains. However, if the take-off of local project demand were slow and margins were thin from low bid prices, the economies of scale for locally manufactured clean energy technologies would be limited. One other important factor is the time needed for licensing and permitting processes, which can slow the build-out of renewables. A mismatch between a project's scope and its feasibility can also lead to delay. On average, a solar project takes three to four years to complete in the Middle East. Given that the average size of the installed projects is currently only about 500 to 800 MW, the uncertainty risk is increased for long-term investments, according to McKinsey analysis. Following are three actions to be considered:

3–4 years

Solar projects in the Middle East take three to four years, on average, to complete

Driving investors' appetite for renewables by enhancing demand and limiting development challenges such as permitting. PPAs implemented at-scale in the region could assure long-term cost recovery cash flows for energy providers, manage competition, and increase investors' appetite. Market frameworks that allow for flexibility in bilateral agreements could increase the corporate PPA uptake through the formation of virtual PPAs. This could be achieved, for example, through open-access reforms.[154]

Further, streamlining the permitting processes in the region could reduce the time project implementation takes. This would mitigate the risk of long-term cost volatility, since rising shipping costs and PV-module price fluctuations could affect deadlines.[155] A mismatch between the targets announced in the country visions and plans and the pipeline of actual projects could lead to uncertainty and inefficient planning among investors and key stakeholders.[156] Testing feasibility of capacity build-out accurately against announced time lines could increase the transparency and reliability of local energy initiatives.

Stimulating buyer-side appetite toward PPAs through new mechanisms such as a single buyer. Today projects have limited profitability, as costs to consumer are below market value. However, countries in the Middle East are expected to move toward cost-reflective tariffs, potentially triggering a rise in the cost of electricity. PPAs could represent an opportunity for industrial companies to hedge electricity prices at current levels, preempting changes in the market.

Strengthening the reliability of the power transmission grid and enabling storage investments to support a scaling up of renewables. Given the Middle East's plans to deploy renewables at a large scale, investments in grid stabilization and storage would be required to ensure the reliability of supply and the integration of renewables into existing grid systems. Because of intermittence and the volatile nature of renewable energies, grid-stabilization technologies such as high-voltage direct current (HVDC) and a flexible alternating current transmission system (FACTS) could play an important role in ensuring a successful energy transition, while maintaining transmission quality and efficiency. By enhancing the flexibility and stability of the power supply, energy storage systems would also play a key role in the integration of variable renewable-energy systems into the power grids.

[153] Harry Apostoleris, Amal Al Ghaferi, and Matteo Chiesa, "What is going on with Middle Eastern solar prices, and what does it mean for the rest of us?" *Progress in Photovoltaics,* February 23, 2021.
[154] Open access is an arrangement under which a power producer establishes a solar power plant at an appropriate location and signs a medium- or long-term power purchase agreement with a consumer.
[155] "Middle East adding solar capacity despite some delays, rising polysilicon costs," S&P Global, July 11, 2021.
[156] "Saudi Arabia—Country Commercial Guide," International Trade Administration, July 6, 2022.

4%

Just 4 percent of the energy consumed in industry in the Middle East is electricity

3

Incentivizing electrification and energy efficiency in buildings, industry, and the transportation sector

Several regions in the Middle East achieved low emission intensity in oil and gas operations—of about 25 kg of CO_2e per barrel, versus 35 kg in the United States—by implementing best practices such as reservoir management, flare minimization, energy efficiency, GHG emissions management, and methane-leak detection and repair.[157] According to McKinsey research, 44 percent of the energy consumed in industry globally is fuel consumed for energy, and half of fuel consumed for energy could be electrified with technologies that are available today.[158] In the Middle East, 95 percent of the energy-related consumption in industry is currently fossil fuel based and only 4 percent of the energy consumed is electricity.[159]

According to McKinsey estimates, public and passenger transport accounted for 64 percent of the transport-related emissions in 2021. The adoption of EVs in the Middle East has been lower than in other regions, because of various factors. First, current grids are overstretched and may be unable to support the high load requirements of fast charging. Second, current battery technologies are designed to operate optimally under a battery temperature of 50°C, but temperatures in several regions of the Middle East can often exceed this value, resulting in potential operational challenges. And, finally, the hot climate as well as long distances between cities leads to heavy air-conditioner use that drains batteries more quickly.[160]

Air transportation accounted for 4.5 percent of employment and 7.6 percent of GDP in Middle Eastern countries as of 2018.[161] Carbon offsets and other global reforms in international aviation could affect the region's aviation industry. Today airlines in the region are focusing mostly on purchasing carbon offsets. Sustainable aviation fuels could also become relevant as the bar for decarbonization targets rises. The Middle East's production of these sustainable aviation fuels could face some regional challenges, including limited availability of biological feedstock, cyclical demand for renewables power, limited storage, and water scarcity.[162] Following are three actions to consider.

Promoting investments in electrification and energy efficiency in the key industrial sectors, particularly refining, chemicals and upstream oil and gas. The electrification of upstream assets could further reduce emissions in oil and gas operations. Research and development of electric industrial equipment and processes could significantly reduce the capital costs and increase the energy efficiency of electric equipment. The integration of renewable energy resources results in both the increase of electricity in the overall power-generation mix, as well as the falling cost of electricity. Other financial factors to promote investments could include a price on carbon emissions to make electrification more attractive to industrial companies.

[157] McKinsey Energy Insights refinery emission model; "Global carbon intensity of crude oil production," *Science,* August 31, 2018.
[158] Occo Roelofsen, Ken Somers, Eveline Speelman, and Maaike Witteveen, "Plugging in: What electrification can do for industry," McKinsey, May 28, 2020.
[159] World Energy Balances: India, IEA, 2022.
[160] Saleh Alotaibi, Siddig Omer, and Yuehong Su, "Identification of Potential Barriers to Electric Vehicle Adoption in Oil-Producing Nations—The Case of Saudi Arabia," MDPI, August 12, 2022.
[161] "Middle East," Aviation: Benefits Beyond Borders.
[162] *Power-to-Liquids Roadmap: Fueling the aviation energy transition in the United Arab Emirates,* World Economic Forum, July 2022.

50%

McKinsey estimates that half of the fuel used for energy could be electrified with technology available today

A McKinsey study estimates that 50 percent of the fuel used for energy could be electrified with technology available today.[163] Up to a heat demand of approximately 400° C, electric alternatives to conventional equipment are commercially available. For example, some industrial sites already use electric heat pumps for low- and medium-temperature heat demand and electric-powered mechanical vapor recompression equipment for evaporation. Electric furnaces for industrial heat demand up to approximately 1,000°C are technologically feasible but not yet commercially available for all applications. For example, BASF is developing electric petrochemical cracking furnaces that can reach 850°C.[164]

Accelerating low-carbon transport uptake by promoting EV adoption for light vehicles and hydrogen-based solutions for medium- and heavy-duty vehicles. Although the purchase cost of EVs is generally higher than that of internal-combustion-engine vehicles, focusing on reducing nonfuel operating costs could further stimulate EV adoption, especially since the Middle East's domestic fuel prices are among the lowest. Scaling benefits for EV users through charging subsidies, parking, tax credits, and vehicle registration fee waivers across the region could also incentivize drivers.

Hydrogen could enable emissions reduction in the transportation sector, particularly in segments such as heavy-duty vehicles that are difficult to electrify. To overcome challenges and de-risk infrastructure investments, operators could focus on building an ecosystem that secures both supply and demand. Such an ecosystem could be developed with the promotion of incentives for fleets to ensure offtake, for original-equipment manufacturers (OEMs) to design and manufacture green-powered vehicles, and for hydrogen producers to invest in hydrogen refueling stations.

If the adoption of EVs is to scale up, the ease of charging them will also be important. EV-charging infrastructure could become a standard part of building design, for example, and requirements and incentives could be introduced for apartment buildings and other multiunit dwellings to offer chargers to residents. Companies could likewise install chargers at workplaces. Utilities could consider offsetting grid modernization costs by developing a new grid fee system that accounts for peak-demand charging needs, protects the grid from overutilization, and keeps charging economically viable at ultrafast charging locations. Using data and analytics, such as geospatial analytics for network planning, could allow planners to optimize charging locations based on traffic flows, local grid status, and other relevant factors. Integrated trip planning or charging-reservations tools could be developed to reduce so-called range anxiety among potential EV drivers.

In the airline and maritime industries, mitigating emissions with fuel-efficiency promotion and progressive uptake of sustainable aviation fuel and other green solutions. The Middle East has some of the world's largest airport hubs and bunkering ports. It is thus well positioned to play an important role in promoting efficiency in the airline and maritime industries. Policies across regions are favoring the production of sustainable aviation fuel (SAF). For example, the European Union's ReFuelEU initiative mandates a minimum 2 percent volume of SAF by 2025 and 63 percent by 2050 for all aircraft operators at EU airports.[165] In addition, California's low-carbon fuel standards in 2019 recognized SAF as eligible to generate credits.[166] Airlines operating in these regions would thus need to make progress in decarbonizing to continue to operate.

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[163] Occo Roelofsen, Ken Somers, Eveline Speelman, and Maaike Witteveen, "Plugging in: What electrification can do for industry," McKinsey, May 28, 2020.
[164] Ibid.; "BASF, SABIC and Linde start construction of the world's first demonstration plant for large-scale electrically heated steam cracker furnaces," BASF, September 1, 2022.
[165] "Sustainable aviation fuels fact sheet," IATA, May 2019; "Fact Sheet: EU and US policy approaches to advance SAF production," IATA.
[166] Ibid.

$15.7 billion

The sustainable aviation-fuel market is projected to grow from $219 million in 2021 to $15.7 billion by 2030

The sustainable aviation-fuel market is projected to grow from $219 million in 2021 to $15.7 billion by 2030, an annual average growth rate of just over 60 percent.[167] Investing in technology around synthetic kerosene from captured CO_2 with hydrogen could facilitate decarbonized air travel in the region's air hubs such as Dubai, Doha, and Abu Dhabi. A push toward low-CO_2 and low-sulphur emitting fuels would further reduce the consumption of heavy fuel oil and marine gas to allow for cleaner alternatives like LNG, ammonia, and hydrogen.

4

Promoting green businesses that are building new energy solutions to diversify the local economy and capture new economic opportunities from the transition

Given the Middle East's heavy dependence on fossil fuel exports, commodity price shocks could affect the local socioeconomic conditions.[168] Hydrocarbon reserves and related revenues may experience greater risk challenges because of volatility in the event of lower oil prices.[169] These factors are motivating Middle Eastern countries to diversify economies by developing nonoil and gas sectors.

Historically, oil and gas have played a significant role in transforming the region's economies, thus boosting both rapid economic and rapid industrial growth. The global energy transition will create new opportunities and technologies for clean energy. Regional economies could benefit from the energy transition by building on their current strengths to diversify, drive innovation, and boost new sectoral growth—for example, in clean-energy technology, low-carbon fuels, and green products, among others. A key challenge is to do so by creating not only GDP but also sustainable jobs and the appropriate talent supply.

Empowering the nonenergy private sector, small and midsize entrepreneurs, and entrepreneurship more broadly could result in faster economic diversification. Entrepreneurs face challenges such as high incorporation costs, lack of financing for small and midsize entrepreneurs, and difficulties with licensing. Research suggests that the Middle East has realized only 8 percent of its overall digital potential, compared with 15 percent in Western Europe and 18 percent in the United States.[170] There are three actions to be considered.

Streamlining market-entry processes to promote public-private partnerships and foreign investments in clean technology. The Middle East could build on its existing infrastructure and R&D capabilities in oil and gas to further drive innovation across sustainable products and to transition as a sustainable energy exporter. Significant technological advancements and investments are required to achieve scale in low-cost CCS, utilization of captured carbon, and low-carbon hydrogen and SAFs, and most such technologies are in a nascent stage. Public-private partnerships involving national oil companies could support the development of technologies that are critical for hydrogen development, namely CCUS, liquefied hydrogen transport, direct air capture, and hydrogen fuel cells for trucks.

Scaling up special economic and technology zones to attract foreign domestic investment (FDI) in nonenergy segments could provide incentives to investors. A framework for allocating

[167] Markets and Markets, "Sustainable Aviation Fuel Market," Report Code AS 7756, February 2022.
[168] "World Bank national accounts data, and OECD national accounts data files," World Bank Group; *BP Statistical Review,* 2022.
[169] "Economic Diversification in Oil-Exporting Arab Countries," IMF, April 29, 2016.
[170] Enrico Benni, Tarek Elmasry, Jigar Parel, and Jan Peter aus dem Moore, "Digital Middle East: Transforming the region into a leading digital economy," McKinsey, October 2016.

a certain share of contracts and auctions to small businesses could provide viable business opportunities for them to operate profitably. Setting up standards for disclosures to improve transparency and reforms to facilitate exits could further encourage investments.

Creating a start-up ecosystem and incentive schemes to promote further innovation in clean technology. Start-ups boost the economy with innovative technology and create new industries over time. Entrepreneurs tend to solve local problems and could potentially drive innovation and shape the future for growth. Crafting investment theses to guide investors and entrepreneurs in their investment decisions and to establish goals in the Middle East context could help attract the right investment talent and capital. Frameworks facilitating coinvesting with other funds could allow for a healthy pipeline of deals while minimizing the downside risk associated with seed-level investments. Setting up patient capital pools and encouraging national oil companies and other global players to participate could boost investments in early-stage technologies. Further, grants, credit support schemes, and funding opportunities could encourage start-ups and small and medium-size enterprises.

Investing in education systems with a focus on developing the skills for green energy and manufacturing and programs to train local talent. The progressive move toward economic diversification would create opportunities to develop new and diversified skills. Reskilling and upskilling could empower domestic talent to drive innovation for the future, creating new employment opportunities. Investing in vocational training centers and technical colleges could spur interest among the younger generation to pursue entrepreneurship and private-sector employment in green industries. Public-private and global partnerships could be potential solutions to providing the mentorship and training required to retrain local talent.

The Middle East is positioned to take an important role in the energy transition, potentially as an exporter of clean low-carbon energy (for example, hydrogen and ammonia) and products such as green steel, thanks to a geographic location that connects markets of the West and the East as well as abundant natural resources such as solar.

Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

Europe

Europe predominantly exhibits the characteristics of the “affluent, energy-exposed” regional archetype. While this report analyzes the overall region from a broad perspective, it focuses primarily on the 27 countries that are member states of the European Union. These countries are typically established economies that are already investing in the energy transition. Many European countries are net importers of energy and thus exposed to energy-reliability and market-volatility risks.

The European Union is a leader in the global energy transition with an ambitious decarbonization agenda and strong support for clean technologies. Yet, to meet 2030 climate targets, it would need to accelerate the reduction of net GHG emissions. The energy transition could have broad economic benefits for Europe. They include increased energy reliability, economic growth and job creation—through reshoring renewables supply chains such as solar PV manufacturing, for example. Our analysis suggests that Europe could reach net-zero emissions at net-zero costs and could create a net gain of five million jobs through 2050.[171] However, realizing these opportunities would require member states to take collective and bold action to meet the goals they have set.

To seize these opportunities and promote a path to an orderly energy transition, the European nations could consider taking the following actions:

- Creating resilient, at-scale supply chains for key decarbonization technologies
- Building out energy grid infrastructure to support resilience and reduce barriers to in-region renewables
- Overcoming land-use, societal, and regulatory constraints to accelerate development of renewables
- Redesigning power markets in line with decarbonization and affordability objectives
- Ensuring affordability of clean technologies to foster their adoption and accelerate the energy transition

[171] *Net-Zero Europe: Decarbonization pathways and socioeconomic implications*, McKinsey, December 3, 2020.

Europe's starting point

The power sector in Europe draws on a wide variety of energy sources, including nuclear, solar, and wind, in addition to fossil fuels. [172] The mix of power-generation sources varies widely from country to country within Europe. For example, the share of fossil fuels in Sweden (28 percent) and France (50 percent), which use more nuclear and hydropower, is lower than in other countries such as Poland (92 percent).[173]

37%

Europe produced 37 percent of its power from renewables in 2021

Fossil fuels account for 37 percent of electricity generation, largely driven by coal, which accounts for 15 percent of the region's total electricity generation.[174] Natural gas accounts for roughly 20 percent of electricity generation,[175] of which more than 80 percent is imported from outside Europe.[176] Historically, Russia has been the largest supplier of gas to Europe; in 2020, for example, more than 40 percent of total imports of natural gas came from Russia.[177] Following the Russian invasion of Ukraine and the imposition of sanctions, total flows from Russia in the first half of 2022 fell 35 percent below the 2021 levels.[178]

Nuclear power accounts for approximately 25 percent of Europe's electricity production, of which more than half is produced in France.[179] Nuclear power production has fallen by 4 percent since 2019, with France (a loss of 18 TWh), Sweden (13TWh), and Germany (6TWh) leading the decline.[180]

Europe delivers high levels of renewable energy generation, producing 37 percent of its power from renewables in 2021. China produces 15 percent and the United States 12 percent.[181] Wind (36 percent) and hydropower (33 percent) represented more than two-thirds of total renewable energy generation, with solar (14 percent) and solid biofuels (8 percent) also constituting large shares of total electricity generated from renewable sources.[182]

While renewable energy generation in the region as a whole is high, renewable potential varies among countries. Northern European countries, such as Denmark (specific PV power output of 2.67 to 3.1kWh/kWp[183]), have lower potential for solar PV than countries in the south, such as Spain (3.08 to 4.9kWh/kWp) and Italy (2.67 to 4.54kWh/kWp).[184] [185] Countries near the North Sea can capitalize on offshore wind potential, as more than half of the 300 GW of offshore wind Europe aims to deploy by 2050 will be located there.[186]

Europe contributed 2.7 Gt per year of GHG emissions in 2021, behind China and the United States.[187] The EU market is the third-largest global emitter. It accounts for 8 percent of global energy-related emissions.[188] Germany is the heaviest emitter (23 percent of Europe's emissions), followed by Italy (11 percent) and Poland (11 percent).[189] Five sectors emit the bulk of Europe's GHGs: 28 percent comes from transportation; 26 percent from industry;

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[172] *European Union 2020,* IEA, June 2020.
[173] "Share of primary energy from fossil fuels," Our World in Data.
[174] "European Electricity Review 2022," Ember, February 1, 2022.
[175] *BP energy outlook,* 2022.
[176] Europe relies primarily on imports to meet its natural gas needs, EIA, February 11, 2022.
[177] Gabriel Di Bella, Mark J Flanagan, Karim Foda, et al., *Natural Gas in Europe: The Potential Impact of Disruptions to Supply,* International Monetary Fund, July 19, 2022.
[178] Ibid.
[179] "European Electricity Review 2022," Ember, February 1, 2022; "Nuclear Power in the European Union," *World Nuclear Association,* October 2022.
[180] Ibid.
[181] How much of U.S. energy consumption and electricity generation comes from renewable energy sources? EIA.
[182] "Renewable energy statistics," European Commission, January 2022.
[183] The PV power output (PVOUT), defined as the specific yield, is used to illustrate this potential. PVOUT represents the amount of power generated per unit of the installed PV capacity over the long-term, and it is measured in kilowatt hours per installed kilowatt peak of the system capacity (kWh/kWp).
[184] Marcel Suri, Juraj Betak, Konstantin Rosina, et. al, *Global Photovoltaic Power Potential by Country,* Energy Sector Management Assistance Program (ESMAP), World Bank; Global Solar atlas.
[185] This metric refers to the average long-term daily kWh per kW of panel capacity.
[186] Magnus Højberg Mernild, "Harnessing the North Sea's green energy potential," State of Green, May 17, 2022.
[187] *BP energy outlook,* 2022.
[188] Ibid.
[189] "Carbon dioxide emissions in the European Union, 2000-2021," Statista; See *Global Energy Perspective 2022,* "current trajectory" scenario.

23 percent from power; 13 percent from buildings; and 13 percent from agriculture. Across sectors, fossil fuel combustion is the biggest source of GHGs, accounting for 80 percent of Europe's emissions.[190]

55%

By 2030, the European Union aims to reduce emissions by 55 percent from 1990 levels

45%

Europe aims for renewables to account for 45 percent of the energy mix by 2030

Nationally determined contributions

In 2020, the European Union's 27 member states approved the European Green Deal. The European Union committed to reaching net-zero emissions by 2050, with an interim target for 2030 of reducing emissions by 55 percent from 1990 levels.[191] In July 2021, the European Commission released the Fit For 55 package, a set of proposals for revising and updating legislation to put it in line with the 2030 target.[192]

In early 2022, the European Commission presented the REPowerEU plan to bolster energy reliability. In response to Russia's invasion of Ukraine, the plan sets out measures to end Europe's dependence on Russian fossil fuels. In addition to replacing coal, oil, and natural gas, the EU Commission estimates that energy savings, efficiency, substitution, electrification, and uptake of green hydrogen, biogas, and biomethane by industry can save an additional 35 billion cubic meters of natural gas beyond the reductions already foreseen in the Fit for 55 proposal.[193] To displace natural gas, the plan raised Europe's target for the share of renewables in the energy mix to 45 percent by 2030. To reach the target, it aims to bring online additional solar PV capacity to achieve this target: more than 320 GW by 2025—which is double today's capacity—and almost 600 GW by 2030.[194]

Despite these climate targets, between 2019 and 2021, the European power sector emissions decreased at less than half the rate necessary to stay on track with the 1.5°C pathway.[195] For Europe to meet its climate commitments, it will need to significantly accelerate its pace of decarbonization.

Priority measures that could accelerate a more orderly energy transition

The challenges of reducing emissions in Europe vary by country. Some economic areas, such as Benelux, rely on heavy industry and serve as hubs for air freight and shipping, which are more difficult sectors to decarbonize. Other countries, such as Poland, rely on coal-based power generation. For all these differences, several common obstacles stand in the way of Europe's ability to realize its climate goals, including: (1) reliance on imports for supply of raw materials and components, in addition to a shortage of qualified labor needed for the energy transition; (2) required upgrade of infrastructure and system flexibility to accommodate a shift to renewables as a primary energy source; (3) slow-paced renewable energy development because of land-use constraints, societal opinion, and demanding regulatory processes; (4) design of power markets that does not optimally support increased supply of low-cost energy from intermittent renewables; and (5) rising energy prices, which have already raised energy bills and affected public support for the energy transition.

Stakeholders could consider taking five near-term actions to overcome these obstacles and meet the 55 percent emission reduction target by 2030, while simultaneously reducing Europe's reliance on energy imports.

[190] *Net-Zero Europe: Decarbonization pathways and socioeconomic implications,* McKinsey, December 3, 2020.
[191] *2030 Climate Target Plan,* European Commission; announcements at COP27 indicate that the European Union intends to update its target to 57 percent reduction by 2030.
[192] "European Union," Climate Action Tracker.
[193] *REPowerEU: Affordable, secure, and sustainable energy for Europe,* European Commission.
[194] Ibid.
[195] Charles Moore, "European electricity review 2022," Ember, February 1, 2022.

1

Creating resilient, at-scale supply chains for key decarbonization technologies

Europe depends on imports for critical raw materials and components required for decarbonization technologies—including solar panels, wind turbines, and batteries. Volume shortages, long lead times, and unreliable supplies of raw materials and components could result in shortages of clean technologies, while price volatility can steeply increase costs. Critical materials, such as nickel and cobalt, are expected to be in short supply by 2025.[196]

The production and processing of many critical materials and components that are crucial for the energy transition are highly concentrated in a few countries. This concentration renders the supply chain vulnerable to geopolitical risks, political instability, and disruptions in trade relationships. For example, hard-to-substitute neodymium and praseodymium—key rare-earth metals in wind turbines and electric vehicles (EV)—depend heavily on China's refining capacity. China also supplies about 70 percent of solar modules and about 60 percent of lithium battery components.[197] Supply chain disruptions, such as export restrictions, could result in severe shortages and price increases of these components and thereby slow the expansion of renewable deployment in Europe. To re-shore production of these technologies, Europe will need to bridge the current large cost gap; solar modules made in Europe are currently 25 to 30 percent more expensive than those made in China.[198]

1 million

Almost one million full-time skilled workers would be needed in 2030 to develop and construct centralized renewable energy assets

Reaching the Fit for 55 target of a 45 percent share of renewables in the energy mix would, moreover, require a massive redeployment of labor. Almost one million full-time skilled workers would be needed in 2030 to develop and construct centralized renewable energy assets alone, according to our analysis, not accounting for the mobility or decentralized energy transition. That is more than triple the number needed today—and the increase will come at a time when the labor pool is shrinking.[199]

Three actions could be taken by business leaders and policymakers to mitigate the impact of supply chain bottlenecks in Europe.

Building partnerships with raw-material suppliers from a diversified set of exporting countries to create a more resilient supply chain. Diversification of import sources for a given commodity could reduce exposure to geopolitical risks. As part of a comprehensive resources and materials strategy, Europe could identify scarce materials and technologies with geographically concentrated production and develop partnerships with a range of suppliers from different geographies. In some cases, these partnerships could result in significant economic development for the partnering nation while reducing cost and risk to Europe.

For example, the European Commission, in partnership with the World Resources Forum Association, proposed an EU-Africa partnership on sustainable raw materials supply chain. This program seeks to secure access to critical raw materials for European industrial value chains, from exploration and extraction to refining and recycling. Similar additional programs may allow countries across Europe to forge a more resilient and diversified supply chain.[200]

[196] Cristina Brooks, "Europe needs EV recycling revolution to meet net-zero goals: study," *S&P Global,* April 26, 2022.
[197] Kevin Adler, "Geopolitics on the rise in solar PV manufacturing," *S&P Global,* February 8, 2022; Al Root, "China is Winning the Lithium Wars. What it Means for Tesla and Other EV Stocks," *Barron's,* May 18, 2022.
[198] *Global Energy Perspective 2022;* International Renewable Energy Agency (IRENA); National Renewable Energy Laboratory (NREL).
[199] European Parliament, press release, "Parliament backs boost for renewables use and energy savings," European Parliament, September 14, 2022.
[200] *Africa-EU Partnership,* European Commission; *Building EU-Africa partnerships on sustainable raw materials value chains (CSA),* European Commission.

Scaling up European manufacturing of critical technologies. Where possible and economically sensible, reshoring of clean-technology manufacturing could reduce vulnerabilities in supply chains. For example, the manufacturing of solar modules, batteries, and subcomponents such as semiconductor products could enable Europe to reduce its dependence on interregional relationships. Investments in local manufacturing could also create jobs and boost the economy.

European states would have a natural role in assessing and prioritizing support measures, such as grants or subsidies, for onshoring of manufacturing capacity. The Innovation Fund, for example, could enable investments to scale production of critical technologies. To make local manufacturing competitive with imports, ecosystems may look to realize scale advantages.

Attracting and training the workforce to ensure adequate labor to scale clean technologies. Companies could attract talent by communicating their green impact and by developing clear professional development pathways for blue-collar workers. Alongside retraining programs through vocational schools and on-the-job programs, companies could also foster the international and cross-sector deployment of workers. Governments could support these programs by providing dedicated funding. Furthermore, policymakers could facilitate and promote intra-Europe migration and potentially provide incentives to help companies attract talent, for example by providing credits to businesses that offer jobs above a wage threshold. Lastly, re-visiting certification requirements could allow for a faster ramping-up of the needed workforce.

2

Building out energy grid infrastructure to support resilience and reduce barriers to in-region renewables

40–70%

Annual grid investments need to increase by 40 to 70 percent to support electrification, integration of renewables and distributed resources, and infrastructure digitization

Increasing the share of renewables in the energy mix to 45 percent by 2030 may require building out and enhancing grid infrastructure. Our analysis indicates that an annual grid investment of 40 to 70 percent more than the average investment of the past five years would be needed to support electrification, integration of renewables and distributed resources, and digitization of infrastructure. In addition, the need for flexibility volumes, including energy storage and demand response, could triple by 2030 because of the increased generation of intermittent renewables, according to our estimates. In Germany, for example, connections between wind power generation in northern Germany and the industrial clusters in southern Germany remain limited, restricting the ability to balance the grid through interregional connections between generation sites and demand centers.

1/3

Spain and Portugal account for one-third of Europe's capacity to process LNG

Energy security requires an adequate supply of gas. To reduce the reliance on gas imports from Russia, Europe is seeking to increase its liquefied natural gas (LNG) capacity. The limited capacity of LNG terminals across Europe currently hinders its ability to regasify LNG for transport through pipelines. Spain and Portugal account for one-third of Europe's capacity to process LNG,[201] but the Iberian Peninsula is not substantially interconnected with the rest of Europe.[202] In addition, existing commitments of main exporting regions limit the ability to secure commercial LNG supply contracts.[203]

As the energy system becomes more complex and intertwined, cross-border collaboration would allow countries to pool their relative advantages and increase resilience along value

[201] Patricia Cohen, "Portugal could hold an answer for a Europe captive to Russian gas", *The New York Times*, September 1, 2022.
[202] Interconnection capacity targets refer to the percentage of electricity produced to be transported across neighboring countries. See "Electricity interconnection targets," European Commission.
[203] "Brimming European LNG terminals have limited space for more gas," Euractiv, February 18, 2022.

15–20%

Meeting Germany's hydrogen demand could be 15 to 20 percent cheaper if the country imports hydrogen from low-cost production areas such as Spain

chains and across technologies, and countries. For example, meeting Germany's hydrogen demand could be 15 to 20 percent cheaper if hydrogen were imported from low-cost production areas such as Spain, rather than being produced locally. [204]

Four actions can be taken to support resilience and the build-out of interregional infrastructure.

Promoting integrated transmission planning and fast-tracking permitting and siting to accelerate buildout. Large-scale interconnection projects face long development times, in part because of public resistance.[205] Given the complex nature of siting new large-scale energy-transmission projects, stakeholders could identify the most critical projects within the integrated plans and preempt delays by fast-tracking permitting and siting support through regional collaboration and cooperation among European countries. Further, European countries might encourage public participation and foster greater transparency to bolster public acceptance for transmission buildout projects.

European countries could also collaborate to integrate their transmission planning. The European Network of Transmission System Operators for Electricity (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSO-G) took a first step to create integrated transmission planning, publishing for the first time in the fourth quarter of 2021 joint scenarios for the 2022 Ten-Year Network Development Plan. Continuing these efforts would likely be important to accelerating the build-out of transmission capacity.

Implementing demand-side measures to reduce peak energy loads and defer grid investments. Grid infrastructure costs are largely fixed, and deployment of new transmission capacity is slow and costly. Any resource that could improve the throughput for these assets at a lower cost and shorter time-to-market could increase their overall societal value.

Using demand-side resources has been discussed at length in some markets, for example in the United States, as a way to augment grid capacity.[206] Resources may include, but are certainly not limited to heating, ventilation, and air conditioning (HVAC) systems using thermal storage to preheat buildings, optimized charging of battery-electric vehicles, time (and locational) shifting of data-center computing loads to areas where the grid is less stressed, traditional industrial load curtailment, and control of large-scale electricity demand such as for more green hydrogen production. The overall loading of the grid infrastructure could be reduced by incentivizing flexible demand-side resources to shift load when grids are most strained to periods of less strain. By relying on flexible demand, Europe could reduce the need for fossil-based energy generation to ensure energy reliability.

Enabling the development of flexible cross-national gas networks with the ability to carry cleaner fuels. Integrating natural gas and hydrogen into European gas networks can help accelerate decarbonization. Supporting the enhancement of interregional gas networks could allow Europe to both increase energy reliability and enable a more orderly energy transition. To spur the development of flexible gas networks, Europe could both retrofit gas infrastructure and build out new capacity to support green hydrogen.[207] As the gas network transitions toward cleaner fuels, Europe could consider setting regulatory standards for blended hydrogen and natural gas infrastructure, as well as revising regulations that dictate the types of fuels that transmission-system operations and distribution-network operations are allowed to transport.[208]

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[204] Hydrogen Council report, *Policy Toolbox for Low Carbon and Renewable Hydrogen—Enabling low carbon and renewable hydrogen globally,* November 2021.
[205] *European Union* 2020, IEA.
[206] See, for example, Evan Polymeneas, Humayun Tai, and Amy Wagner, "Less carbon means more flexibility: Recognizing the rise of new resources in the electricity mix," McKinsey, October 1, 2018.
[207] "Briefing: EU directing on gas and hydrogen networks," European Parliament.
[208] Ibid.

Raising LNG regasification capacity to support mid-term energy security and help alleviate the current energy crisis. Europe could invest in expanding LNG regasification capacity to diversify and secure supply of natural gas. Temporary floating storage and regasification units (FSRUs) are already being deployed to increase the LNG import capacity in Europe. Despite short-term market fluctuations, the current energy crisis could heighten the resolve to accelerate infrastructure expansion. The horizons, project lifetimes, and fossil fuel flows vary for different types of infrastructure, whether additional temporary FSRUs, onshore regassification terminals, or pipelines to bring LNG-based gas to load centers. Policy makers and investors could consider the balance of cost, reliability, and emissions in making investment decisions.

3

Overcoming land-use, societal, and regulatory constraints to accelerate the development of renewables

3–5x

Between 2022 and 2030, annual solar and wind installations need to grow by three to five times 2018 to 2020 levels

A rapid shift in supply to renewable energy will be needed to reach climate targets by 2030. Our research indicates that annual solar and wind installations would need to grow between 2022 and 2030 by three to five times their 2018–20 levels to meet the region's goals. Additionally, 60 percent of coal capacity would need to be retired.

However, restrictions on land use and other societal and regulatory constraints hinder the acceleration of renewables deployment. Europe's population density and growing concerns about how land is used have made it more challenging to gain access to adequate land on which to build onshore wind and solar power. In Germany, more restrictive regulations have reduced annual installations of onshore wind capacity in recent years. Furthermore, renewables often compete with alternative uses of land, such as agriculture and biomass.

Long permitting timelines further impede renewables' deployment. For example, lead time for permitting for onshore wind facilities can take three to 10 years because of complex and non-uniform regulation, varying permitting capabilities among authorities and developers or transmission system operators, and limited societal acceptance.[209]

Business leaders and policymakers would take four important actions.

Simplifying and streamlining permitting processes to shorten renewable project development timelines. Permitting is the part of the renewable energy resources and transmission expansion process that takes the longest. Lead times for permits vary significantly across Europe: permitting can require three to 10 years for onshore wind and one to six years for solar PV.[210] Harmonizing regulations and establishing a central infrastructure authority to oversee permitting timelines, as has been done in the UK through the Government Major Projects Portfolio, could help streamline processes across Europe. In addition, creating a fast-track process for repowering and introducing process flexibility to accommodate changes in technology could help to shorten timelines. For instance, in Germany, repowering most plants for the same capacity can be done without requiring new authorizations.

Reviewing and potentially revising regulations to increase access to and safeguard land. A significant share of the land that could be used for renewable energy deployment today

[209] *"Guidance to Member States on good practices to speed up permit-granting procedures for renewable energy projects and on facilitating Power Purchase Agreements,"* European Commission, Commission Staff Working Document, May 5, 2022.
[210] Ibid.

39%

In Germany, 39 percent of potentially available land for renewable energy deployment is excluded by rules that set a minimum distance to infrastructure

is either not technically suitable or subject to regulatory rules.[211] In Germany, for example, 39 percent of potentially available land is excluded by rules that set a minimum distance to infrastructure, such as airports, railways, water, and settlements, according to our analysis. Reviewing regulations about the distance between settlements and onshore wind facilities could help increase the area suitable for wind power generation. For example, relaxing the distance-to-settlement rules in Bavaria to be the same as those in Lower Saxony would increase suitable land for renewable development eightyfold, allowing for the generation of 100 GW of additional capacity, according to our analysis. Additionally, public bodies could attract investment by proactively identifying areas that are suitable and available for renewables development and prioritizing these to accelerate permitting and interconnection.

Maximizing the re-powering of existing installations to improve land productivity. Over the past few decades, innovation has significantly improved energy capture of clean technologies. Innovations include tracking and bifacial solar panels, larger wind turbine generators built on taller towers, and blades with the aerodynamic ability to better capture energy at differing windspeeds.

At the same time, existing wind and solar farms are often located on sites with the highest renewable potential, for example high-capacity factors of solar or wind sources and with close interconnections. Given that these projects often deploy older technologies, they may be producing less energy than the renewable potential. As projects age, owners and grid planners could seek out locations where sites can produce incrementally more energy with the same footprint and re-power where the scrapping is outweighed by improved output.

Launching social awareness campaigns and implementing incentives to improve public acceptance of solar and wind projects. Public opinion concerns about renewables are usually local issues that could be best addressed with local solutions. These would involve the public, not just landowners, in the planning process. Participation of the local community in the benefits of the project and increased procedural transparency could also ease local concerns.

Projects aimed at gaining public acceptance have encouraged and incentivized local ownership (by citizens and businesses) of renewable energy sources. For example, to achieve its target of 6 GW of onshore wind power by 2020, the Netherlands initiated a goal of 50 percent local ownership of production of onshore renewables by 2023.[212] To overcome public concerns, the Netherlands afforded residents and businesses the opportunity to participate in the decision-making process, from location and siting to sharing in the revenues. Ultimately, fostering public participation and shared ownership in the development of renewables bolstered widespread acceptance of wind parks across Dutch provinces.[213]

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[211] Suitable land excludes urban areas, forests, water, airports, low renewable capacity zones, high slope areas, military zones, protected land (e.g., biodiversity areas), regulatory constraints on distance to settlement for onshore wind and ban of solar PV on cropland (for Italy only).

[212] Jaclijin Matijssen, "The cooperative wind of change? Research on the effect of cooperative ownership and vicinity of existing wind turbines on the development of wind projects in the Netherlands," Radboud University, February 2019.

[213] Esther Verkaik, "Dutch wind farm blows away opposition as 'new millers' get a stake," *Reuters,* August 29, 2022.

4

Redesigning power markets in line with decarbonization and affordability objectives

10–20%

Operations and maintenance expenses over the life of a solar or wind farm are just 10 to 20 percent of its lifetime cost

Power and commodity markets have generally been designed around energy systems for which variable expenditures are expected to be made. As a result, these markets fluctuate according to variable costs. While the natural gas burned by a combined cycle gas plant built in the mid-2000s might have expected to be 60 percent to 70 percent of its lifetime cost, the variable expenses over the life of a solar or wind farm are very low, with operations and maintenance expenses of just 10 percent to 20 percent, according to our analysis.

Current market designs factor in operating costs, as prices are set based on marginal production costs for power generation units. This has been an incentive for technological developments such as more efficient combustion turbines. However, given that in the future more primary energy supply will come from variable intermittent renewable resources with marginal cost of dispatch, current markets do not provide an equivalent operational mechanism to support the transition. Indeed, the current market structure pays for neither the energy that is produced, nor for the characteristics of the current fleet that are necessary for a reliable and resilient system. Four actions could be considered to address this.

Revising power markets to strengthen the system in the long term and attract investments. Current wholesale power markets are mainly based on energy markets, reflecting the cost of the power-generation technology producing the incremental (marginal) unit of energy at any given time. While the current system ensures effective dispatching of resources, it does not support long-term infrastructure of supply investment decisions, such as flexible capacity to enable an increase in renewables. Power markets could be revised to create long-term resilience and attract investments, while stabilizing the cost of supply for end-users. Governments could consider ways to redesign power markets from options that include centralized competitive auctions, such as contract-for-differences for renewables and long-term auctions for energy storage, to PPAs through, for example, centralized market platforms or green sourcing obligations on large customers and retailers.

A potential design outcome that could help balance longer-term price signals for reliability, resilience, and system decarbonization with incentives for short-term resource efficiency, scarcity, and system balancing. Regardless, market participants, planners, and policymakers would likely need to continue to pay close attention to managing price and supply volatility to which consumers are exposed. The recent energy volatility has caused significant public distress and could affect confidence in an orderly transition. However, volatility may also create a price signal for investments in system flexibility and balancing.

Creating more transparency in energy pricing with more granular bidding zones. Many national markets have a single clearing price for electricity, with little to no accounting for transmission-grid constraints. However, grid constraints often cause discrepancies between demand and supply of power within clearing regions. Complex mechanisms have been introduced to ensure grid balancing, but they often do not provide clear pricing signals—particularly to demand-side resources.

Introducing more granular bidding zones, as has been done in many global markets, including Norway, Sweden, Texas, and New York, could create more transparent pricing signals across the energy system. More localized bidding zones enable price clearing to occur at or near the point of generation. The resulting local price reflects transmission constraints. By including the basis risk in the market, the signals for where to build additional supply or where to site demand would lead to more efficient outcomes.

Developing mechanisms that incentivize long-term reliability of energy supply. Gas storage enables long-duration energy storage and seasonal balancing across the energy system in Europe. To secure energy supply, especially during winter months when demand peaks, mechanisms and policies could be developed to minimize shortages. One possible option would be to offer market participants a financial incentive to fill storage. Long-term arrangements for additional sources of gas may be supported through these requirements, given more-easily contracted offtake.

Creating compensation mechanisms to reconfigure, rather than stranding, assets. Fossil fuel-fired power plants do not always recover their costs, given their higher operational costs compared with renewables. Under the current market design, early retirement of these assets is sometimes more economically viable than continuing to operate them. However, these plants could become critical for securing energy supply, for example during multi-day droughts of renewables. Capacity markets could be implemented to compensate assets that can ensure system stability to reduce supply volatility. For example, gas plants in Europe could gradually transition to low-utilization assets that provide power during multi-day periods of low renewables production. Instead of classifying these as stranded assets, decision makers could designate those with good operational records as sources of surplus capacity whose role helps mitigate system volatility and provide reliability of supply.

5

Ensuring affordability of clean technologies to foster their adoption and accelerate the energy transition

10%

Meeting Europe's emissions goals could reduce average energy costs in the region of about 10 percent

1/3

A fully electrified family consumes around one-third of the energy of an average family

Our analysis indicates that, when using pre-crisis commodity forecasts, meeting Europe's emissions goals could lead to a reduction of average energy costs in the region of about 10 percent—a result of lower energy consumption and substitution of carbon-intensive energy with lower-cost clean energy.

Final energy consumption could be reduced by 10 to 15 percent through electrification of final consumption and energy efficiency (including energy management, HVAC, insulation, and smart lighting, among others). For example, a fully electrified family consumes around one third of the energy of an average family, according to our analysis.[214] In addition, the unit cost of supplying power can be reduced, as renewable energy support schemes expire and the levelized cost of electricity of new installed renewable energy lowers the average generation cost. These decreases are likely to more than offset the increasing costs of flexibility and transmission and distribution.

However, the current energy crisis in Europe presents the region with an acute and immediate problem. The affordability challenge is a major concern to households and business across Europe, prompting government action in many countries. Two actions can accelerate the energy transition without adversely affecting affordability.

Lowering financial barriers, such as high up-front investments, to adopt clean technologies through incentives and subsidies. For households, making the transition to more sustainable energy sources can require high up-front capital spending on items such as air-source heat pumps, upgraded building insulation, or switching to electric vehicles. The longer-term savings to consumers on these items may be important—for example, the total cost of ownership of an EV is in many cases less expensive than that of an internal combustion engine vehicle. However, the up-front capital outlay may be daunting for many

[214] A family with electric space and water heating (heat pumps), cooking (induction/electric ovens) and transport (electric vehicles).

consumers, and act as a barrier to adoption. To help overcome such challenges, a range of financial incentives could be offered including, for example, tax benefits or purchase incentives for EVs, grants covering part of the heat pump installation, or monthly payments.

To make EVs, heat pumps and other clean technologies cost competitive in the short term, Europe could also consider offering subsidies, tax credits, and additional investments while waiting for the technologies to scale and become less expensive.

Enabling active demand participation by removing regulatory and technical constraints for end users and promoting stabilization measures to mitigate volatility. Customers could participate in providing green energy and flexibility services with their own renewable distributed sources. Active demand participation in the energy markets could allow customers to profit from stable and cheap distributed generation and contribute to the integration of renewables in the system. Introducing long-term contract options for customers could increase their appetite for active market participation as well as shelter from commodities volatility.

Demand resources are used less in Europe to provide flexibility services to the grid than in other mature markets, such as the United States. Removing technical constraints that limit access of demand response, such as minimum size or duration, could accelerate the uptake of demand response solutions and in turn increase system flexibility.

Finally, to tackle avoidable future bankruptcies that have raised costs for end users during the recent crisis, stakeholders may need to consider a balanced set of interventions that protect customers against volatility, while avoiding excessive barriers to competition. These could include, for example, strengthening the resilience of retailers through capital requirements, similar to those applied in the banking sector, or setting minimum back-up levels such as long-term supply contracts or hedging ratios for sales with fixed prices.

In 2020, the European Union's 27 member states approved the European Green Deal. Europe committed to reaching net-zero emissions by 2050, with an interim target for 2030 of reducing emissions by 55 percent from 1990 levels.

Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

Japan

Japan exhibits characteristics of the "affluent, energy-exposed" regions archetype with a highly developed and diversified economy that could adapt to decarbonization. However, it will remain partly dependent on imports for full decarbonization.

Despite its current dependence on imported fossil fuels and a relatively low renewables capacity, Japan could achieve carbon neutrality by increasing renewable power generation, restarting nuclear plants, and importing hydrogen. Leveraging its strengths in innovation and efficiency, Japan could become a global leader in the development of green technologies such as hydrogen and CCUS. If Japan would push for renewables to constitute about 70 percent of its power generation and deploy 45 GW of nuclear, we estimate that Japan's self-sufficiency would rise from 12 to 88 percent and reduce electricity cost by 15 percent by 2050.[215]

To seize the opportunities and promote a path to a more orderly energy transition, Japan could consider taking the following actions:

- Developing solutions to overcome land constraints, such as offshore wind and rooftop solar, to maximize renewables penetration
- Scaling infrastructure and the supply chain to enable hydrogen and ammonia imports that can help meet total energy demand
- Establishing the value chain for CCUS, including developing equipment and facilities
- Enhancing transmission capacity and grid resilience
- Enhancing the current carbon pricing and trading scheme

[215] Tasuku Kuwubara, Detlev Mohr, Yuito Yamada, and Benjamin Sauer, "How Japan could reach carbon neutrality by 2050," McKinsey, August 4, 2021.

Japan's starting point

89%

Eighty-nine percent of the power generated in Japan in 2020 came from fossil fuels

Eighty-nine percent of the power generated in Japan in 2020 came from fossil fuels, compared with a global average of 81 percent.[216] Coal (30 percent of total power generation) and natural gas (32 percent of total power generation) represent the lion's share of power generation in Japan.[217] More than 99 percent of these fossil fuels are imported, mainly from Australia and the Middle East.[218] Japan is the world's second-largest importer of liquid natural gas (101 bcm), third-largest importer of coal (5 exajoules), and fourth-largest importer of crude oil (122 million tons).[219]

This high level of dependence on fossil fuels is due, in part, to land constraints that limit Japan's potential for renewable energy production. For example, its deep coastal waters make installing offshore wind turbines difficult, and its mountainous terrain limits open space for onshore wind and solar farms. Despite these challenges, as of 2021, Japan has deployed more than 78 GW of solar (12.9 percent of power production) and 4.6 GW of wind (1.3 percent of power production).[220]

Before the 2011 Great Japanese Earthquake and the resulting Fukushima nuclear disaster, Japan operated 54 nuclear reactors that generated roughly 30 percent of its electricity.[221] Today only five nuclear reactors provide power,[222] accounting for 6 percent of Japan's power generation.[223]

Plans to reinstate four reactors, alongside the current five in operation, are being considered, aiming to further increase nuclear energy to around 20 percent by 2030.[224] Indeed, more than 32 GW of nuclear capacity is under construction.[225] In addition to reinstating shuttered plants, Prime Minister Fumio Kishida announced plans to develop new nuclear reactors that would include small modular reactors (SMRs).[226] The Japanese government's reversal on nuclear power also includes investing in increasing the life span of plants from 40 to 60 years, potentially even longer.[227]

Japan contributes nearly 3 percent of global CO_2e emissions, making it the seventh largest GHG emitter in the world, following China, the United States, the European Union, India, Russia, and Brazil.[228]According to our analysis, most of the country's emissions came from three sectors: power (40 percent), industry (30 percent), and transport (19 percent).[229]

National determined contributions

Japan has set a target of reducing GHG emissions to net zero by 2050.[230] To achieve that goal, Japan has recently committed to an interim target of reducing emissions in 2030 to 46 percent below the 2013 level. Japan plans to achieve this by receiving 20 to 22 percent of its electricity mix from nuclear power, and 36 to 38 percent from renewable energy, of which 14 to 16 percent would come from solar and 5 percent from wind. This would require

[216] *Japan 2021: Energy Policy Review,* revised version, IEA, May 2021.
[217] Ibid.
[218] *BP energy outlook,* 2022.
[219] Ibid.
[220] *Japan 2021: Energy Policy Review,* revised version, IEA, May 2021; Jonathan Gifford, "Japan—After the FITs," *pv magazine,* March 5, 2022; Lucas Morais, "Japan ends 2021 with close to 4.6 GW of wind power," *Renewables Now,* March 3, 2022.
[221] *Nuclear Power in Japan,* World Nuclear Association, September 2022.
[222] Eric Johnston, "Kishida sets high nuclear power target that Japan may struggle to meet," *Japan Times,* July 15, 2022.
[223] *Nuclear Power in Japan,* World Nuclear Association, September 2022.
[224] Kantaro Komiya and Ritsuko Shimizu, "Japan election may be tailwind for nuclear restarts as public mood shifts," Reuters, July 7, 2022.
[225] *Nuclear Power in Japan,* World Nuclear Association, September 2022.
[226] The Sankei Shimbun, "Next-Gen Small Nuclear Reactors Take Center Stage in Japan's Power Policy Talks," *Japanforward,* October 21, 2021.
[227] Ariel Cohen, "The Ghosts of Fukushima and Japan's Nuclear Turnaround," *Forbes,* September 7, 2022.
[228] *Historical GHG Emissions,* Climate Watch, 2019; based on CAIT data.
[229] *Global Energy Perspective, 2022,* data for Current Trajectory, 2021.
[230] "Net-zero coalition," United Nations Climate Action, updated June 2021.

the country to double and triple its solar and wind capacity,[231] respectively, and almost quadruple its nuclear power plant capacity.[232]

Japan is also one of the few countries in the world to set a target for the use of hydrogen and ammonia in the power sector. The country aims to increase hydrogen production from 2 million tons per year today to 3 million tons per year by 2030—which is roughly equal to 1 GW of power capacity.[233] Japan seeks to expand the role of hydrogen in the transport sector, aiming to increase use of fuel-cell electric vehicles (FCEVs) from more than 5,000 in 2021 to 800,000 by 2030[234] and increasing the number of refueling stations from 161 to 900 during the same period.[235]

Priority measures that could accelerate a more orderly energy transition

46%

By 2030, Japan aims to reduce emissions to 46 percent below 2013 levels

Japan faces a set of obstacles that may impede its ability to reach its 46 percent emissions reduction target by 2030.[236] These challenges include: (1) the untapped potential of renewables because of land constraints and idle nuclear power plants; (2) lack of a value chain that enables imports and the use of hydrogen; (3) limited deployment of CCUS to offset remaining emissions to meet the 2030 target; (4) lack of transmission capacity required to balance supply and demand within a decentralized grid; and (5) limited scope and impact of the current carbon pricing and trading scheme.

To solve these challenges and achieve Japan's NDCs, stakeholders could consider a broad set of near-term priority measures. These action items aim to realize full renewables potential, scale the hydrogen supply chain and CCUS to meet remaining demand, reinforce the grid through transmission capacity build-out, and implement a standardized carbon trading and pricing scheme.

1

Developing solutions to overcome land constraints, such as offshore wind and rooftop solar, to maximize renewables penetration

Japan's distinctive topography limits overall renewables capacity. For example, mountainous terrain creates challenges for installing large-scale onshore wind and solar farms, and deep coastal waters have hindered the development of offshore wind capacity. Population density and the prevalence of megacities also hinder the deployment of large-scale renewables.

Societal pressures and procedural delays also limit further deployment of renewables. Residential regulatory challenges limit the deployment of distributed solar PVs in dense megacities. Multifamily residences with shared roofs and high-occupancy turnover rates create challenges in the purchasing and registration processes for distributed solar.

8x

Offshore wind has the potential to generate almost eight times Japan's total energy demand

Expanding offshore wind solutions by promoting greater transparency and fast-tracking auctioning and approval processes. Offshore wind has the potential to generate

[231] *Sixth Strategic Energy Plan,* Japanese Ministry of Economy, Trade, and Industry, October 22, 2021.
[232] Justin McCurry, "Japan eyes return to nuclear power more than a decade after Fukushima disaster," *The Guardian,* August 25, 2022.
[233] "Japan's hydrogen industrial strategy," Center for Strategic and International Studies, October 21, 2021; *Japan 2021: Energy Policy Review,* revised version, IEA, May 2021.
[234] "Number of fuel cell electric vehicles in use in Japan from 2015 to 2021," Statista, November 2021; data based on ARIA.
[235] Ministry of the Environment, Japanese Government; "Number of hydrogen fueling stations for road vehicles in Japan as of June 2021, by region," Statista, May 2022; based on NeV data.
[236] *Sixth Strategic Energy Plan,* Japanese Ministry of Economy, Trade and Industry, October 22, 2021.

approximately 8,000 TWh of energy—almost eight times Japan's total energy demand.[237] However, only about 1 percent of this potential is currently realized, largely because of the only recent issuance of national offshore tenders and the additional challenge of needing floating platforms for the deep coastal waters.[238] To further facilitate the deployment of offshore wind, Japan may look to accelerate public tenders for fixed-bottom offshore wind. Establishing greater transparency surrounding the scale and scope of planned projects may promote greater alignment between private and public stakeholders. Fast-tracking approval procedures in early stages of infrastructural development after the initial bidding phases may also facilitate expanding offshore wind solutions.[239]

Reintroducing and scaling nuclear power plant operations while accelerating regulatory reviews. Accelerating the recommissioning of nuclear power plants across Japan will be critical to meeting 2030 renewables targets. After the 2011 earthquake and resulting Fukushima disaster, the Japanese government formed the independent, external Nuclear Regulation Authority (NRA). In 2012, the NRA developed stringent regulations to help restore public trust in nuclear energy, undertaking a comprehensive review of restart applications for power plants. To accelerate these regulatory reviews, the NRA may invest in human and financial resources to review the applications. The NRA can also continue working with local communities to discuss the benefits of nuclear power.

3x

To meet emissions reduction targets, solar PV will need to triple by 2030

Implementing standards for solar PV installation on all eligible buildings. To meet emissions reduction targets, solar PV will need to triple by 2030, according to our analysis. Achieving this potential in Japan may require building owners to install solar panels on their rooftops, as only about 5 percent of suitable roofs currently have solar capacity.[240] The Japanese government has implemented a mandate that requires solar-panel installation on all public buildings. So far, private buildings have been excluded from this mandate. An expansion of the solar-panel mandate to private buildings could help realize the full potential for distributed solar, which is particularly important considering Japan's land constraints and the complexities of installing large scale solar. Financial incentives to help individuals who may not be able to afford the up-front investment could further help the growth of distributed solar.

Phasing out coal power plants or exchanging them for combined-cycle gas turbines. To increase the share of renewables in the overall power mix, Japan may also look to draft a schedule for phasing out coal and scaling alternative technologies as substitutes. For example, replacing traditional coal-fired power plants with combined-cycle gas turbines may help decarbonize the power sector to meet 2050 emissions reduction targets. These turbines could improve efficiency by combining a gas-fired turbine with a steam turbine to produce up to 50 percent more electricity than traditional coal-powered plants.[241] For plants that will not be retrofitted, Japan could set clear targets and deadlines to phase out inefficient coal-fired plants, as well as set stringent efficiency targets for existing plants.

[237] *Offshore Wind Outlook 2019,* IEA, November 2019.
[238] Japan currently has 4.6 GW installed wind capacity and the potential offshore capacity of 608 GW. Lucas Morais, "Japan ends 2021 with close to 4.6 GW of wind power," *RenewablesNow,* March 3, 2022; Chisaki Watanabe, "GE Says Japan Has More Potential to Harness Wind Power," *Bloomberg,* February 27, 2014.
[239] Sven Heiligtag, Katsuhiro Sato, Benjamin Sauer, and Koji Toyama, "Japan offshore wind: The ideal moment to build a vibrant industry," McKinsey, August 12, 2020.
[240] Yoshitaka Unezawa, "Tokyo considers solar power requirement for all new houses," *The Asahi Shimbun,* October 18, 2021.
[241] "Combined cycle power plant: How it works," GE Gas Power.

2

Scaling infrastructure and the supply chain to enable hydrogen and ammonia imports that can help meet total energy demand

10x

Japan may require 22 million tons of hydrogen a year by 2050, more than ten times what is required today

The power sector in Japan may need to rely on imported hydrogen and ammonia to provide green electricity and meet emissions reduction targets. Japan may require up to 22 million tons of hydrogen a year by 2050, more than ten times the roughly 2 million tons required today.[242] This hydrogen supply would be especially critical for industry, which relies on fossil fuels because of manufacturing processes that are hard to decarbonize through electrification.[243] Although switching to electric heat pumps for low-temperature processes in the industry and building sectors may curb emissions, Japan would need to build out the hydrogen supply chain and accompanying infrastructure to reduce remaining emissions to meet its ambitious NDCs.[244]

Furthering partnerships with exporting countries. Japan may look to continue to secure a diversified supply of hydrogen and ammonia from overseas. The Hydrogen Energy Supply Chain project, scheduled to launch in 2030, establishes a commercial-scale supply chain from Australia to Japan.[245] Forming partnerships with major hydrogen exporters may represent a path toward developing a full-fledged hydrogen economy in Japan. In 2021, Japan's Ministry of Economy, Trade and Industry (METI) signed a memorandum of cooperation with the United Arab Emirates for the potential supply of green and blue hydrogen and ammonia.[246] Solidifying and expanding these bilateral partnerships will be critical in ensuring a stable supply for Japan's future energy needs.

Developing infrastructure to transport liquid hydrogen, ammonia, and liquid organic hydrogen carriers. To scale the use of hydrogen as an alternative fuel, Japan may need to lay the groundwork for long-term infrastructure for the transport and storage of hydrogen. Establishing the hydrogen supply chain would entail building large-scale pipelines for hydrogen and ammonia transmission. These pipelines would need to be integrated into an expanded power grid across Japan and its coastal waters. Although Japan is in the process of developing the infrastructure to cover the 9,000-kilometer expanse between Australia and Japan, the country may accelerate development by creating incentives for producers to invest further in the transportation. These could include aggregating demand for off-takers to mitigate uncertainty surrounding the end market of transported hydrogen.[247]

Liquid organic hydrogen carriers (LOHCs) could be easily transported with ships and require a fueling infrastructure similar to that of gasoline. Gas stations would need to be retrofitted to replace gasoline with LOHC.

Creating a dense network of hydrogen refueling stations. Another critical aspect of hydrogen infrastructure is rolling out hydrogen refueling stations across Japan. Given the prevalence of highly dense and populous megacities throughout Japan, scaling the necessary infrastructure to support hydrogen-fueled vehicles will require both technological innovation and government support.[248] Multinational companies and infrastructure developments may form joint ventures to pool resources for the development

[242] Tasuku Kuwubara, Detlev Mohr, Yuito Yamada, and Benjamin Sauer, "How Japan could reach carbon neutrality by 2050," McKinsey, August 4, 2021.
[243] Ibid.
[244] Ibid.
[245] "The world-first hydrogen energy supply chain project," Hydrogen Energy Supply Chain.
[246] Takeo Kumagai, "Japan signs first hydrogen cooperation deal with UAE to consider supply chain," S&P Global, April 8, 2021.
[247] Takeo Kumagai and Fred Wang, "Commodities 2021: Japan to enter new era of hydrogen in 2021 with launch of liquefied transport," S&P Global, December 23, 2020.
[248] Tomoya Suzuki, "Quantitative risk assessment using a Japanese hydrogen refueling station model," *International Journal of Hydrogen Energy,* volume 46, issue 11, February 11, 2021.

of refueling infrastructure. Regulatory bodies may also develop uniform standards for the elements of the filling station, such as dispensers and control panels, to allow pooling among manufacturers, thereby reducing costs. [249]

3

Establishing the value chain for CCUS, including developing equipment and facilities

4x

By 2050, Japan needs to capture more than four times today's global carbon-capture volumes

Our estimates indicate that Japan would need to capture 173 million tons of CO_2 via CCUS technology by 2050, an amount corresponding to more than four times today's global carbon-capture volumes. [250] In order to scale CCUS to this degree, Japan could use its strong technological and innovation base to invest in building a new nationwide system of storage sites and infrastructure. The country could also develop the transportation and storage infrastructure required for overseas carbon storage sites.

146 billion tons

Potential storage in already-identified carbon storage sites in geological formations offshore may exceed 146 billion tons

Finalizing research and selection of carbon storage sites. To mitigate the lack of suitable onshore locations for carbon storage, the Japanese government and private companies may need to expedite research on offshore carbon storage sites.[251] Although potential storage in already-identified carbon storage sites in geological formations offshore may exceed 146 billion tons, Japan may seek to accelerate research on the extent of usable storage within these formations, given challenges associated with deep offshore waters and recurring natural disasters.[252] In 2019, Japan launched a carbon storage demonstration project in Hokkaido, which successfully used a pipeline for CO_2 injection into two offshore aquifers.[253] Increasing the rate of these demonstration projects may allow Japan to gain sufficient technological ability to scale carbon storage technology across its coasts.

Forming consortia of relevant players in industrial clusters for CCUS. To expedite the development of necessary CCUS technologies, corporations such as equipment manufacturers, utilities, and oil and gas companies could pool resources and commit funds to the R&D process. These consortia may also work with the Japanese government to develop and commercialize CCUS technologies.

Committing to long-term funding of infrastructure and technology development. Fostering the innovation necessary to enhance Japan's CCUS capabilities may call for significantly higher investments in technology. In 2021, Japan's METI formed the Asia CCUS Network in collaboration with the Economic Research Institute for ASEAN and East Asia.[254] This forum committed to knowledge sharing. Pursuing more concrete efforts to lock in funding for CCUS research may accelerate the development of critical CCUS technologies.[255]

[249] *Japan 2021: Energy Policy Review,* revised version, IEA, May 2021.
[250] Tasuku Kuwubara, Detlev Mohr, Yuito Yamada, and Benjamin Sauer, "How Japan could reach carbon neutrality by 2050," McKinsey, August 4, 2021.
[251] Lorenzo Moavero Molanesi, Eveline Speelman, Yoshitaka Urida, and Yuito Yamada, "Meeting Japan's Paris Agreement targets—more opportunity than cost," McKinsey, March 1, 2020.
[252] *Japan 2021: Energy Policy Review,* revised version, IEA, May 2021.
[253] Ibid.
[254] *Carbon Capture, utilisation and storage: The opportunity in Southeast Asia,* IEA, June 2021.
[255] *Asia CCUS Network Vision and Mission,* ERIA, April 28, 2021.

4

Enhancing transmission capacity and grid resilience

On the self-contained island of Japan, the electricity system is separated into ten regional grids at two frequency levels. Eastern Japan, including Tokyo and Kawasaki, operates at 50 Hertz (Hz) while western Japan, including Osaka and Kyoto, operates at 60 Hz.[256] While this may not become a major bottleneck until 2030, the fragmentation of the electricity grid may present future challenges in balancing supply and demand, especially as offshore wind and solar PV are expected to increase to meet 2050 targets. Regional interconnections between load centers and renewables hubs have not yet scaled to match energy demand across the country. To overcome critical challenges in grid reliability, particularly given Japan's vulnerability to natural disasters, Japan may need to scale regional interconnections between load centers and renewable hubs.[257]

Regulatory hurdles and a shrinking skilled labor supply exacerbate the key challenge of scaling transmission and distribution capacity across Japan. Four actions may be considered to address these challenges.

Identifying critical and delayed transmission projects connecting renewables to load centers and streamlining environmental and planning approvals. To build out transmission infrastructure, Japan could streamline environmental and planning approvals, and identify areas where it is most critical for transmission to connect to load centers. From 2011 to 2020, annual use of cross-regional interconnection lines from Tohoku to Tokyo increased from 9 TWh to 31 TWh.[258] The ambitious renewables targets require more capacity in renewables-rich regions—such as Hokkaido, Kyushu, and Tohoku—which are far from demand centers such as Chubu, Kansai, and Tokyo.[259] Japan also may invest in interregional power sharing of capacity between decentralized regions to stabilize supply and demand across the two central regions of Japan's grid.

3.5x

From 2011 to 2020, annual use of cross-regional interconnection lines from Tohoku to Tokyo increased from 9 TWh to 31 TWh, roughly 3.5 times

Accelerating automation and reskilling efforts to increase the available labor supply. Japan's construction sector in general, including the power-construction contractor industry, faces the significant challenges of aging skilled labor and a shrinking workforce.[260] In order to ensure sufficient skilled labor to build out transmission capacity and flexibility, Japan may encourage employers to improve efficiency, including through the use of digitization, to automate work and transfer skills, especially within electricity transmission, which requires specialized skills and knowledge.[261]

[256] *Japan 2021: Energy Policy Review,* revised version, IEA, May 2021.
[257] *Sixth Strategic Energy Plan,* Japanese Ministry of Economy, Trade, and Industry, October 22, 2021.
[258] *Aggregation of Electricity Supply Plans FY 2021,* Organization for Cross-Regional Coordination of Transmission Operations, updated December 17, 2021.
[259] Ibid.
[260] Maya Horii and Yasuaki Sakurai, "The future of work in Japan: Accelerating automation after COVID-19," McKinsey, July 2020.
[261] Ibid.

5

Enhancing the current carbon pricing and trading scheme

$10 trillion

We estimate that reaching net zero would require total investment of $10 trillion by 2050

We estimate that reaching net zero would require a total investment of $10 trillion by 2050, or $330 billion annually. Of that investment, $8 trillion would come from redirecting funds that would have been invested in incumbent technologies. An additional $2 trillion—an average of $70 billion annually, or 1 to 2 percent of Japan's GDP—would be needed to cover the higher net cost of the decarbonizing technologies and infrastructures that are more expensive to implement, such as an expanded power grid and pipelines for hydrogen and ammonia transmission.[262]

The government could implement tax credits and subsidies for early-stage technologies and projects that do not yet have reliable revenue streams. To mobilize private capital, the government could consider using techniques to reduce investment risks, such as a carbon-trading price floor, loss guarantees, and models like public-private partnerships and blended finance. In addition, both the breadth and depth of the carbon trading and pricing scheme could be enhanced to create more positive private-investment cases.

Japan has launched the Green Transformation (GX) League, a mechanism in which companies set their own emissions-reduction goals in line with the national goals and annually disclose their reduction efforts. Emissions are traded between participating companies or, if individual reduction goals are not achieved, carbon credits are procured.[263] However, this trading market is voluntary and not yet standardized across the industry.

The existing carbon-pricing scheme, in its design, may also have a limited impact on the two highest-emitting sectors: power and industry. This is because Japan's emissions trading systems (ETS) permit price for solid and gaseous fuels is lower than the G20 average.[264] Given that the power and industry sectors mainly utilize gaseous and solid fuels, the current ETS permit price may spare these heavy-emitting sectors. Policy makers and businesses could use the following three levers to strengthen the current carbon trading and pricing scheme.

40%

Just 440 companies, accounting for roughly 40 percent of Japan's emissions, have endorsed the Green Transformation League

Establishing a nationwide carbon pricing and trading scheme through coordination with companies. The full-scale launch of the GX League is planned for April 2023, and currently only 440 companies, representing more than 40 percent of Japan's emissions, have endorsed it.[265] To expand the breadth of this emissions trading platform, Japan may implement a standardized, industry-wide system. To ensure compliance, the government could set compliance targets, as opposed to companies setting their own voluntary targets for carbon credit trading.[266]

[262] Tasuku Kuwubara, Detlev Mohr, Yuito Yamada, and Benjamin Sauer, "How Japan could reach carbon neutrality by 2050," McKinsey, August 4, 2021.
[263] "Clean Energy Strategy to Achieve Carbon Neutrality by 2050," Japan Government, June 23, 2022.
[264] "Carbon Pricing in Japan in Times of COVID-19: Key Findings for Japan," OECD.
[265] "Clean Energy Strategy to Achieve Carbon Neutrality by 2050," Japan Government, June 23, 2022.
[266] "Japan to launch first exchange for carbon emissions trading," *Nikkei Asia,* May 13, 2022.

Adding a carbon tax on heavy emitters could potentially target the power and industry sectors more effectively. Japan could consider improving the depth of its existing carbon pricing and trading scheme by targeting heavy emitters. If it chose to add explicit carbon taxes directed at the power and industry sectors and implement a more stringent ETS permit price for nonliquid fuels, the government could incentivize emissions reduction in the power and industry sectors. To ensure a fair allocation of carbon taxes and fuel excise across sectors, emissions from transport, buildings, and agriculture would need to be taxed proportionately.[267] However, policy makers would likely want to carefully consider the affordability of a new carbon tax, as it could raise electricity prices for residential and industrial customers in the near term.[268]

Implementing internal carbon-pricing models and hedging strategies, to minimize the impact of market volatility. Government-mandated carbon pricing and trading schemes could exhibit market volatility, so regulated companies in Japan could benefit from implementing their own internal carbon-pricing models and hedging strategies to minimize the impact of potential dislocations between ETS supply and demand.[269] This may require companies to measure their direct and indirect emissions, quantify their carbon exposure across all company activities, model a range of scenarios for the expected future price of carbon, adopt advanced hedging-execution technology, and hire commodity trading experts.[270]

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[267] *Carbon Pricing in Japan in Times of COVID-19: Key Findings for Japan,* OECD.
[268] Hemangi Gokhale, "Japan's carbon tax policy: Limitations and policy suggestions," *Current Research in Environmental Sustainability,* Volume 3, 2021.
[269] Jessica Fan, Werner Rehm, and Giulia Siccardo, "The state of internal carbon pricing," McKinsey, February 10, 2021; Joseph Aldy and Gianfranco Gianfrate, "Operations strategy: Future-proof your climate strategy," *Harvard Business Review,* May–June 2019.
[270] Greenhouse Gas Protocol, ghgprotocol.org.

Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

China

China exhibits the main characteristics of the "large, emissions-intensive economies" archetype, as it has a high-growth economy still highly dependent on fossil fuels.

Indeed, fossil fuels account for 83 percent of energy consumed in China.[271] Going forward, as energy demand is expected to grow, renewables will need to assume a more prominent role in the generation mix. This could potentially amount to more than 1,900 GW of installed capacity from solar PVs and wind by 2030 and more than 6,900 GW by 2050, according to our analysis. Such growth in renewables would help limit China's dependence on fossil fuel as well as move the region toward its carbon-reduction targets. China could further leverage its manufacturing capabilities to innovate across clean technology production such as storage or hydrogen.

To seize these opportunities and promote a path to a more orderly energy transition, China could consider the following priority measures:

- Limiting and mitigating coal emissions in the power and industry sectors and substituting coal with renewables
- Enabling and scaling grid connectivity between demand centers and renewable capacity
- Promoting development of renewables and flexibility solutions, while considering enhancements to market structures
- Scaling up hydrogen-based fuels and carbon capture, utilization, and storage
- Enabling greater carbon transparency and incentivizing the private sector to pursue more ambitious targets

[271] *An Energy Sector Roadmap to Carbon Neutrality in China*, International Energy Agency, September 2021; *BP energy outlook*, 2022.

China's starting point

83%

Fossil fuels account for more than 83 percent of energy consumed in China

China's economy is strongly linked to fossil fuels, which account for more than 83 percent of energy consumed. Coal is the most prominent energy source (55 percent), followed by oil (19 percent) and natural gas (9 percent).[272] China relies on coal for energy security, with 95 percent of it mined domestically.[273] The country is a net importer of natural gas and oil—domestic production of natural gas (6.3 trillion cubic feet [tcf]) accounts for 56 percent of demand, while oil (8.2 quadrillion British thermal units [Btu]) accounts for 29 percent of demand.[274] In transitioning to a new energy mix, supply adequacy and security is expected to be a top priority.

Despite its reliance on fossil fuels, China is the world leader in the development of wind and solar projects. Over the past three years China has, on average, installed more than 90 GW annually. [275] Yet, even with this progress, solar and wind still account for only 4 percent and 9 percent, respectively, of the country's total electricity generation.[276]

36%

China has the largest reserves of rare-earth materials at 36 percent of the world's total

China has the largest reserves of rare-earth materials—36 percent of total world reserves[277]—which will be essential to the energy transition. Additionally, China has developed significant domestic capabilities for processing key transition-critical minerals into critical components—for example, by using copper for solar, wind, and hydropower as well as cobalt and lithium for batteries. Indeed, the country is one of the largest contributors to energy transition equipment manufacturing. China holds a more than 80 percent global share across the entire solar PV value chain, is rated among the top ten manufacturers in wind, and contributes 80 percent of the world's battery storage manufacturing capacity.[278]

In 2021, China accounted for 10.5 Gt of CO_2e of energy emissions, representing 31 percent of global energy-related emissions. [279] China has achieved significant improvements in emissions intensity, from 0.68 tCO_2 per $1,000 of GDP in 2010 to 0.45 tCO_2 per $1,000 in 2021, although it is still above the global average of 0.26 tCO_2 per $1,000 of GDP.[280] Power represents 44 percent of emissions, followed by the industrial sector (41 percent), mostly from steel, cement, and industrial-chemicals emissions.

Nationally determined contributions

China pledged to NDCs that target peak emissions by 2030 and carbon neutrality by 2060.[281] With these aims in mind, China plans to limit increases in coal consumption until 2025 and then gradually reduce coal use starting from 2026 onward.[282]

Priority measures that could accelerate a more orderly energy transition

China faces five key challenges: (1) reliance on coal to fuel demand growth in the power and industry sectors; (2) inadequate infrastructure to address the geographical mismatch between the demand centers and high-potential renewable sources; (3) market frameworks that offer limited appeal to investors in renewables and storage solutions; (4) a large footprint

[272] *An Energy Sector Roadmap to Carbon Neutrality in China,* IEA, September 2021; *BP energy outlook,* 2022.
[273] "China coal," Worldometer, 2016.
[274] "Country analysis executive summary: China," US Energy Information Administration, August 8, 2022.
[275] *Renewable energy capacity,* 2022.
[276] Dillon Jaghory, "China Sector Analysis: Energy," Global X, February 22, 2022.
[277] *Mineral Commodity Summaries,* US Geological Survey (USGS), 2022.
[278] "An Energy Sector Roadmap to Carbon Neutrality in China," IEA, September 2021.
[279] *Global Energy Perspective,* 2022, data for Current Trajectory, 2021.
[280] *"Global Energy Review: CO_2 Emissions in 2021,"* IEA, March 2022.
[281] "United Nations Nationally Determined Contributions Registry," United Nations Climate Change.
[282] Ibid.

for "hard-to-abate" industries and heavy transport sectors; and (5) limited incentives for private action, including low prices in the emissions trading scheme.

To address these challenges and make near-term progress toward meeting China's achieved commitments path, stakeholders could consider a set of priority measures.

1

Limiting and mitigating coal emissions in the power and industry sectors and substituting coal with renewables

44%

Coal accounted for 44 percent of energy consumption in the industrial sector in 2020

73%

From 2016 to 2020, approved coal capacity additions declined by 73 percent

China relies heavily on coal to sustain its economic and demographic growth. Coal accounted for 44 percent of energy consumption in the industrial sector in 2020.[283] Progressively reducing dependence on coal while mitigating its carbon footprint will be a key challenge for China's decarbonization. The need for baseload power to fuel the country's growth and the time required for renewables to fully substitute coal indicate that a full coal phase-out would likely be a long process and face obstacles in the near term. Following are five actions for stakeholders to consider taking.

Considering measures to limit additions of new coal plants by optimizing capacity utilization. China has been making strides to reduce its reliance on coal power generation. From 2016 to 2020, approved coal capacity additions declined by 73 percent, and more than 280 plants were canceled.[284] Coordinated long-term national and regional planning with long-term assumptions for plant utilization and demand will help the examination of the attractiveness of solar, wind, and battery storage for meeting new incremental demand, potentially avoiding coal expansions as well as additional coal investment, which increases stranded-asset risk. These planning mechanisms could help send stable price signals to the market for new renewables development.

Promoting investments in coal power conversion and efficiency, reducing carbon emissions via heat cogeneration, retrofitting, and carbon capture and storage. Efficiency and flexibility solutions could mitigate the carbon footprint of existing and new coal plants. For example, plants could be retrofitted for improved efficiency converted into combined heat and power plants, as in the case of the Junliangcheng plant in Tianjin City.[285] This would enable China to partially mitigate its coal footprint while maintaining the current generation capacity required to support the economy. High capital expenditure on coal retrofits should be carefully compared against alternative options to avoid additional stranded-capital risk in existing coal plants.

Coal plants in China would also benefit from investments in enhanced operational flexibility. Our analysis indicates that the plants are likely to move from an approximately 55 percent capacity factor to approximately 16 percent by 2040.[286] Going forward, coal-plant operations will become increasingly intermittent, as their generation will likely be needed to balance intermittent renewables production and maintain grid reliability. Since the coal power generation fleet was originally designed to operate as inflexible "baseload," coal plants would be subject to significantly more cycling and lower utilization. Plant operators could prepare to modify procedures for high cycling by adopting new predictive and inspection maintenance methods, training staff for new operating norms, and installing digitally enabled temperature and pressure monitoring.

[283] *Global Energy Review 2021,* IEA, April 2021.
[284] "Global coal plant tracker," Global Energy Monitor, July 2022.
[285] "Coal-to-Gas Transition in China: Junliangcheng Power Plant Adds over 650 Megawatts with GE's Advanced 9HA Technology," GE press release, February 01, 2021.
[286] *An Energy Sector Roadmap to Carbon Neutrality in China,* IEA, September 2021.

Early decommissioning of inefficient coal plants, including moving them to strategic reserves. Without intervention, the end-of-life decommissioning of coal plants would be a relatively slow process. The average age of China's coal assets is 12 years, while the average plant life span ranges from 40 to 60 years.[287] McKinsey analysis estimates that China's 1,100 GW of installed coal capacity is responsible for nearly 5,000 TWh of energy generation annually. As renewable capacity expands and inefficient plants are used less, one option is to repurpose a portion of the fleet as strategic reserves for reliability purposes.

Addressing emissions in the coal-mining value chain and promoting measures to reduce emissions such as methane. Methane abatement is a critical piece of the decarbonization puzzle, as China produces more than 70 percent of global coal-mine methane emissions—approximately 660 million tons in 2020.[288] One option is to deploy established technologies that capture coal-mine methane and use it to generate power onsite or for other industrial applications. Today solutions that address flare, heat, power, or feedstock emissions range from $9 to $29 per ton emitted.[289] This compares to a carbon price of $6 a ton. However, the cost of these solutions is likely to become more competitive as carbon- pricing incentives develop further.

25%

Energy efficiency in China has already contributed to savings of 25 percent from 2010 to 2018

Promoting energy efficiency. Investing in additional energy efficiency in industry, transport, and buildings could limit further expansion of coal in China. Energy efficiency in China has already contributed to savings of 25 percent from 2010 to 2018, a large part of which would have been fueled by coal power. China's mandatory energy efficiency policies, such as digital energy labeling and the Top 10,000 Program for industrial buildings seem to have had great success.[290] China could further invest in these measures to limit the coal-plant additions required on the supply side.

2

Enabling and scaling grid connectivity between demand centers and renewable capacity

Like a number of other countries, China has a geographical mismatch between demand centers and high-potential renewables areas that will require solid grid interconnections as renewables scale up. While demand centers are typically located on the east coast of China in places such as Hebei, Shanghai, and Guangdong—which, according to our estimates, collectively represent 75 percent of total demand—areas with the largest renewables potential are typically found in the western regions in places such as Xinjiang and Qinghai. The distance between renewables demand centers and resource centers could range between 1,000 and 3,000 kilometers. This makes establishing adequate grid connectivity an essential part of China's energy transition. There are two actions to consider taking.

Streamlining permitting and cooperation across regions to promote coordinated development of transmission systems. The deployment of a long-range grid for China would involve multiple stakeholders from the public and private sectors as well as the regions that could benefit from the transmission lines. Cooperation between these parties on issues such as cost allocation agreements and long-term budgeting plans will be crucial to

[287] McKinsey Power Model; *BP energy outlook,* 2022; Friedrich Kahrl et al., "Sunsetting coal power in China," *iScience,* September 2021, Volume 24, Number 9.
[288] *Global Methane Initiative Coal Mine Methane Country Profile: China,* US Environmental Protection Agency, June 2020.
[289] Sam DeFabrizio, Will Glazener, Catherine Hart, Kimberly Henderson, Jayanti Kar, Josh Katz, Madelina Pozas Pratt, Matt Rogers, Alex Ulanov, and Christer Tryggestad, "Curbing methane emissions: How five industries can counter a major climate threat," McKinsey, September 2021.
[290] The Top 10,000 Program aims to cover two-thirds of China's total energy consumption, or 15,000 industrial enterprises that use more than 10,000 ton of coal equivalent (tce) per year.

accelerate progress. Research suggests that China has invested more than $330 billion since 2016 to sufficiently increase its transmission and distribution capacity.[291]

$22 billion

In the second half of 2022, China plans to invest $22 billion to finance ultrahigh voltage lines to connect western regions to big cities

In the second half of 2022 alone, China plans to invest $22 billion to finance ultrahigh voltage lines to connect western regions to China's big cities.[292] It will be important to develop plans based on long-term scenarios to optimize these transmission corridors for the likely evolution of supply and demand. Employing the latest best practices on large capital project planning and execution, as well as evaluating developments in new conductor materials and power flow control technologies, will likely be helpful for reducing total costs.

Coordinating industry development in areas that have high resource availability, building on incentives for private and public stakeholders. Relocating flexible demand centers and energy-intensive industries closer to remote energy sources could be a key way to bridge the supply-demand geographical mismatch. For example, data centers have a significant load requirement and are good candidates for demand relocation. They currently consume 200 TWh of electricity, equal to approximately 3 percent of China's total electricity demand, and are projected to consume 400 TWh by 2030.[293] Ten data-center hubs already are planning to relocate to renewables-rich areas. Ones that handle latency-sensitive tasks, such as financial trading and telecommunication, would go to eastern energy hubs, while those that are in western hubs and close to resource-rich areas would handle more power-intensive tasks such as data processing and cloud storage.

3

Promoting development of renewables and flexibility solutions while considering enhancements to market structures

As renewables scale up, China's electricity system will need more flexible power supply to accommodate the intermittence of renewable supply, especially given the relative inflexibility of the coal fleet. To support the flexibility needs of intermittent renewables, China could consider introducing storage solutions such as batteries and demand-response programs. However, the electricity market currently has limited compensation mechanisms and limited potential premiums for flexibility solutions, making them less attractive for investors. For example, current storage market participants see about 5 percent in returns, according to our research. To enable flexible usage of electricity generated by intermittent renewables, McKinsey estimates suggest that battery storage would need to increase by 1,000 times the current capacity, or 775 GW of capacity by 2050, with an interim target of 62 GW by 2030.

Similar market gaps could exist in the renewables market. The corporate PPA market is nascent in China. with only a handful of deals announced to date that represent approximately 9.7 GW in 2020.[294] That is around 10 percent of the annual installed capacity, less than half of the 20 percent to 25 percent in the European Union.[295] However, other markets have seen significant renewables expansion through voluntary corporate PPAs, either in physical form or as a financial settlement (such as virtual PPAs). Expansion and simplification of purchase options could help unleash latent corporate demand. There are two actions to consider.

[291] "China's State Grid to invest over 500b yuan in power grid projects in 2022," State Council, People's Republic of China, June 4, 2022.
[292] "China's State Grid to invest $22 bln in ultra-high voltage power lines," *Reuters,* August 3, 2022.
[293] Fan Feifei, "Green data centers in focus," The State Council, December 9, 2021.
[294] "China's corporate clean energy market sets record," Bloomberg, September 17, 2021.
[295] Estimate based on Jonathan Luan, "China's Corporate Clean Energy Market Sets Record," *Bloomberg,* September 17, 2021; "RE-Source 2020 – The European PPA market – an overview," Renewable Market Watch.

Enabling companies to sign green power deals quickly and efficiently through flexible PPAs. In 2021, China launched its Green Power Purchase Agreement program across 259 companies and 17 provinces to increase access to renewable energy and increase power-market flexibility.[296] Although most PPAs in China are onsite, their availability is limited due to a lack of qualified and available sites. China could boost domestic and international investments through flexible PPAs by enabling off-site PPAs via public grids. Introducing market structures that allow for better price formation could lead to more flexible ways of monetizing renewable energy, with higher internal rates of return for developers. For example, in March 2022, German chemical company BASF signed its first ever long-term green PPA for its Verbund site in Zhanjiang.[297]

Building market structures that incentivize storage remuneration, such as capacity markets, to make storage development more attractive investments. Introducing market mechanisms, such as ancillary services and capacity markets, to make storage investments competitive and bankable will be critical to supporting intermittent renewables. The development of flexible solutions could also accelerate the transition of coal plants to strategic reserves and counteract the need to use fossil fuels for power baseload. One successful example is represented by the Shandong province, where both an ancillary service market and capacity market compensation mechanisms were introduced. This has in turn driven a boost in peak revenues for six storage power stations in the area and enabled higher returns.[298]

4

Scaling up hydrogen-based fuels and CCUS

58%

China accounts for 58 percent of global consumption in the iron and steel industry

25%

China generates about one-quarter of the global volume of hydrogen

China has a strong industrial footprint, particularly in hard-to-abate industries. The country accounts for 58 percent of global consumption in the iron and steel industry and 58 percent in nonmetallic minerals such as cement.[299] China also has an active hydrogen industry, generating more than 25 million tons per year—about one-quarter of the global volume—mostly from fossil fuels. In addition, China has developed capabilities along the green-hydrogen value chain, accounting for 35 percent of the global electrolyzer manufacturing capacity. [300] It also has significant potential for renewables installations. These factors put China in a unique position to become a potential market leader for green hydrogen, both from a production standpoint and for applications in hard-to-abate industries and heavy transport. Following here are three actions for consideration.

Transitioning existing hydrogen production from gray to green, building on incentive schemes and technological improvements. There is an emerging opportunity to invest in green hydrogen production in China, building on local availability of renewables and the value-chain maturity in the region. The decommissioning of coal plants and the deployment of renewables additionally pave the way for a strong green economy built around hydrogen products. Hydrogen can act as a flexible option for storing energy from intermittent renewables, contributing to system stabilization. According to McKinsey estimates, China could achieve cost parity for green hydrogen solutions before 2030. This cost of green

[296] "China launches pilot green power purchase scheme," Argus Media, September 8, 2021.
[297] *BASF confirms ambitious climate targets and takes steps to reduce product-related emissions,* BASF press release, March 28, 2022.
[298] *Shandong Energy Storage participates in ancillary service market for the first time,* CNESA, July 4, 2021.
[299] *Short range outlook,* World Steel, October 22, 2022; *Cement production share worldwide by region,* Statista, 2022.
[300] *China's Hydrogen Industrial Strategy,* Center for Strategic and International Studies, February 3, 2022.

hydrogen production is estimated at a competitive rate of $2.4 per kilogram by 2030, compared with a global cost range from $1.3 to $3.5 per kilogram.[301]

95%

Industrial sectors account for 95 percent of hydrogen use in China

Providing economic support for early adoption of hydrogen in industry and transportation, including for heavy-duty vehicles. Industrial sectors account for 95 percent of hydrogen use in China. The country is looking to promote hydrogen use in the transportation sector, particularly for heavy-duty vehicles. According to McKinsey research, by around 2025 the total cost of ownership (TCO) of heavy-duty vehicles is expected to be within 15 percent of the TCO for internal-combustion-engine vehicles (ICEVs) and 7 percent for battery electric vehicles (BEVs). The TCO reduction could promote an early switch toward fuel-cell electric vehicles (FCEVs). Full cost parity for FCEVs, BEVs, and ICEVs is expected by 2030, after which FCEVs could become the most competitive solution for heavy-duty vehicles by the measure of TCO. This could promote a significant uptake of FCEVs in the next few years and help decarbonize China's heavy-duty-vehicle footprint—which today contributes to 32 percent of the country's total transportation emissions.

Developing enabling infrastructure for hydrogen and CO_2, such as pipelines and storage capacity. To enable such a vision, China could develop the infrastructure to support development of the hydrogen market. The most competitive solution is to improve distribution through pipeline transport, which carries hydrogen liquid or gas through pipes, although it requires long installation times. Until this solution becomes more scalable, small-scale transportation of hydrogen via trailers and tank trucks will be important.

5

Enabling greater carbon transparency and incentivizing the private sector to pursue more ambitious targets

In 2021, China's emission-trading scheme (ETS) became fully operational, regulating carbon emissions from power plants, with an initial coverage of approximately 2,200 energy producers.[302] After one year, China's ETS has become the world's largest carbon market, three times bigger than the European Union's. With the planned addition of heavy industry and manufacturing, China's ETS could become the largest global climate policy, covering more emissions than the rest of the world's carbon markets combined.[303]

While the ETS establishment was successful, to date the system covers mainly the power sector. Furthermore, the price of carbon is relatively low compared with prices on other carbon ETSs globally.[304] In 2021, the average carbon price was $8.5 per ton, compared with carbon prices of $40 to $80 in other economies.[305] Additionally, ETS trading opportunities in China are limited to allowances, while more structured products such as derivatives and futures are not yet at scale. Following are three actions to consider.

[301] *China's first hydrogen plan focused on lowering costs, building capabilities,* S&P Global, March 29, 2022; *An Energy Sector Roadmap to Carbon Neutrality in China,* IEA, September 2021.
[302] *China's New National Carbon Trading Market: Between Promise and Pessimism,* Center for Strategic and International Studies, July 23, 2021.
[303] "China's Emissions Trading System Will Be the World's Biggest Climate Policy. Here's What Comes Next," *Forbes,* April 18, 2022.
[304] Tan Luyue, "The first year of China's national carbon market, reviewed," China Dialogue, February 17, 2022.
[305] "The first year," February 17, 2022; "Few countries are pricing carbon high enough to meet climate targets," OECD, September 18, 2018.

Consider extending China's ETS from power sectors to cover the entirety of emissions from all sectors. Reports suggests that lack of transparency and the poor quality of reported data could cause delays in the expansion of the ETS beyond power generation.[306] Establishing digital processes that govern where projects are registered and credits are verified and issued could mitigate integrity risks. Frameworks to address the heterogeneous nature of credits and limited price transparency could minimize errors and facilitate faster adoption of ETS across different sectors. The eight key industries of cement, iron and steel, nonferrous metals, building materials, chemical, petrochemical, paper, and domestic civil aviation are expected to join the ETS by 2025.[307]

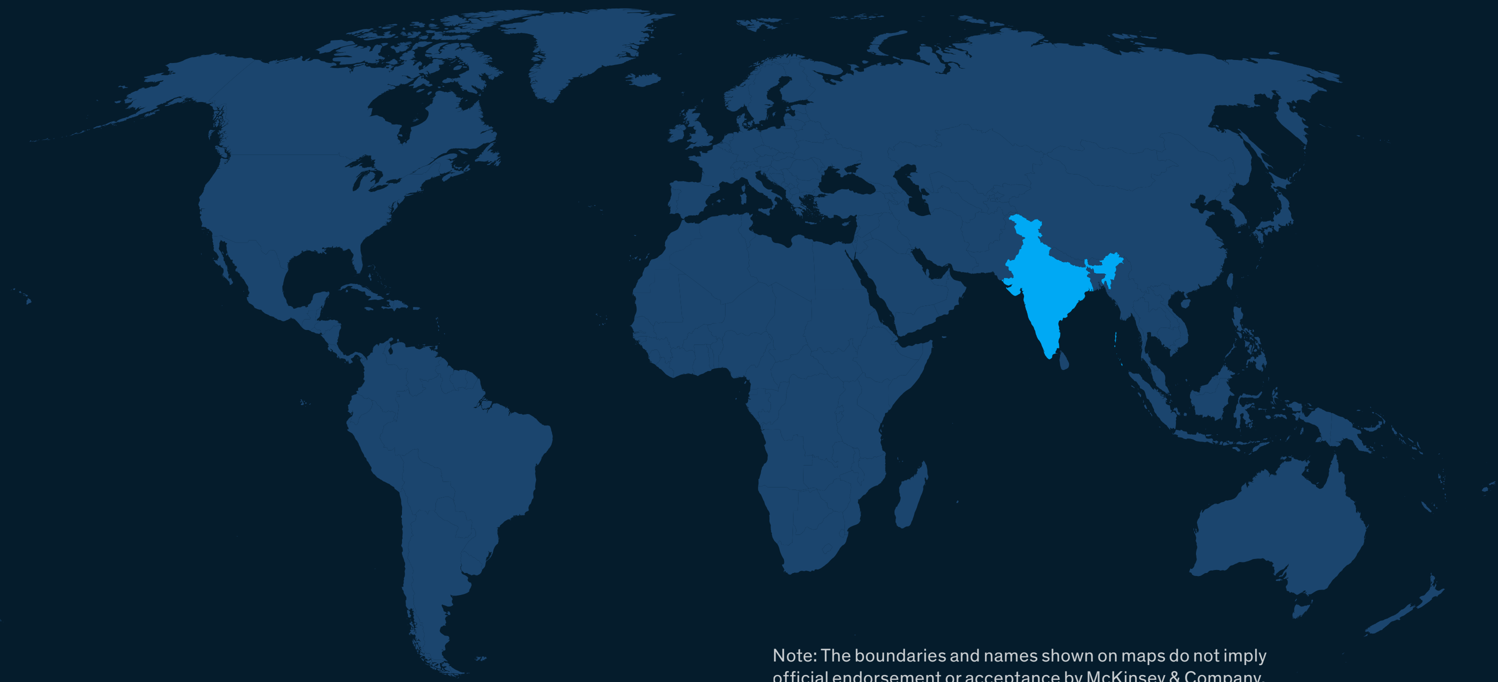
Structuring the ETS market for the growth of carbon credit trading activities and the development of structured financial products. Launching structured products such as derivatives, repurchase options, and futures could drive innovation in carbon markets. This could enable risk hedging for emissions-reduction technology manufacturers and minimize risk for investors. For instance, derivatives markets play a major role in enhancing emissions transparency by providing forward information on carbon, which contributes to meeting long-term sustainability objectives and provides helpful signals to policy makers about the regulation of carbon prices. In turn, investors can use price signals from carbon derivatives to assess climate-transition risk in their portfolios, access liquidity pools to manage risk, and allocate capital toward their energy transition goals.

Building carbon tracking capabilities and establishing standards and databases for carbon accounting and carbon auditing. With the expansion of the ETS, emitters in China would have an incentive to invest in carbon tracking and tracing capabilities. This would enable them to participate in setting sectoral benchmarks and standardizing data-collection processes to ensure data quality. Recently, China launched an action plan with a tailored set of guidelines for companies in different industrial sectors, pointing out what each entity needs to do to ensure both efficient decarbonization and sustainable economic growth.[308] Studies indicate that this framework has an 80 percent chance of achieving a peak for CO_2 emissions by 2026.[309] Given China's prominence as a manufacturing hub serving global needs, Chinese manufacturers of commodities and tradable products would benefit from proactively investing in carbon transparency across scope 1, scope 2, and eventually scope 3 emissions. Doing so could position them to compete for a growing global market of green products.

80%

China's recently launched action plan with tailored guidelines for companies has an 80 percent chance of achieving a peak for CO_2 emissions by 2026

[306] "National carbon market expansion may be delayed to 2023," China Dialogue, May 19, 2022.
[307] *China's New National Carbon Trading Market: Between Promise and Pessimism,* Center for Strategic and International Studies, July 23, 2021.
[308] Qian Zhou and Arendse Huld, "What is China's Green and Low-Carbon Plan and Why is it Relevant to Foreign Investors?" China Briefing, June 6, 2022.
[309] Jiandong Chen et al., "Carbon peak and its mitigation implications for China in the post-pandemic era", *Nature,* Number 3473, March 2, 2022.



Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

India

India exhibits the principal characteristics of the “large, emissions-intensive” economies regional archetype. The country has a rapidly growing economy and historically strong dependence on fossil fuels. India’s expected economic and demographic growth and ambitious NDCs will likely require new sources of supply to meet the increased energy demand. India could move on to an orderly transition path by accelerating the deployment of renewables from 10 GW to 80 GW a year, while keeping the emissions of its fossil fuels under control through electrification and energy-efficiency measures. The country also has the opportunity to promote the creation of a domestic supply chain (in solar PV, for instance) for the energy transition and leverage the local availability of natural resources such as rare-earth oxides. India has pledged to reach net zero by 2070. However, studies show that a further acceleration of the energy transition to reach the net-zero target by 2050 could boost India’s economy by as much as 4.7 percent above the projected baseline growth and create nearly 20 million additional jobs by 2032.[310]

To seize these opportunities and promote a more orderly path for the energy transition, India could consider the following priority measures:

- Expanding land availability and reducing acquisition barriers for renewable deployment
- Streamlining the contracting process through state utility buy-in to facilitate state and corporate PPAs
- Creating new financial mechanisms to de-risk projects and improving the financial and operational health of distribution companies
- Accelerating the development of green manufacturing capacity and promoting access to raw materials and local supply-chain opportunities
- Reducing the carbon intensity of high-emission power and industrial sites

[310] “Net zero can boost India’s GDP, says report,” *The Hindu*, August 26, 2022.

India's starting point

60%

Per capita CO_2 emissions in India is 60 percent lower than the global average

Today India accounts for 2.6 Gt of CO_2e of energy emissions, representing 7.5 percent of global energy-related emissions.[311] The per capita CO_2 emissions in India is 60 percent lower than the global average (1.7 tCO_2 per capita in India versus a global average of 4.4tCO_2 per capita in 2019).[312] However, emission intensity per unit of energy in India is higher than the global average, with 72 Mt of CO_2 emissions per exajoule (EJ), compared with the global median of 53 Mt.[313]

India's power mix has been shaped by the need to serve growing power demand, which has grown by 488 million tons of oil equivalent (MTOE) or 110 percent in the past 20 years[314] as the share of population with access to electricity grew from 59 percent in 2000 to 99 percent in 2020.[315]

This surging demand has been met mostly with the development of coal plants, drawing predominantly from domestic coal supply. Coal power generation represents 45 percent of India's primary energy demand but 70 percent of power sector emissions.[316] Three-quarters of its coal consumption[317] is secured domestically, while the remainder is imported, mostly from Indonesia, Australia, and South Africa.

About 48 percent of India's emissions are linked to electricity generation. The industrial sector represents about 30 percent of emissions, mostly from the iron, steel, and cement sectors, and emissions grew annually by 9 percent from 2005 to 2013. However, emissions intensity (or energy intensity) in the industrial sector decreased by 60 percent from 1990 to 2019.[318]

India's renewables market has grown in the past five years to 10 GW installed per year, reaching a total installed capacity of more than 100 GW in 2022.[319] Over the past five years, India has started establishing policy and regulatory frameworks to push clean energy and domestic manufacturing. Through these measures, India's renewable energy industry has made progress that has resulted in the development of sizable portfolios (more than 6 GW to 7 GW operational) by multiple players and the attraction of large investments from global investors.[320] However, clean energy from renewables still represents only about 10 percent of power generation with an additional 15 percent from hydropower.[321]

India is a regional manufacturing hub for mechanical, electrical, and other components and has expanded its industrial manufacturing output sixfold since 2000.[322] While wind equipment is produced locally, domestic capacity for solar and storage still represents a small fraction of the local demand. For example, only 15 to 20 percent of the solar modules installed in 2021 were manufactured locally.[323] The government has announced production-linked incentive schemes to accelerate development of the domestic solar PV supply chain.

The country also possesses a considerable amount of rare-earth minerals—6 percent of world reserves—that are critical for the energy transition.[324] A large portion of these reserves remains untapped.

[311] *BP energy outlook,* 2022.
[312] World Bank data on CO_2 emissions.
[313] World Bank data on CO_2 intensity.
[314] *Renewable Energy Capacity Statistics,* International Renewable Energy Agency (IRENA), 2022.
[315] World Bank data on electricity access.
[316] *India energy outlook 2021,* IEA, February 2021.
[317] *India Coal,* Worldometers, 2016.
[318] *India Energy Outlook 2021,* IEA.
[319] *Renewable energy capacity,* 2022; *Annual report 2021,* Central Electricity Authority Ministry, of Power, Government of India.
[320] Arjun Joshi, *FDI in Indian Renewable Sector Up by 100% to $1.6 Billion in FY22,* Mercom research focus, June 3, 2022.
[321] *Annual report 2021,* Central Electricity Authority, Ministry of Power, Government of India.
[322] *India Manufacturing Output 1960-2022,* Macrotrends.
[323] "India's solar power prospects compromised by steep import duty, commodity hikes," S&P Global, April 1, 2022.
[324] "Rare Earth Elements (REE) and strategic metals security: How the best way forward for India diverges from the Chinese model?" *Financial Express,* April 3, 2021.

Nationally determined contributions

45%

India has pledged to reduce emissions intensity per GDP in 2030 to 45 percent below 2005 levels

At COP26, Prime Minister Narenda Modi announced a target of net zero by 2070. The country pledged, in the interim, to reduce emissions intensity per GDP in 2030 to 45 percent below 2005 levels. Under its NDCs, India is also committed to reaching 50 percent cumulative electric power installed capacity from non-fossil-fuel-based energy resources by 2030—450 GW by 2030.[325]

Our analyses show that under a 4 to 8 percent GDP growth assumption, India would still produce net annual emissions above the amount needed to achieve the 1.7° pathway. Under our "current trajectory" scenario, India's emissions could peak in the early to mid-2030s because of a projected 5 to 6 percent growth in power demand per year, a large part of which would be met by the use of fossil fuels. After reaching its peak, emissions would then decline as coal is progressively phased out along with legacy assets.[326]

Priority measures that could accelerate a more orderly energy transition

India faces a set of challenges to achieve its carbon emission targets by 2030: (1) renewable projects' scalability issues relating to fragmented distribution and ownership of available land and barriers around permits and clearances; (2) roadblocks in the processes for corporate PPAs—including approval from distribution companies (DISCOMs) and delays in the state tendering process—and counterparty risks, such as payment security; (3) operational and financial challenges of DISCOMs that inhibit modernization and new resource integration; (4) dependence on imports to meet local demand of raw materials and components, as well as bottlenecks to local availability for clean-energy components; and (5) reliance on emissions-intensive, hard-to-abate fuels like coal for power and industry and nascent or limited carbon schemes to drive the fossil-fuel-to-green switch.

To meet these challenges and make near-term progress toward meeting India's emission targets, stakeholders could consider the following set of high-priority measures.

1

Expanding land availability and reducing acquisition barriers for renewables deployment

Among the constraints preventing India from scaling up the pace of development, land availability is one of the most crucial. More than 60 percent of the densely populated country is used for agriculture alone,[327] which makes procuring and scaling land for renewable use difficult. India would need 65,000 to 95,000 km^2 of land by 2050, or 1.7 to 2.5 percent of its total available land, to help meet the 2050 NDC target.[328] However, land parcels in India are fragmented: India has 140 million land parcels with an average size of just above 0.01 km^2,[329] and two-thirds of them are less than 0.01 km^2. Therefore, acquiring sufficient land to deploy large-scale renewables is complex and requires interaction and aggregation of land from multiple owners and stakeholders. Following are three actions to be considered.

[325] *India's Updated First Nationally Determined Contribution Under Paris Agreement,* UNFCC, August 2022.
[326] McKinsey Power Model.
[327] World Bank data.
[328] "Reducing land-use impacts of renewable generation could smooth the path for India's energy transition," Institute for Energy Economics and Financial Analysis (IEEFA), September 5, 2021.
[329] Avinash Kishore, Sunipa Dasgupta, and Pramod K. Joshi, "Why private rural extension fails? Lessons from Hariyali experiment," in *Agricultural Extension Reforms in South Asia: Status, Challenges, and Policy Options,* Academic Press, 2019.

1,789 GW

Estimates suggest that wastelands across India have a potential capacity of more than 1,789 GW, enough to meet 2030 installed capacity needs for wind and solar

Using geospatial technology to identify sites suitable for renewable development and prioritizing readily available land. Private and public stakeholders in India could use geospatial technology to combine land availability data with solar and wind potential to prioritize areas for development, such as high-potential and contiguous land. For instance, stakeholders could prioritize wastelands (lands degraded by human activities) for solar development. Estimates suggest that wastelands alone have a potential capacity of more than 1,789 GW across India, which could easily meet 2030 installed capacity needs for wind and solar.[330]

Facilitating the identification of land pockets suitable for renewable build-out. India could facilitate developers' efforts to procure fragmented and smaller land parcels. One immediate solution would be to address barriers such as poorly maintained land records, land procurement, and environmental approvals. Another option could be to create mechanisms to aggregate smaller land parcels.

Streamlining and accelerating the project permitting process. India could streamline land procurement by minimizing the number of government approvals required, establishing a single office facility for all needed approvals, or creating a timeline for clearance from all departments. The government could also simplify private transactions with farmers. Transparency in the land-acquisition process could also mitigate purchasers' risk. As an example, public and private stakeholders could simplify private transactions with farmers. Standardizing the process across different states and delegating the responsibilities to district-level officers could also speed up the approval process.

2

Streamlining the contracting process through state utility buy-in to facilitate state and corporate PPAs

90%

More than 90 percent of PPAs are under state DISCOMs with terms that last from 20 to 25 years

Meeting India's NDCs will require significant renewable uptake. Clean energy project off-take in India is delayed by limitations in the voluntary corporate PPA market, which represents 1 to 2 GW per year,[331] a small fraction of the nearly 10 GW deployed annually. Currently, more than 90 percent of the PPAs are under state DISCOMs, with terms that last from 20 to 25 years. India is not demand constrained, as large Indian corporates and multinational companies are showing interest. Yet limited corporate PPA activity is mostly due to delays in regulatory approvals arising from DISCOMs' conflicts of interest, transaction complexity, and short-term agreement timelines, which typically last 12 to 15 years.[332]

In terms of counterparty and contractual risk, renewables projects in India are subject to a significant amount of uncertainty related to project revenues. Unsigned PPAs alone account for 19 GW of renewable capacity in limbo.[333] As of April 2022, power producers were waiting on $14 billion in overdue payments stemming from complex billing and collection and energy theft, with an average delay of almost four months.[334] This led to a counterparty credit risk increase of 1.0 to 1.5 percent, which in turn translated to an additional risk premium for renewable energy projects. Following are four actions to consider when addressing these challenges.

[330] Sanju John Thomas, Sheffy Thomas, Sudhansu S. Sahoo,Ravindran Gobinath, and Mohamed M. Awad, *Allotment of Waste and Degraded Land Parcels for PV Based Solar Parks in India: Effects on Power Generation Cost and Influence on Investment Decision-Making*, MDPI, December 30, 2019.
[331] *Corporate renewable PPAs in India: Market update,* WBCSD, January 2021.
[332] Ibid.
[333] Vibhuti Garg, Jyoti Gulia, and Akhil Koshy Thayillam, *India's power sale agreement hold-up: Fixing a renewable energy bottleneck,* JMK Research & Analytics, IEEFA, March 2021.
[334] Peter White, *Indian Distribution Companies' delayed payments reach $14.4 billion,* Rethink Research, August 17, 2022.

Removing barriers and complexities in executing and implementing PPAs within state utilities. India could take actions to streamline the PPA signing process for DISCOMs, thus limiting project cost increases and delays. Potential solutions include tariff pooling—for example, every six months, the weighted average of a tariff would be used to determine the composite tariff. Integrated renewable energy planning could also enable systematic procurement of renewable power based on demand projections. Further, guidelines to enforce contract obligations and PPA signing deadlines could lead to PPAs being signed and executed.

$14 billion

As of April 2022, power producers were waiting on $14 billion in overdue payments stemming from complex billing and collection and energy theft

Structuring transaction frameworks and gaining state utility buy-in to accelerate customer access to clean energy sources. Corporate action could accelerate renewable deployment and offer solar developers an additional route to market. State utility buy-in and market frameworks that allow flexibility within bilateral PPAs are required to allow the formation of a market for virtual PPAs. For instance, open access[335] arrangements facilitated by a virtual PPA provide flexibility to consumers through zero up-front investments. These use grid infrastructure to transmit solar power generated at a different location. Open access also promotes competition and increases efficiency in the power distribution sector. For example, the Indian government, under its new policy, allows consumers with contracted demand or a sanctioned load of 100 kW (previously 1 MW) to be eligible for open access. It also created a central nodal agency to accelerate approvals to a fixed 15 days, avoiding the need for longer processes with DISCOMs. This policy enabled micro, small, and medium-size enterprises to transition to green energy and resulted in a 58 percent increase (513 MW) in open-access capacity between the fourth quarter of 2021 and the first three months of 2022.[336]

Developing frameworks for round-the-clock hybrid models to increase industry-level renewables penetration. India could consider creating frameworks to support the large-scale adoption of renewables and storage systems through round-the-clock (RTC) initiatives,[337] which could also address the concern around intermittent power supply from renewable sources. RTC initiatives could prove particularly effective in the industrial sector, where continuity of energy supply is required to fuel industrial processes. RTC frameworks could further boost PPA uptake by offering flexibility to both distribution companies and industry to meet peak load demand, thus providing a reliable energy source that could replace emissions-intensive back-up power systems. Examples include the use of pumped hydro-storage, a mixture of wind and solar power, or a hybrid of wind and solar power and storage capacity. Further, virtual PPA frameworks could facilitate transactions in which green attributes are transferred directly.

Increasing visibility into future renewable energy demand. Visibility into the upcoming tender pipeline and stability around future renewable energy project demand could allow bidders to achieve scale and operational efficiency. In turn, they could also meet their expectations for an internal rate of return in a competitive market. Demand transparency supported through nascent technologies, such as RTC, could enable manufacturers, suppliers, and contractors to plan long-term investments to attain efficiency across the value chain and limit costs. Furthermore, states could ensure demand stability to facilitate optimum production-capacity utilization for better returns on investment.

[335] Open access is an arrangement where a power producer establishes a solar power plant at an appropriate location and signs a medium/long-term power purchase agreement with a consumer.
[336] *Open Access Solar Installations Rise by 58% QoQ to 513 MW in Q1 2022,* Mercom research focus, June 8, 2022.
[337] Round-the-clock (RTC) power means power supply that is available 24×7, throughout the year.

3

Creating new financial mechanisms to de-risk projects and improving the financial and operational health of distribution companies

$150 billion

India is estimated to need at least $150 billion per year until 2050 to meet its 2050 net-zero target

20%

In 2020, DISCOMS saw aggregate technical and commercial losses reach more than 20 percent

Stable, reliable, and affordable access to the grid is a prerequisite to a smooth energy transition. To meet its 2050 net-zero target, India is estimated to need at least $150 billion per year, or about 2 percent of GDP, up until 2050.[338]

Capital from private investors, both domestic and foreign, will likely play a significant role in the energy transition. The attractiveness of investments will depend greatly on financial viability and risk levels. A major factor adversely affecting the flow of private investments into renewable energy is the perceived payment risk as a result of the financial condition of Indian DISCOMs.

DISCOMs play a crucial role in facilitating transactions within an integrated renewable system. However, in India, most grid DISCOMs are experiencing financial losses. The high number of technical and nontechnical losses further complicates their cost structure and financial position. In 2020, for instance, DISCOMS saw aggregate technical and commercial losses reach more than 20 percent.[339] Such inefficiencies over the years resulted in approximately $100 billion of debt for grid companies.[340] The uncertainty around the financial health of distribution companies impedes investments in the integration of electrification and renewables and creates uncertainty for clean energy developers and customers. Following are three actions to consider.

Adopting new financing mechanisms to increase access to domestic and foreign low-cost capital. India's investments to meet renewable targets will likely require access to scalable, long-term, and low-cost debt capital. Underutilized sources of financing, such as infrastructure investment trusts, green bonds, sustainability funds, and credit enhancements, could be scaled to meet investment needs. For example, infrastructure investment trusts pool multiple operational projects into which individual or institutional investors can directly invest small amounts of money. This allows independent power producers to raise money from multiple retail and institutional investors to pay off other debts and invest in building new projects or acquisitions.

Furthermore, the government, NGOs, and startups could encourage patient capital[341] from large oil and gas companies and service-sector companies to diversify revenue sources and address environmental, social, and governance (ESG) concerns. And green bonds offer tradability for investors and fixed rates for independent power projects to mitigate interest-rate risk (85 percent of green bonds in India have fixed coupons).[342]

In addition, reforms and policy changes to the current financial mechanism could enable low-cost capital. For example, creating a separate lending category for renewables and raising lending limits could increase capital from banks and nonbanking financing.[343] Using a third party or insurer to reduce the cost of conducting external credit enhancements (improving the credit-risk profile of a business to get better terms for debt repayment) could further increase the uptake of external improvements. This could upgrade the creditworthiness of a green bond and produce lower yields.

[338] Montek Singh Ahluwalia, and Utkarsh Patel, *Getting to Net Zero: An Approach for India at COP-26,* CSEP, September 2021.
[339] *AT&C Losses Among Distribution Companies Dips by 2% Between FY 2016 and 2020,* Mercom India, August 12, 2021.
[340] Tim Buckley and Vibhuti Garg, *India's power distribution sector needs further reform,* Institute for Energy Economics and Financial Analysis, September 2020.
[341] Patient capital is a type of long-term capital where the investor is willing to forgo an immediate return in anticipation of more substantial returns down the road.
[342] Shantanu Jaiswal and Rohit Gadre, "Financing India's 2030 renewable ambition," *BloombergNEF,* June 22, 2022.
[343] Vibhuti Garg, *India's Power Distribution Sector Needs Further Reform,* September 2020.

Mitigating counterparty and off-take risks to increase private stakeholder participation through payment security mechanisms. Mitigating counterparty risk in India could provide an opportunity for innovation in insurance and risk management products. Insurers could create tailored products that measure this risk, offering more certainty to aspiring project developers. Further, creating a built-in mechanism to ensure that the DISCOMs honor their contracts through government or bank-backed contracts could reduce investor risk and, in general, create a lower-risk investment atmosphere for renewable project developments.

Developing long-term stability in a distribution company regulatory framework, measuring and rewarding performance, and enhancing financial discipline. DISCOMs could outsource underperforming operations through models such as a distribution franchising, distribution licensing, or a public-private partnership. DISCOMs could also use smart meters or prepaid metering to improve billing and collection efficiency. By increasing their emphasis on continuous improvement and developing a stable, performance-focused regulatory model, Indian DISCOMs could enhance their performance significantly. For example, India has started an integrated rating exercise across 71 DISCOMs and power departments that evaluates their financial and operational performance. This exercise resulted in 12 DISCOMs making it to "A+ grade" and 26 utility companies reducing their transmission losses to less than 15 percent.[344] An improved financial rating provides a DISCOM with access to low-cost investments and the capital required to make further grid and operational efficiency improvements.

4

Accelerating the development of green manufacturing capacity and promoting access to raw materials and local supply-chain opportunities

80–85%

India imports 80 to 85 percent of its solar PV modules

McKinsey analysis suggests that on the way to meeting its 2030 NDC, India is expected to spend $200 billion to $300 billion for clean energy projects.[345] While this could represent a significant opportunity to develop domestic capacity for green energy manufacturing, India lags behind other global regions in this regard. For example, while it ranks second in global manufacturing capacity and output, it imports 80 to 85 percent of its solar PV modules.[346] A review of India's approved list of models and manufacturers[347] indicates that only a handful of domestic players are approved manufacturers. The picture is further complicated by the need to import various types of raw materials. For example, India imports more than 80 percent of copper for grids, nickel and cobalt for batteries, and rare-earth minerals for wind turbines, batteries, and components.[348]

With its strong manufacturing capabilities and focus on development and industrialization, India could consider a taking a bolder stance in the domestic development of green manufacturing. Following are four actions to consider.

[344] *Annual Integrated Rating & Ranking: power distribution utilities,* Ministry of Power, Government of India, August 2022, pfcindia.com.
[345] *Renewable Projects Remain Cost-Competitive Through 2021 Amid Fuel Crisis,* Mercom research focus, July 20, 2022.
[346] *India's solar power prospects compromised by steep import duty, commodity hikes,* S&P Global, April 1, 2022.
[347] The approved list of models and manufacturers (ALMM) is a list of models and manufacturers of solar PV modules approved by the Ministry of New and Renewable Energy (MNRE).
[348] *The Role of Critical Minerals in Clean Energy Transitions,* IEA, May 2021.

Pursuing opportunities for low-cost, local manufacturing of key clean energy components to meet local demand and create export opportunities. India could leverage the production-linked incentive scheme to encourage domestic manufacturing, such as the development of solar PV capabilities around wafer and polysilicon manufacturing. The scheme aims to offer incentives for incremental sales of goods manufactured in India in key business areas. Indian private-sector companies could rethink and reprioritize their investments in the domestic production of clean energy components, such as PV gigafactories, storage, and electrolyzers. For example, Vikram Solar has invested in developing a local supply chain to become the largest PV module manufacturer in India. An increase in local manufacturing of clean energy components could also promote opportunities for the export of components in the growing international cleantech market.

6.9 Mt

At 6.9 Mt, India has the fifth-largest rare-earth oxides reserves in the world

Investing in exploration and production of untapped domestic mineral reserves. India has the fifth-largest rare-earth oxides reserves in the world at 6.9 Mt.[349] As yet, India does not mine elements that are critical for renewable manufacturing; it imports almost 100 percent of the rare-earth minerals that renewable manufacturing requires. All stakeholders could consider investments in upstream extraction and downstream processing capabilities across the value chain to leverage the region's natural endowments.

India could also optimize trade alliances and partnerships to secure the imports needed of key raw materials such as copper and lithium.

Promoting material recycling to reduce the need for imports of critical materials and establish standards for testing and refurbishing second-life equipment. India could also consider solutions, such as recycling and the circular economy, that will limit the demand for imported raw materials. While India does not have significant local lithium reserves and extraction capabilities, 3.5 GWh to 17 GWh of lithium-ion batteries in the transportation sector are expected to reach the end of usable life by 2030.[350] Metals account for 30 percent of the value of such batteries. India has proposed legislative frameworks to include lithium-ion and nickel cadmium batteries under extended producer responsibility; manufacturers will become accountable for the entire life cycle of lithium-ion batteries. According to forecasts, recycled metals could meet 80 to 90 percent of the demand for precious metals by 2070. [351]

20–40%

Sodium-ion batteries could reduce storage costs by 20 to 40 percent

Encouraging R&D-led innovation to enable global renewable technologies and new energy solutions. India could consider scaling up its cleantech sector and speeding up deployment by leveraging innovation for renewable technologies that are designed and optimized for the local operating conditions and that make use of domestic resources. For example, sodium-ion batteries could reduce storage costs by 20 to 40 percent.[352] Green innovation clusters comprising renewable companies, public agencies, academia, and start-ups could lead R&D, prototyping and scaling up of future energy technologies. These could include off-river pumped storage, fuel cells, novel chemistries for storage, and electrolyzers. Such efforts could require an increase in R&D spending, which in turn would involve attracting investments from private-equity and venture-capital funds and promoting dedicated incentives. India could also explore new energy solutions that work best in the country's specific environments, such as batteries designed to withstand high heat and dust.

[349] *Mineral commodity summaries,* USGS, January 2021.
[350] *Towards a sustainable battery manufacturing industry,* RMI India, March 2022.
[351] Ibid.
[352] Marija Maisch, "Sodium-ion batteries go mainstream," *PV Magazine,* March 26, 2022.

5

Reducing the carbon intensity of high-emission power and industrial sites

74%

Seventy-four percent of India's power generation comes from coal

With 74 percent of its power generation from coal, the Indian coal fleet emitted 1.1 Gt of CO_2 in 2019.[353] Relatively inefficient use of resources and technological backwardness have led to decreases in efficiency over time. The average efficiency of the plants was 33 percent (the world average is 37.5 percent), one of the lowest among major coal-based power-producing countries. India's average CO_2 emissions are 1.08 kg/kWh, 14 percent higher than China's.[354]

27%

Twenty-seven percent of emissions in industry still come from coal-based processes for manufacturing

In industry, India is the world's second-largest producer of sponge iron, and coal accounted for 88 percent[355] of final energy consumption in the iron and steel sector. This reflects the sector's heavy dependence on coal-based direct reduced iron (DRI) and the low penetration of natural-gas DRI. The technical requirements within industrial processes and the long lifetimes of existing industrial assets indicate that chemical fuels will continue to play a major role in the country. The industry sector is also responsible for the nonenergy use of fossil fuels as industrial feedstocks—for example, in petrochemical and fertilizer production. Furthermore, most industrial customers use backup power generators. As a result, according to our analysis, 27 percent of emissions in industry still come from coal-based processes for manufacturing, such as coal-fired boilers or cement kilns, compared with 6 percent in Europe or the United States. Following are three actions to be considered.

Setting up decarbonization targets in hard-to-abate sectors and providing viability-gap funding to drive green hydrogen expansion. India currently consumes 6 Mt of gray hydrogen a year for industrial uses and aims to achieve cost parity between green and gray hydrogen by 2030. Cost-competitive green hydrogen could open the possibility for market development, especially in industries that already consume gray hydrogen. The cumulative value of the green hydrogen market in India could be $8 billion by 2030 and $340 billion by 2050.[356]

Viability-gap funding mechanisms to address industry-specific cost differentials could increase the uptake of green hydrogen and in turn drive significant emission reduction across industries including refining, steel, and methanol. For example, investments in alternative steel production using hydrogen-based DRI could reduce emissions.

Currently, India ranks second in steel production worldwide but eighth in steel exports.[357] Hydrogen-based processes for green products such as green steel could enable India to capture a larger market share of the global green-product market. Other applications might include the use of low-carbon hydrogen fuels within the existing infrastructure and industrial processes developed for fossil fuel use, such as natural gas, coking coal, and oil products.

Investing in industrial efficiency to reduce energy and emissions intensity. A push toward higher-capacity utilization could allow demand fulfillment without the building of new power plants. For existing plants, India could reduce its coal power emissions by exploring efficiency upgrades for its coal fleet—for example, upgrading subcritical units to supercritical or ultra-supercritical. The efficiency rate of the average coal power plant is around 35 percent, compared with 47.5 percent for plants with low heating value.[358]

[353] "Coal power in India: A pathway to reduced emissions," *NS Energy Business,* April 2, 2021.
[354] "India's first-ever environmental rating of coal-based power plants finds the sector's performance to be way below global benchmarks," Centre for Science and Environment, February 21, 2015.
[355] *India energy outlook 2021,* IEA.
[356] Kowtham Raj, Pranav Lakhina, and Clay Stranger, *Harnessing green hydrogen,* NITI Aayog, RMI, June 2022.
[357] *December 2021 crude steel production,* World Steel Association, January 25, 2022; *Export attractiveness of India's steel sector,* India Brand Equity Foundation, June 9, 2022.
[358] Debo Adams, Toby Lockwood, Paul Baruya, Dr. Malgorzata Wiatros-Motyka, and Dr. Qian Zhu, *A pathway to reducing emissions from coal power in India,* IEA Clean Coal Center, CIAB, January 2021.

Accelerating the setup of compliance and voluntary carbon markets to accelerate investments in low-intensity alternatives. India could develop a framework that includes voluntary and compliance carbon markets outside of the energy-efficiency schemes to increase the trade of carbon credits in the carbon markets. Perform Achieve and Trade (PAT) schemes are one example. Regulatory instruments used to reduce specific energy consumption in energy-intensive industries, they have an associated market-based mechanism to enhance cost effectiveness through the certification of excess energy saving, which can be traded. Developing the guidelines for compliance markets could encourage the energy transition and emission reductions in high carbon-emitting industries such as steel, cement, and power. Voluntary markets could enable companies, governments, nonprofit organizations, and individuals to purchase carbon credits (offsets) on a voluntary basis and drive more exchange of credits. They could also allow low-intensity service sectors to invest in the energy transition as part of their ESG initiatives.

India's renewables market has grown in the past five years to 10 GW installed per year, reaching a total installed capacity of more than 100 GW in 2022.

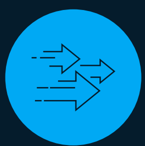
Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

Latin America

Latin America[359] exhibits the main characteristics of both “developing, naturally endowed” as well as “developing, at risk” archetypes. Indeed, countries in this region vary widely in terms of natural endowments available such as solar and wind potential and mineral resources, and have different energy needs and emissions footprints.

The region has a lower share of fossil fuel energy generation than the world average, mostly because of a large share of hydro generation.[360] While wind and solar represent a smaller portion of the energy mix, countries such as Brazil and Chile are increasing investment levels to expand low-cost renewables capacity.[361] Transportation and industry remain emissions-intensive because of limited emissions standards and funding mechanisms in place to accelerate the transition to cleaner solutions. However, Latin America has a significant opportunity to build on its natural endowments and create economic growth and a durable competitive advantage for the region, both domestically and internationally.

Latin America could focus on six priority measures to move toward a more orderly transition:

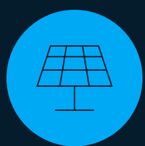


Streamlining, accelerating, and increasing certainty of project permitting, and promoting simpler frameworks for public-private collaboration

Improving and stabilizing pricing schemes, market designs, and guarantees to de-risk energy transition investments and improve access to domestic and international capital

Introducing demand-side measures to promote the switch from fossil to electric and other energy-efficient alternatives in transportation

Developing regulated carbon tracking mechanisms and markets, and driving green incentives to decarbonize industry footprint



Promoting local manufacturing of parts and equipment, and exporting clean energy commodities and products

Developing a qualified regional workforce to support the transition and create socioeconomic benefits

[359] Latin America in this report includes South America, Central America, and Mexico.
[360] *BP Energy Outlook 2022 edition*, BP.
[361] Craig Dempsey, “Renewable energy in Latin America revives after pandemic,” *BizLatinHub*, May 25, 2022.

70%

Fossil fuels account for 70 percent of Latin America's primary energy consumption

Latin America's starting point

Latin America's energy mix is relatively greener than that of other regions. Fossil fuels account for 70 percent of total primary energy consumption, compared to the world's average of 82 percent.[362] The energy mix includes nearly 20 percent of hydroelectric power[363], and countries in this region including Brazil are among the largest producers of biofuels.[364] The region today is an exporter of fossil fuels, in particular oil—in 2021, it exported 1.5 billion barrels of oil.[365]

Total renewables installed capacity adds up to 270 gigawatts, of which 39.4 gigawatts is from wind and 30 gigawatts from solar.[366] The majority—nearly 200 gigawatts—is from hydro.[367] The region has extensive renewable potential, both in wind and solar. For instance, the Atacama Desert in Chile has a photovoltaic (PV) capacity of 1800 gigawatts, with capacity factors over 20 percent higher than those of the best locations in Africa, the Middle East, or Australia.[368] The Patagonia region in Chile and Argentina has onshore wind capacity factors that are more than 30 percent higher than Argentina's average wind-capacity factors.[369] Brazil and Uruguay have complementary wind and solar for more reliable energy supply or green-hydrogen production. Uruguay, Mexico, and Colombia have significant wind power potential, while Bolivia, Mexico, and Peru can benefit from high solar exposure.[370]

The region is also rich in biomass, with Brazil as the world's leading producer in bioenergy.[371] Biomass has multiple potential use cases, from the production of biofuels—for example, biodiesel as a replacement for diesel in heavy-duty transport—to the development of the biogas and biomethane industries, biomaterials such as solid wood for construction and bioplastics, and steel production and other high-temperature processes. Biomass holds significant potential for both domestic use and export.

With its above-average renewable penetration, Latin America is also well positioned to become a large producer and potential exporter of green hydrogen derivatives such as green ammonia and synthetic fuels. The region has built a large project portfolio of such projects, equivalent to tens of GW of power and growing, mainly in Brazil and Chile, but rapidly expanding to other geographies, such as Uruguay, Argentina, and Colombia.[372]

The region is rich in minerals that are critical for the energy transition. The lithium "Golden Triangle," around the borders of Chile, Argentina, and Bolivia, holds 56 percent of the world's lithium resources and 48 percent of reserves: Chile holds the largest share of lithium (42 percent of worldwide total), and Argentina the third largest (10 percent of total). Chile also has the largest reserves of copper (23 percent) while Peru has the third largest (9 percent). Brazil holds the third-largest reserves of nickel (16 percent of total) and rare earth (17 percent).[373]

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362 *BP Energy Outlook 2022 edition,* BP.
363 Ibid.
364 *How competitive is biofuel production in Brazil and the United States?* IEA, March 11, 2019; *BP Energy Outlook 2022 edition,* BP.
365 *BP Energy Outlook 2022 edition,* BP.
366 *Renewable Energy Capacity Statistics,* International Renewable Energy Agency (IRENA), 2022.
367 *Hydropower Status Report,* International Hydropower Association, 2021.
368 Julien Armijo, Cedric Philibert, "Flexible production of green hydrogen and ammonia from variable solar and wind energy, case study of Chile and Argentina", *International Journal of Hydrogen Energy,* May 2019.
369 Argentina Wind Sector Overview, Wind Energy International.
370 *How competitive is biofuel production in Brazil and the United States?* International Energy Agency, March 11, 2019.
371 *Renewable Energy Capacity Statistics,* International Renewable Energy Agency (IRENA), 2022.
372 *Hydrogen in Latin America: From near-term opportunities to large-scale deployment,* IEA, 2021.
373 "Mexico seeks lithium association with Argentina, Bolivia and Chile," Reuters, May 3, 2022; *Mineral Commodity Summaries,* USGS, 2022.

The combination of the above factors presents significant opportunities for the region to materially contribute to the decarbonization of the economy within and beyond the continent, and to drive sustainable economic growth throughout the region. In particular, among the main opportunities are:

— Further accelerating local energy decarbonization within industry and transportation, making use of the large potential for solar, wind, biomethane, and biofuels, as well as existing hydroelectric power

— Substantially increasing the mining of transition-critical minerals such as copper, lithium, nickel, and rare earth and developing a local manufacturing sector to produce some of the equipment that the energy transition and low-carbon export sectors require

— Becoming an "export powerhouse" in the global energy transition, promoting the international trade of green commodities including hydrogen and products such as ammonia and green metallics.

45%

Transportation is the greatest source of CO_2 emissions, at 45 percent

Total energy-related emissions in the region amount to 1.6 Gt of CO_2 as of 2021.[374] Among countries, the largest absolute emissions come from Brazil (28 percent of regional total), followed by Mexico (24 percent), and Argentina (11 percent).[375] Three sectors contribute to more than 90 percent of total energy-related CO_2 emissions. According to McKinsey estimates, transportation is the largest source—at 45 percent, almost double the global average of 23 percent. Industry is the second sector, with 28 percent of the region's CO_2 emissions. The power sector accounts for 18 percent of CO_2 emissions.

Nationally determined contributions

23

Twenty-three of the 24 analyzed countries have submitted NDCs for lower emissions

Among the 24 countries that we analyzed in Latin America, 23 have submitted formal NDCs, with the exception of Curacao. The level of commitment to emission reduction varies widely across countries. For example, among the countries which are the largest contributors of CO_2 emissions, Brazil and Chile have pledged to achieve carbon neutrality by 2050, while Mexico and Argentina have not set specific net-zero targets.[376]

Carbon markets in the region are embryonic but developing. For instance, Mexico has launched its emission trading system (ETS) pilot program, the first of its kind in Latin America.[377] This initially covers the power and industry sectors, which, according to our estimates, generate around 40 percent of national emissions. In Chile, the Climate Change bill, currently under consideration by Congress, outlines provisions for emission-reduction certificates that could be traded and used for compliance purposes with national GHG emissions standards. In Colombia, the national climate change law set a three-year timeline for the development of an emissions-trading system, which would operate alongside Colombia's carbon tax and its offsetting program, in place since 2017.

Priority measures that could accelerate a more orderly energy transition

Latin America faces a diverse set of challenges if it is to accelerate its decarbonization progress in line with the "achieved commitments" pathway and successfully capture the green growth opportunities that the transition holds for the region. These challenges include, to varying degrees among countries: (1) complexities in permitting and social license approvals which slow down the development of green technologies such as renewables, hydrogen and derivatives, and biofuels; (2) limited access to low-cost capital for energy transition investments, including for grid and storage, coupled with volatile market frameworks for

[374] *BP Energy Outlook 2022 edition*, BP.
[375] Ibid.
[376] *United Nations Nationally Determined Contributions Registry*, World Resources Institute, 2022.
[377] "The LatAm countries with carbon pricing instruments in place," BNAmericas.

renewables; (3) limited penetration of electrification and low-carbon alternatives in transport, and gaps in infrastructure required to scale up adoption; (4) limited decarbonization incentives and underdeveloped carbon frameworks restricting industry appetite for electrification and energy efficiency; (5) lack of incentives for localization of energy transition manufacturing and export; (6) gaps in specialized talent required to support the energy transition, including engineers and technicians.

To overcome these challenges and make near-term progress toward achieving a more orderly transition, stakeholders could consider the following set of priority measures.

1

Streamlining, accelerating, and increasing certainty of project permitting, and promoting simpler frameworks for public-private collaboration

330 GW

Amount of renewables needed to be installed in Latin America by 2030 in an accelerated scenario

Latin America has significant renewable potential, but the development of new projects has been relatively slow and could accelerate significantly. For instance, Latin America combined has about half of the installed solar capacity of Germany, and about a third of the installed wind capacity of the United States.[378] Our estimates indicate that, in an accelerated scenario, 330 gigawatts of renewables would need to be installed by 2030, nearly five times today's levels (equal to 67 gigawatts as of 2021). Among the factors slowing down deployment of renewable are uncertainty of permitting processes and lack of simple frameworks.

Countries in the region could consider two key actions:

Ensuring clarity and transparency of the permitting requirements and protecting their validity. Latin America could consider improving the predictability and stability of project frameworks as a key enabler to drive appetite for investments in renewables and green technologies. The permitting process, regulatory expectations, tax incentives, supporting legal frameworks, and guarantees are key areas that could benefit from more stable frameworks. Further, countries could consider long-term renewable plans implemented through competitive processes for developers to invest in renewable and green projects.

Securing engagement of communities and developing awareness and campaigns to foster social acceptance. The benefits of projects have not always been transparent to local communities and ecological impacts have at times been significant. This limited community engagement has led to delays and at times even outright cancellations of energy projects. The public and private sectors could both consider working on broadening public support for the fast, large-scale buildout required for the energy transition.

Firstly, countries could set standards for environmental permits and ensure local benefits in quality of life and economic development. This could include local hiring and fostering initiatives that could have a positive impact on the long-term economic development of the region, including investment in education, training programs, and support for local enterprises.

Secondly, the region could develop frameworks for how to measure impact and improvements in the quality of life of local communities and set minimum standards and targets for incorporation in energy projects, either binding or as selection criteria.

[378] *Renewable Energy Capacity Statistics,* International Renewable Energy Agency (IRENA), 2022.

Thirdly, countries could promote effective communication campaigns to increase awareness of energy transition benefits, reaching local communities as well as broader society. Publicizing success stories could showcase positive impact throughout the region.

Finally, active involvement and real participation by the affected communities could ensure a sense of ownership in projects. This includes information sharing, solid processes for bi-lateral communication, involvement in solving daily issues, and "live" collaboration to resolve complex topics. Public and private stakeholders could foster collaboration by engaging communities earlier on in the project lifecycle, and by clearly communicating the trade-offs for communities between benefits and risks.

Brazil, on the other hand, has taken steps to measure and communicate the benefits for communities. For example, Abeolica, the Brazilian association of wind power, commissioned an independent study that showed how cities with wind farms had better scores on Human Development Indices (HDIs).[379] This study could support the engagement of communities in the Northeast of the country. This area of Brazil has the highest renewables and hydrogen potential but a lower HDI than the country average.[380] Although progress in measuring this data has been made, countries across the region could continue to communicate socioeconomic impacts to local societies to increase social acceptance of clean energy-related projects.

2

Improving and stabilizing pricing schemes, market designs, and guarantees to de-risk energy transition investments and improve access to domestic and international capital

Factors hampering the development of renewables in the region include limited frameworks for energy storage infrastructure—especially in areas with lower penetration of hydro—uncertainties on tariffs and permitting, and higher than average cost of capital.

Storage development is still limited because of limited incentives in the region. While countries such as Brazil and Uruguay can use hydro to balance intermittency of renewables, others have lower hydro resources and need storage assets to balance the power system.

Economic and political shifts have created uncertainty for energy transition investments, in particular around the presence of continuous, uninterrupted government subsidies and the clarity for project-permitting requirements. This has created uncertainty for developers in the region, who must at times make multiple submissions for project approval to obtain the necessary authorizations. For instance, in Colombia developers have faced difficulties in obtaining environmental licenses for constructing renewable and transmission infrastructure due to tensions with local indigenous communities.[381] In Panama, uncoordinated transmission planning, regulation, and technical tracking have created barriers to environmental licensing.[382] Mexico has been in the top three countries for solar and wind energy investment in the region, but recent legal and regulatory changes have slowed investments and progress towards climate goals.[383]

[379] *Impactos socioeconomicos e ambientais da geracao de energia eolica no Brasil,* GO Associados, 2020. According to the United Nations Development Programme (UNDP), the Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living.
[380] *Desenvolvimento humano nas macroregioes,* IPEA, 2016.
[381] Tom Azzopardi, "Transmission delay could slow Colombian wind rush," *Wind Power Monthly,* July 2021.
[382] *Renewables Readiness Assessment: Panama,* IRENA, 2018
[383] *Renewable energy market analysis: Latin America,* IRENA, 2016.

10%

Brazilian wind projects have a relatively low weighted average cost of capital of around 10 percent

21 GW

Brazil has close to 21 GW of installed wind capacity compared with 3.3 GW in Argentina

Higher-than-average country risks, lack of certainty about renewables offtake, and uncertainty in continued policy support mechanisms have pushed up the cost of capital. Country risk is also unevenly distributed across the region. For example, Argentina has stronger wind capacity factors than Brazil—but Brazilian projects have a weighted average cost of capital of around 10 percent, lower than Argentine projects.[384] As a result, Brazil has close to 21 gigawatts of installed wind capacity, while Argentina has only 3.3 gigawatts.[385]

To accelerate deployment of energy transition projects in the region, countries could explore three main actions.

Establishing incentives, market participation, and scaling market mechanisms to increase project returns and attract investments, including foreign capital. To promote the development of storage in the region, incentives and market mechanisms could be put in place. For instance, incentive mechanisms could be introduced to promote capital investments in technology and assets, to remunerate the services that storage operators provide to the grid, and to provide predictability for project investors. In addition, power capacity markets could be scaled and streamlined to allow for storage providers to independently pursue compensation from the market, for example through peak shaving.

In some Latin American countries, the electricity market currently does not reward resources that offer flexible capacity and balance intermittent renewable energy. For example, the market participation model and pricing of flexibility does not allow for storage players to capture market price swings and premiums. An example is Mexico, which is proposing to change the "merit order" in dispatch rules. According to a White & Case regulatory analysis, in the past, the dispatching order prioritized lower cost energy, such as the one produced by renewables. This new regulation prioritizes energy dispatching from state owned power companies regardless of cost-efficiency and sustainability implications.[386] A study published by the National Renewable Energy Laboratory (NREL) of the US Department of Energy assesses that prioritizing state-owned generation could increase Mexico's annual CO_2 emissions by 26 percent to 65 percent.[387] The modification of the dispatch rules could also impair the operation and profitability of renewable projects and private investments, as financings may face obstacles resulting from the reduced or limited potential revenue.[388]

Reviewing market participation and creating mechanisms that reveal the true price of flexible capacity, such as binding day-ahead bidding or real-time ancillary services markets, could help incentivize flexible resources to participate in the market. Some countries are taking action: the Chilean Senate voted in favor of storage legislation to promote the incorporation of centralized and distributed (including EV batteries) storage capacity to the energy system, which will enable further growth in the share of renewables in the energy mix.[389]

Increasing transparency and long-term clarity on policy support such as government incentives. The remuneration for investments in renewables and cleantech is secured progressively over time. Therefore, it is important for developers to be able to rely on stable frameworks and policies and avoid uncertainties. Setting clear ambitions and directions in green technology development and policies could provide the necessary long-term perspective to attract domestic and foreign developers' investments. Further transparency in future demand and the pipeline of renewable projects could enable power producers, investors, and clean technology manufacturers to plan capital deployment with a long-term view. This could in turn enable efficiency and better return on investments across the value chain.

[384] Carlos St. James, "Getting WACC'd in Latin America: How renewable energy policies affect the cost of capital," *Clean Energy Review,* February 15, 2016.
[385] *Renewable Energy Capacity Statistics,* International Renewable Energy Agency (IRENA), 2022.
[386] "Energy Investors Face Mexico Risks in the Electricity and Lithium Sectors", White & Case, 19 July 2022.
[387] See Riccardo Bracho et al., *Impacts analysis of amendments to Mexico's unit commitment and dispatch rules,* National Renewal Energy Laboratory, technical report 6A50-81350, January 2022.
[388] "Energy investors face Mexico risks in the electricity and lithium sectors," White & Case, July 19, 2022.
[389] Cameron Murray, "Chile passes major energy storage bill," *Energy Storage News,* October 24, 2022.

For example, Brazil is advancing in the development of the National Hydrogen Plan to provide a longer-term perspective on the development of a green hydrogen market in the country and enable players across the value chain to orient and sequence their investments.

De-risking clean energy projects to lower the cost of capital through guarantees and other incentives, in particular for more risky countries. Among the solutions to reduce uncertainty around institutional enforcement and reliability, Latin America could consider introducing guarantees on power purchase agreements (PPAs) and on foreign exchange rates, potentially supported by government and financial institutions including multilateral development banks. This could lower capital risks, thereby reducing the cost of deploying renewable energy.

Potential incentives could be introduced alongside guarantees. These include grants, subsidies, ownership rights, regulatory and tax stability for the life of the project, cash flow protection schemes, free trade agreements, and debt guarantees from development banks. For instance, grants and seed capital could help accelerate the deployment of new, innovative clean energy technologies and issuance of sustainability-linked bonds, to obtain low-interest financing as long as sustainability targets are met. Brazil, Chile, and Mexico are already relying on this option for decarbonization projects in the transportation sector.

3

Introducing demand-side measures to promote the switch from fossil to electric and other energy-efficient alternatives in transportation

According to McKinsey estimates, transportation is the largest source of energy related emissions in Latin America, accounting for nearly half (45 percent) of carbon emissions in the region. Passenger cars (13 percent), trucks (13 percent) and light commercial vehicles (7 percent) are the main emitters. Latin America is the region with highest absolute CO_2 emissions from LCVs, and third largest from trucks, after North America and Greater China.[390]

0.7%

In 2021, EVs made up only 0.7 percent of new car sales in Latin America

EV adoption has been slower than in other regions, at 0.7 percent of new car sales in 2021, compared to 20 percent of sales in Europe, 15 percent in China, and 5 percent in the US.[391] This is largely because of high upfront costs and tariffs on imported vehicles, low to no domestic EV production, and few or no subsidies. These factors, combined with relatively low gasoline prices and lower vehicle kilometers travelled, translate into a less favorable total cost of ownership for EVs compared to vehicles with internal combustion engines (ICEs).

At the same time fleet renewal is slow, with a large fraction of scrapped vehicles replaced by used imported vehicles. Additionally, there are no or only few regulations aimed at taking the heaviest emitting vehicles out of circulation.

A further potential barrier to the uptake of EVs in the region is the limited number of EV charging stations.

At the same time, there is significant potential in Latin America for biofuels including ethanol and biodiesel. Already today, these solutions constitute a substantial share of vehicle fuel in countries like Brazil, where approximately 10 percent of the diesel mix is biodiesel[392], making transport based on ICEs more sustainable than elsewhere.

[390] *Global Energy Perspective,* 2022, data for Current Trajectory, 2021.
[391] “Electric vehicles start gaining traction in Latin America,” *Bloomberg,* April 6, 2022.
[392] *Implementation of bioenergy in Brazil,* IEA Bioenergy, 2021.

Rethinking tax breaks and subsidies for fossil fuel vehicles. One option to consider to speed up the energy transition in transport would be to rethink and possibly re-allocate direct and indirect subsidies for fossil fuel powered vehicles. This could include subsidies and tax breaks that reduce fuel cost in the downstream oil and gas sector, as well as direct subsidies or tax cuts at the pump.

The potential re-thinking and re-allocation of subsidies would need to happen progressively and in a socially responsible manner, to avoid overburdening lower income sectors and losing public support for the energy transition.

In Colombia, for example, fossil fuels remain heavily subsidized. The newly elected government has taken steps to partially diminish these subsidies to decrease fossil-fuel consumption and reduce the fiscal burden of subsidies.[393] In the future, such subsidy elimination programs would need to carefully balance benefits on sustainability and public finances with surging inflation and the risk of social unrest.

Incentivize EV adoption for cars and light-duty transportation and build out EV charging infrastructure. Latin America could lift demand for EVs by promoting the advantages of EV ownership and making them more accessible to the broader population. Already today, cities including Mexico City, Rio de Janeiro, and São Paulo offer incentives including tax exemptions for personal EV purchases. EV owners in Mexico City have access to preferential parking while EV owners in São Paulo are exempt from certain road restrictions. Further opportunities to improve EV attractiveness for end-users include providing access to preferential lanes in large cities or offering free services at charging stations.

A fleet renewal strategy could also help reduce transportation emissions. Introducing more rigid emissions standards such as mandatory smog checks, stricter fuel economy limits, or road restrictions, could accelerate the phase-out of high-emission vehicles.

Chile is a relevant example of a comprehensive approach to transportation decarbonization in the region, with its energy efficiency law (Law 21305-2021[394]) and its Electromobility strategy.[395] The country has set ambitious EV sales targets as well as fuel economy standards for all vehicle segments. Other countries have also taken steps towards transport decarbonization—for instance, Costa Rica has enabled easier access to loans for EV purchases while in Uruguay, commercial EVs are exempt from import taxes.[396]

To build the enabling infrastructure would likely require infrastructure investment as well as a commitment from distribution companies to increase the reach of the network. Zones with higher penetration in EVs could require upgrades to the distribution network to be able to handle the further increase in power demand.

300

Uruguay has announced plans to build 300 electric charging stations by 2023

Initial support and incentives might be required to spark the development of infrastructure. This could help balance the initial business case for charging infrastructure: initially, utilization is expected to be relatively low but then ramp up as the uptake of EVs increases. Uruguay has taken steps to invest in EV charging stations along its roads and the National Administration of Power Plants and Electrical Transmissions (UTE) has announced plans to complete 300 electric charging stations by 2023, with at least one station every 50 kilometers.[397]

[393] Angela Picciariello, Adriana Quevedo, Ipek Gençsü, "Phasing out fossil fuel subsidies in Colombia: a crucial step towards a just energy transition," Overseas Development Institute (ODI), June 2022.
[394] *Ley 21305 sobre la Eficiencia Energética,* Biblioteca del Congreso Nacional de Chile, February 2, 2021.
[395] *Estrategia Nacional de Electromovilidad,* Ministerio de Energía, Gobierno de Chile, October 2021.
[396] *Latin America and the Caribbean hop into electric mobility,* UNEP, August 7, 2018.
[397] "La Ruta Eléctrica de Uruguay más cerca del objetivo de un punto de recarga cada 50 km", *PV Magazine LatAm,* August 3, 2022.

36%

Heavy-duty vehicles contribute 36 percent of transport emissions in Latin America, compared with 26 percent worldwide

Promoting a switch to advanced biofuels, synthetic fuels, or fuel cells for heavy-duty maritime and air transport, and using advanced biofuels for light-duty vehicles. Heavy-duty vehicle emissions in Latin America represent a significant portion of the transportation carbon footprint. While worldwide emissions from heavy duty vehicles account for 26 percent of total transportation emissions, emissions from heavy-duty vehicles constitute 36 percent of transport emissions in Latin America, particularly from trucks.[398]

To mitigate these emissions in the near term, the region could explore transition fuels that are less carbon intensive than traditional diesel, such as advanced biofuels and natural gas. Brazil, where the biofuel industry is well established, is already promoting adoption of biodiesel and bioethanol in the fuel mix. The country is also investing in the development of purpose-grown crops for advanced biofuels, such as from Macauba, a palm tree that grows extremely fast, and shows high potential as a fuel source.

Beyond biofuels, the region could also explore fuel cell EVs that use the local potential to produce low-cost green hydrogen. Investments would likely be required to advance and deploy technologies and additional incentives such as carbon taxes could be considered to promote the switch to green alternatives.

4

Developing regulated carbon tracking mechanisms and markets, and driving green incentives to decarbonize industry footprints

28%

Industry contributes 28 percent of energy emissions in Latin America

Our estimates indicate that industry contributes about 28 percent of the energy emissions in Latin American, emitting about 445 Mt CO_2 per year. More than half of the consumption of the industrial sector comes from fossil fuels, in line with the rest of the world, and nearly two-thirds of industry-related emissions pertain to hard-to-abate industries such as iron and steel.[399]

Given the region's diverse economies, the specific industry of focus would likely vary by country. For instance, mining is a significant part of the economy for Perú and Chile, while natural gas is strong in Argentina, oil and gas in Colombia and Brazil, and steel and cement production are significant in Brazil.

Carbon standards and markets in the region remain limited. This in turn has limited the drive towards the decarbonization of industry. Moreover, existing fossil fuel consumption subsidies could delay efforts to decarbonize industry. For instance, Ecuador spends around 1 percent of their GDP on fossil fuel consumption subsidies; this percentage is similar to India and Indonesia, for example, but higher than most countries in Europe. Venezuela has even higher fossil fuel subsidies, at 6.8%.[400]

Finally, investments in technologies for hard-to-abate decarbonization, such as CCUS and hydrogen, are still limited, and incentives are lacking. Two actions could potentially help address these issues.

[398] *Global Energy Perspective,* 2022, data for Current Trajectory, 2021. We categorized emissions from transportation into heavy duty (i.e., trucks and buses), light duty (i.e., light commercial vehicles, passenger cars, and 2- or 3- wheelers), and others (i.e., aviation, maritime, and rail).
[399] *Global Energy Perspective,* 2022, data for Current Trajectory, 2021.
[400] *Energy Subsidies: Tracking the impact of fossil fuel subsides,* IEA, 2020.

Establishing clear standards for carbon tracking and carbon pricing mechanisms in industry. Latin American countries could accelerate the development of clear market structures that incentivize decarbonization such as emission standards, mandatory emissions reporting, and carbon markets. These could raise awareness about the region's emissions footprint and prompt industry to implement decarbonization measures.

20%

Latin America contributes 20 percent of the global supply of carbon market credits

Although most countries in Latin America are in early stages of creating and implementing structured carbon pricing instruments (CPIs), Latin America contributes 20 percent of the global supply of carbon market credits.[401] Among the countries doing this, Argentina, Chile, Colombia, and Mexico all have carbon taxes in place. Additionally, Chile is considering a compliance carbon market, Colombia and Brazil are developing an ETS and Mexico already has an ETS. Other countries in Latin America could look at these examples to evaluate implementation of similar policies.

Further, even in countries where carbon pricing has been established, there are opportunities for improvement. For instance, in Chile the carbon tax amounts to $5/tCO2 and applies to emitters of more than 25 kt of carbon dioxide per annuum, compared to $88/tCO2e in Norway.[402] Targeted carbon pricing could potentially move the needle of the switch from fossil fuel to green. The Chilean government is working on legislation to gradually increase the carbon tax over the remainder of the decade.[403]

Introducing targeted incentives to level the playing field for private investments in electrification, clean fuels, and energy efficiency solutions. Latin America has the opportunity to invest in hydrogen, CCUS, and alternative fuel sources to both decarbonize industry and create the basis for a green product industry. Tax incentives or loan guarantees may be required to promote investments in clean technologies.

5

Promoting local manufacturing of parts and equipment and exporting clean energy commodities and products

Latin America has significant opportunities to create value from green growth opportunities, both domestically and internationally. The region could use the transition to strengthen and further develop the domestic manufacturing industry, including leveraging local availability of critical raw materials such as lithium, nickel, and copper. Manufacturing could range from batteries as well as other critical equipment to enable local production such as electrolyzers. As the energy transition unfolds, Latin America countries will have the opportunity to develop and scale the equipment manufacturing industry together with other high-value segments such as project engineering and commodity and materials processing.

Alongside domestic manufacturing, Latin America has a significant opportunity to export clean energy resources, including energy-transition minerals, power-to-X, biofuels, sustainable materials including solid wood for construction and bio-chemicals, green hydrogen and derivatives such as ammonia and synthetic fuels, green metallics including hot briquetted iron (HBI), steel, and aluminum. Below we outline some of the export opportunities:

Green hydrogen. Strong opportunities exist in the export of hydrogen. Some countries are already installing green hydrogen projects, making use of the low-cost renewable energy available. Chile has some of the best solar and wind resources in the world and accounts

[401] *Status and trends of compliance and voluntary carbon markets in Latin America,* International Emissions Trading Association (IETA), 2022.
[402] *Ley 21.210,* Ministerio de Hacienda; *Carbon pricing dashboard,* World Bank, 2022.
[403] Ibid.

5%

Chile alone accounts for 5 percent of the world's installed capacity of renewable energy

600 million

Brazilian ethanol exports to Europe are expected to reach a record high of 600 million liters

for 5 percent of global renewable energy installed capacity.[404] The country also has 25 GW of hydrogen electrolysis capacity announced to be active by 2030, across 26 publicly announced projects.[405] Chile, together with Brazil, is among the most competitive places to produce green hydrogen, with a levelized cost of green hydrogen (LCOH) of less than $1.50 per kilogram (kg) expected by 2030, paving the way for ultra-low-cost hydrogen derivatives and downstream products.[406]

Biomass. Biomass can be used as feedstock for advanced fuels, chemicals, and plastics. Biofuels are a clean energy source particularly abundant in Brazil and Colombia.[407] Biofuels have the potential to contribute to local decarbonization as well as for export. In 2022 Brazil's ethanol exports to Europe are expected to reach 600 million liters[408], a record high compared to previous years.

Green metallics. Another potential export opportunity is the production of green ore-based metallics, through direct reduction of iron pellets using green H2. As an example, Brazil is the largest producer of steel in the region and ninth largest in the world, in addition to its unique advantage in HBI because of low green H2 production costs and the high-quality of iron ore pellet feed.[409] Green HBI is produced through the briquetting of green DRI, a process in which GH2 is used to reduce iron ore pellets to create sponge iron. Adaptation of processes and ways of working would be required to "greenify" production.

Two key actions that countries could consider to capture these opportunities are:

Promoting incentives to encourage local manufacturing, capitalizing on significant domestic availability of minerals and renewables. Incentives could be introduced to attract investments in domestic manufacturing across multiple use cases. For example, the region could consider increasing investment in re-shoring EV production, at least partially, by using the locally available critical raw materials required for batteries manufacturing, given that half of the world's lithium reserves are in Chile and Argentina.[410]

Potential incentives to be considered by the public sector could include creating special economic zones and providing tax relief. Production-based incentives and policies requiring a minimum of manufactured parts produced domestically could further boost domestic manufacturing. For instance, Brazil has introduced the ROTA 2030 law which provides tax credits and R&D incentives to encourage local manufacturing. The country has also offered long-term, low-cost financing for capital spending on wind power projects that are at least 60 percent national.[411] Indeed, Brazil has been successful on developing a wind power value chain, including setting up wind turbine processing facilities in the country, frequently by attracting foreign capital.

Similar efforts could be replicated in other countries, which could create green growth opportunities for Latin America, promoting jobs and value creation.

Establishing an international presence and trading agreements for the export of green commodities and products. Countries in the region could consider establishing international partnerships to promote value from trading green commodities and products. The appetite for hydrogen and its derivative products such as ammonia and synfuels is increasing and expected to continue growing. International markets such as Europe, East Asia, and the United States could become likely buyers for competitive hydrogen products.

[404] Renewable Energy Capacity Statistics, International Renewable Energy Agency (IRENA), 2022.
[405] Chile Environmental Defense Fund (EDF).
[406] *Green Hydrogen: An opportunity for the decarbonization of the mining industry,* Chilean Government Department of Energy, September 2021.
[407] *Renewable energy market analysis: Latin America,* IRENA, 2016.
[408] "Brazil to export record volume of ethanol to Europe this year," S&P Global Commodity Insights, September 19, 2022.
[409] *Crude steel production,* World Steel Association, June 22, 2021.
[410] *Mineral Commodity Summaries,* U.S. Geological Survey (USGS), 2022.
[411] Dr Britta Rennkamp, "Renewable Energy - Made in Brazil", Climate & Development Knowledge Network.

To scale up international opportunities, Latin American countries could consider streamlining trading regulations including frameworks to cover conflict resolution, taxation, and permitting. Securing the right trading partners today could help the region maximize value from its green exports in the future.

6

Developing a qualified regional workforce to support the transition and create socioeconomic benefits

44%

Forty-four percent of all biofuel jobs are in Latin America

1.3 million

Brazil has over one million renewable-energy jobs

Latin America accounts for 44 percent of all biofuel jobs worldwide.[412] Brazil alone had 10 percent of jobs in renewable energy in 2021 (1.3 million), most of which were in liquid biofuels (almost 900,000[413]) and hydropower (almost 200,000).[414] However, the region lags when it comes to a qualified workforce for wind and solar installation, maintenance, and operations.

Along with the acceleration of investments in new clean energy projects, Latin American countries could consider developing new competences in the workforce—in particular, in the areas of renewable power generation, storage, and in green hydrogen and derivatives.

The energy transition could have significant, positive socioeconomic impact in the region. Beyond environmental and climate risk resolution, countries will benefit from new markets being developed, jobs being created, and policies that will affect daily lives. Below are a few potential actions to consider.

Working with education and training systems to promote development of talent. Developing the necessary talent needed to accelerate the energy transition will require a combination of working with the current established education and training systems and promoting new innovative models. In both cases, creating mechanisms for transferring applicable best practices would likely be important. Energy transition competencies could be incorporated into existing educational programs at vocational and higher education institutions. For example, the traditional electrician vocational program could be updated to ensure professionals are skilled in installing solar panels. New program offers would likely naturally arise from energy transition opportunities. To accelerate both this curriculum "greening" and new program offers, best practices and educational resources could be made available to education authorities and public and private education institutions, as well as technical assistance on how to best incorporate them.

Finally, new educational business models are emerging globally, some with innovative and disruptive approaches to tackle massive needs such as corporate reskilling to help companies make the transition to a new economy. These innovations could have a substantial impact in Latin America. Collaborations and joint ventures with local entrepreneurs could accelerate the pace of innovation in education in the region.

Seeking financing support and industrial cooperation to expand training offerings at the academic level as well as for experienced professionals. The main barrier to accessing vocational and higher education in Latin America is often financial. Improving access to financial support could thus accelerate the development of the talent pool oriented to energy transition roles. As several countries in Latin America have already implemented ambitious

[412] *Renewable Energy and Jobs Annual Review,* International Renewable Energy Agency (IRENA), 2022.
[413] Ibid. About 180,600 jobs in sugarcane cultivation and 166,700 in alcohol/ethanol processing in 2019, the most recent year available. Figure also includes a rough estimate of 200,000 indirect jobs in equipment manufacturing, and 323,800 jobs in biodiesel in 2020.
[414] Fareed Rahman, "Renewable energy jobs hit 12.7 million in 2021 amid green transition efforts," *The National News,* September 22, 2022.

vocational and higher education financial support programs, it would likely be important to explore innovative ideas to ensure additional impact. For instance, one mechanism to ensure that employers are actively engaged, and funds are targeted towards critical job needs would be to combine incentives from energy transition funds with capital from employers that are struggling to find talent to institute academies and training centers aiming at developing critical capabilities for the energy transition.

Coordinating stakeholders to ensure adequate balance of supply and demand of talent to supporting the energy transition. Maintaining an adequate balance between supply and demand of talent would be critically important to ensure a successful talent development flow toward the energy transition. This is particularly important for training programs that are developed specifically for future uptake in clean energy work. If there is undersupply, the risk is that the broader energy transition pace would slow down. But if countries experience oversupply of talent, it could lead to inefficient efforts from funders, the educational system, and learners, as well as potentially generating negative perspective about opportunities in the field. Therefore, it is critical to develop good coordinating mechanisms involving employers, funders, and education providers to adjust the pace of talent generation. Some skilled positions can be developed to match specific projects, but in general it is important to create effective coordinating governance at the regional and national level.

Countries in Latin America could increase interest in energy-related careers to expand the workforce. For example, countries could promote STEM from early education in a more purposeful way, facilitate access to students pursuing engineering degrees via special grants and additional support, leverage international curriculum to improve quality of classes, and improve career prospects for graduates, including salary and other incentives.

Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

Africa

Africa exhibits the main characteristics of the "developing, at risk" economies regional archetype, as 34 percent of the continent's population is living in poverty, average GDP per capita is less than 13 times the global average, and 600 million Africans still lack energy access.[415] The continent is also among the world's regions with the greatest exposure to climate risk, which could further exacerbate the socioeconomic challenges.[416]

As the world moves toward net zero, global demand for fossil fuels is expected to fall and the carbon intensity of commodity production will become more important. The resulting transition risks threatening key economic pillars of African countries and could have adverse consequences for employment and fiscal health. African economies are more dependent on commodities than any other region in the world, with commodity exports—notably oil, gas, and minerals—accounting for about 16 percent of the continent's GDP.[417] Without actions to mitigate the transition risks, up to $150 billion of commodity revenue and more than 1 million jobs in Africa could be at risk.[418]

At the same time, the continent has enormous potential. Almost half of the continent's potential GHG-producing industries have not been built yet, creating an opportunity to build a thriving low-carbon manufacturing sector from the ground up. By doing so, Africa could avoid the costly transition from fossil fuels to renewables and build a competitive and resilient economy that doesn't rely on fossil fuels. New green opportunities could deliver revenues of up to $2 billion per year and create about 700,000 direct and indirect jobs by 2030. [419]

The continent has an abundance of natural resources, including solar and wind power, minerals, and agricultural land, that are needed to scale green manufacturing, build a green transportation sector, and provide energy at a low cost for the 600 million people in Africa who are still without it. This is also important for the global effort to reach net zero by 2050. Although African per-capita emissions are on average less than half of those of countries the Organisation for Economic Co-operation and

[415] *Economic Development in Africa Report 2021: Reaping the potential benefits of the African Continental Free Trade Area for inclusive growth,* UNCTAD, December 8, 2021; World Bank data on GDP per capita, 2021; Africa Energy Outlook 2022, International Energy Agency.
[416] *Climate Change 2022: Impacts, Adaptation and Vulnerability,* the sixth assessment report of the Intergovernmental Panel on Climate Change (IPCC), February 2022.
[417] *State of Commodity Dependence,* UNCTAD, 2019.
[418] Lyes Bouchene, Ziyad Cassim, Hauke Engel, Kartik Jayaram, and Adam Kendall, "Green Africa: A growth and resilience agenda for the continent," McKinsey, October 28, 2021.
[419] Kartik Jayaram, Adam Kendall, Ken Somers and Lyes Bouchene, "Africa's green manufacturing crossroads: Choices for a low-carbon industrial future," McKinsey, September 27, 2021.

Development (OECD) countries,[420] the continent accounts for about 10 percent of global annual GHG emissions.[421] If no steps are taken, emissions are likely to rise as a result of the expected population and economic growth.

Africa could also contribute to the global energy transition with green exports. Capitalizing on the continent's renewables potential, green hydrogen could be produced and used as feedstock in industries such as ammonia and steel. Exporting hydrogen and materials such as green steel could accelerate economic growth and diversify African economies.

Africa is home to more than 40 percent of global reserves of cobalt, manganese, and platinum, which are critical materials for lithium-ion batteries, wind turbines, and fuel cells. African countries could benefit from exporting critical materials and components of clean technologies that the global energy transition needs, yielding significant economic opportunity.[422]

Seizing these opportunities, Africa could consider the following actions to catalyze economic growth, ensure a just energy transition, and contribute to the global effort toward net-zero emissions.

- Ensuring attractive returns on green development projects to mobilize capital
- Deploying green off-grid solutions at scale to provide universal access to energy
- Establishing infrastructure, supporting environment, and regulations, to build green industries and realize export opportunities
- Expanding gas pipeline capacity and downstream infrastructure to shift to clean cooking and balance the grid

[420] Organisation for Economic Co-operation and Development. Average annual per capita emissions of OECD countries are 10.0 tons of CO_2 equivalent, compared to 4.5 tons of CO_2 equivalent per capita for African countries. Source: Lyes Bouchene, Ziyad Cassim, Hauke Engel, Kartik Jayaram, and Adam Kendall, "Green Africa: A growth and resilience agenda for the continent," October 28, 2021.
[421] Annual greenhouse gas emissions, including non-energy emissions, land-use emissions and all greenhouse gases, of the continent are estimated to be 5.4 gigatons of CO_2 equivalent. Source: Lyes Bouchene, Ziyad Cassim, Hauke Engel, Kartik Jayaram, and Adam Kendall, "Green Africa: A growth and resilience agenda for the continent," McKinsey, October 28, 2021, .
[422] *Africa Energy Outlook 2022,* IEA, June 2022.

Africa's starting position

14 million

If extreme heat cut working hours, Africa would be at risk of losing 14 million jobs

Africa is among the world's regions at the greatest risk from the changing climate.[423] About 370 million people—nearly one-third of the population—live in areas of high exposure to climate hazards such as extreme heat, drought, and flooding. The continent could lose nearly 14 million jobs by 2030 if extreme heat were to cut working hours by just 10 percent.[424] The direct economic impacts are high, and low levels of resilience are likely to exacerbate the socioeconomic impacts of intensifying climate hazards.[425]

With 34 percent of the continent's population living in extreme poverty and average GDP per capita less than one-thirteenth of the global average, economic growth is crucial[426]—which makes increasing access to reliable energy imperative for the African continent.[427] More than 600 million Africans lack access to grid electricity, and electricity is often unreliable for those with access.[428]

Africa's energy supply is currently dominated by biofuels and fossil fuels. Biofuels and waste account for approximately 45 percent of Africa's energy supply, largely due to the residential burning of wood and charcoal; about 970 million Africans lack access to clean cooking. [429] Oil, natural gas, and coal account for 23 percent, 16 percent, and 14 percent, respectively, of the total power supply.[430] However, energy comes from coal only in a few countries: Botswana, Kenya, Malawi, Mozambique, Senegal, South Africa, and Zimbabwe.

Africa is home to nearly 9 percent of the world's gas reserves, with Algeria, Egypt, Libya, Mozambique, and Nigeria together accounting for more than 92 percent of the continent's reserves.[431]

90%

Nearly 90 percent of electricity in South Africa comes from coal

Africa's fossil fuel–producing countries are highly exposed to the risks of the energy transition, as their economies rely heavily on exports and many jobs are tied to these carbon-intensive industries. More than half of African oil and gas–producing countries rely on oil and gas exports for more than 50 percent of their total revenues. In Nigeria, for example, oil represents 10 percent of GDP and accounts for more than 80 percent of the government's total export revenues.[432] In South Africa, almost 90 percent of electricity comes from coal, and coal mining contributes to more than 2 percent of its GDP—with more than 40 percent from exports. Declining global demand for coal and the decommissioning of coal plants will affect South Africa, in particular the northeast region of Mpumalanga, where 90 percent of the country's coal mines and 70 percent of its coal power plants are located. In Mpumalanga, 74,000 jobs are expected to be lost between now and 2030 because of the decommissioning of coal plants.[433]

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423 *Climate Change 2021: The Physical Science Basis,* the contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change, 2013.
424 *Working On a Warmer Planet: The impact of heat stress on labour productivity and decent work,* International Labour Organization, July 1, 2019.
425 Lyes Bouchene, Ziyad Cassim, Hauke Engel, Kartik Jayaram, and Adam Kendall, "Green Africa: A growth and resilience agenda for the continent," McKinsey, October 28, 2021.
426 *Economic Development in Africa Report 2021: Reaping the potential benefits of the African Continental Free Trade Area for inclusive growth,* UNCTAD, December 8, 2021; 2021 GDP data from World Bank.
427 Chandrashekar Raghutla and Krishna Reddy Chittedi, *Energy Poverty and Economic Development: Evidence from BRICS Economies,* Environmental Science and Pollution Research, volume 29, 2022.
428 *Africa Energy Outlook 2022,* IEA, June 2022.
429 Ibid.
430 Ibid.
431 "Natural gas in Africa: Why fossil fuels cannot sustainably meet the continent's growing energy demand," Climate Action Tracker, May 30, 2022.
432 *Nigeria Poverty Assessment 2022: A Better Future for All Nigerians,* The World Bank, March 2022.
433 *From Coal to Renewables in Mpumalanga: Employment effects, opportunities for local value creation, skills requirements, and gender-inclusiveness,* COBENEFITS, January 2022.

70%

Renewable-energy consumption by Egypt, Morocco, and South Africa accounts for 70 percent of Africa's total

While the continent holds enormous potential for solar, wind, hydropower, and geothermal power, it is largely untapped today. Wind and solar combined account for only 2 percent of energy generation.[434] Egypt, and Morocco, and South Africa generate the majority of solar and wind energy and together account for 83 percent of renewable installed capacity in the region.[435] The consumption of these countries also accounts for 70 percent of total renewable energy consumption in Africa.[436]

The continent is also home to many of the minerals and rare-earth metals that clean energy technologies such as batteries and hydrogen technologies require. More than 40 percent of global reserves of cobalt, manganese, and platinum are in Africa.[437] These reserves have significant potential for mining and manufacturing, which could create economic growth.

Africa currently contributes to about 4 percent of global CO_2 emissions from energy.[438] Thirty-six percent of total energy-related emissions come from the power sector, 29 percent from industry, and 27 percent from transport.[439]

Nationally determined contributions

All African countries apart from Libya have submitted NDCs, although most of them do not yet include emissions targets or have long-term strategies to decarbonize. Forty-eight of the 53 countries that submitted NDCs have targets that are conditional on financial support from advanced economies.[440]

At COP26, South Africa and Nigeria—which together contribute more than 40 percent of Africa's emissions—committed to reduce emissions to net zero by 2050 and 2060, respectively, together with ten other countries that have a combined share of 2 percent of the continent's emissions.[441] Morocco has pledged not to build any new coal-fired power plants, while Egypt and South Africa committed to phase out coal plants. [442]

The African Union's Agenda 2063, Africa's blueprint to become a global powerhouse, emphasizes that renewable and clean energy sources should be the foundation of its energy systems, to ensure energy security and enable decarbonization.[443] However, African governments need to create economic growth and jobs, and the traditional route to doing so—industrialization—is often considered at odds with the push toward sustainability and the energy transition that is an essential part of it.

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[434] *Primary energy consumption by fuel 2021, BP energy outlook,* 2022.
[435] International Renewable Energy Agency (IRENA) power capacity data, 2021.
[436] *Primary energy consumption by fuel 2021, BP energy outlook,* 2022.
[437] *Africa Energy Outlook 2022,* IEA.
[438] *BP energy outlook,* 2022.
[439] Ibid.
[440] *Africa Energy Outlook 2022,* IEA, May 2022.
[441] São Tomé and Príncipe achieved climate neutrality in 1998; Côte d'Ivoire pledged to be carbon neutral by 2030; Cabo Verde, Liberia, Malawi, Mauritania, Namibia, Rwanda, Seychelles and South Africa by 2050; Nigeria by 2060 and Mauritius by 2070. See *Africa Energy Outlook 2022,* IEA, May 2022.
[442] *Africa Energy Outlook 2022,* IEA, May 2022.
[443] *The Africa We Want, Goals & Priority Areas,* African Union, Agenda 2063.

Priority measures that could accelerate a more orderly energy transition

African countries vary widely in terms of natural resources, reliance on fossil fuels, economic development, and exposure to climate risk. While generalizations are difficult, there are some common challenges that could impact or impede each country's growth prospects: (1) limited capital deployment into Africa despite sufficient capital pools with investment appetite in the African continent, because of financially challenged utilities and limited bankable projects; (2) lack of scaling up of distributed energy resources (DERs) caused by high up-front costs, affordability challenges for end users, limited financial incentives for expansion, and regulatory obstacles; (3) limited infrastructure, government support, and regulations to build green industries and realize export opportunities for Africa's natural resources; (4) a lack of gas-pipeline capacity and downstream infrastructure to tap into new gas reserves, difficulties in securing financing for gas projects, and poor economic incentives to minimize flaring.

Although there is no one-size-fits-all solution, following are four high-priority measures that could be taken to achieve growth across the continent.

1

Ensuring attractive returns on green development projects to mobilize capital

$280 billion

Africa would require $280 billion to meet its NDCs

14%

Only 14 percent of climate project funding in Africa comes from the private sector

To seize the opportunity to build clean industries and realize economic growth, Africa will need to attract substantial amounts of capital. Although there is momentum—annual investments in renewable energy increased elevenfold, from $0.5 billion between 2000 and 2009 to $5.5 billion between 2010 and 2020—more capital is required.[444] To meet its NDCs, Africa would require around $280 billion, yet the current climate finance investment stands at $29.5 billion.[445]

Studies suggest that the financing gap should be smaller, given global commitment and local financial capabilities. Industrialized countries have pledged $100 billion per year for decarbonization and adaptation in developing countries.[446] International investors with an appetite for Africa have an estimated $11 trillion in assets under management.[447]

Nonetheless, capital deployment into African countries remains limited. The annual funding for climate projects in Africa is estimated at only $30 billion, of which only 14 percent comes from the private sector.[448] Investors may be dissuaded by the limited bankability of projects, the result of financially challenged utilities, a lack of return guarantees from governments, weak country balance sheets, poor regulatory environments, and a mismatch between investors' risk perceptions and reality.

Among the most significant problems impeding capital deployment to renewables is the financial performance of power utilities in the region. About three out of four utilities in sub-Saharan Africa fail to recover their operating and debt-service costs, in large part because of non-cost-reflective energy tariffs, high transmission and distribution losses, and low electricity bill collection rates.[449] This is causing growing liquidity problems, resulting

[444] *Renewable energy market analysis: Africa and its regions,* International Renewable Energy Agency, January 2022.
[445] *Landscape of Climate Finance in Africa,* Climate Policy Initiative, September 21, 2022.
[446] Lyes Bouchene, Ziyad Cassim, Hauke Engel, Kartik Jayaram, and Adam Kendall, "Green Africa: A growth and resilience agenda for the continent," October 28, 2021.
[447] Kannan Lakmeeharan, Qaizer Manji, Ronald Nyairo, and Harald Poeltner, "Solving Africa's infrastructure paradox," March 2020.
[448] *Landscape of Climate Finance in Africa,* Climate Policy Initiative, September 21, 2022.
[449] Excludes subsidies. See Ani Balabanyan, et al., *Utility Performance and Behavior in Africa Today,* World Bank, June 2021.

in limited investments in assets and their maintenance, which in turn reduces operational performance. As a result, policy makers are reluctant to risk public concern by increasing tariffs, while private-sector investments are dissuaded. This further undermines the financial viability of the sector and causes a vicious cycle. [450]

Most utilities rely on subsidies to recover costs, creating a financial burden on government budgets with an average of $11 billion in energy subsidies per year.[451] For example, Prodel, the generation utility in Angola, reported in 2018 that 72 percent of its total utility income came from subsidies, which was equal to 0.2 percent of Angola's GDP.[452] Subsidies can also discourage utilities from investing in efficiency improvements, which results in higher electricity bills for end users.

While some unbundling of utilities has occurred in Africa in recent decades, 44 countries have vertically integrated utilities with little or no private participation, limiting the development of the grid and attraction of capital. Only ten countries have unbundled utilities with either an independent transmission system operator or a legally unbundled transmission system.[453]

To catalyze pledged climate finance and mobilize more private investment to the power sector in Africa, three actions could be considered, as follow.

Ensuring financial viability of utilities by imposing cost-reflective electricity tariffs and implementing managerial reforms. On average, electricity tariffs in sub-Saharan Africa cover only 64 percent of the cost of power production.[454] To improve the financial health of utilities, electricity tariffs could be revised to cover operational costs. Cost-reflective tariffs have been implemented or are under discussion in fewer than half the countries in Africa, despite being urgently needed to allow utilities to be financially viable and avoid defaulting on their loans. Multilateral financial institutions could include transition plans toward cost-reflective tariffs as a contingency for lending, to foster their adoption. However, setting cost-reflective tariffs could be politically sensitive, as governments need to justify tariff increases to avoid public concern and potential impact on the cost of living. In situations where there is significant public resistance, service-based tariffs could be implemented. Service-based tariffs, which allow for higher tariffs when better service quality is delivered, are currently being rolled out in Nigeria, with positive early results.

64%

Electricity tariffs cover only 64 percent of power production costs in Africa

Rethinking the magnitude and allocation of subsidies, or making the provision of subsidies conditional on improvements, could help to incentivize the operational performance of utilities. Allocating subsidies to renewables instead of fossil fuels could also help African countries make renewables more cost competitive and accelerate their uptake.

Further, managerial and operational reforms could help restore the financial health of utilities. Possible measures could include involving the private sector in owning or operating utilities, establishing independent power producers, or ring-fencing utilities to intensify competition and incentivize improvements. These measures could reduce operational inefficiencies, resulting in stronger financial performance, which could in turn attract investments.

[450] Ani Balabanyan et al, *African Utilities during COVID-19: Challenges and Impacts,* World Bank, June 2021.
[451] *Africa Progress Report 2015 - Power, People, Planet: Seizing Africa's Energy and Climate Opportunities,* Africa Progress Panel, 2015.
[452] Ani Balabanyan et al., *Utility Performance and Behavior in Africa Today,* World Bank, June 2021.
[453] *Electricity market report,* IEA, December 2020,
[454] *The Renewable Energy Transition in Africa,* International Renewable Energy Agency, March 2021.

Reducing risks for investors by providing guarantees backed by development financial institutions. Private investors considering investing in Africa often have perceptions of legal, and regulatory risk that often are not commensurate with expected returns. To mitigate private-sector risks, governments could provide guarantees or financial collateral. However, in many cases, their balance sheets prevent them from being able to do this. Donors and multilateral development financial institutions (DFIs), such as the African Development Bank and the International Finance Corporation, could step in to provide financial collateral, and give investors more confidence in the commercial viability of projects. In addition, this is a role that philanthropies potentially might play.

Ensuring capital allocation toward green investments with green financing instruments, such as carbon markets. New green financing instruments that match the different risk and return profiles for green investments could be required to allocate more capital to green investments. These might include carbon credits, green insurance, green bonds, green guarantee mechanisms, and payments for performance. South Africa is currently the only African country with a carbon pricing system, which was signed into law at the end of 2019.[455] In Zimbabwe and Mauritius, taxes on fossil fuels act as a mechanism for reducing carbon emissions, while Kenya has announced plans to launch an emissions-trading system that allows companies to buy emissions allowances through a carbon credit and green-asset registry.[456] Other countries could follow to implement financing instruments, such as carbon market mechanisms, that either generate additional revenue streams for low-carbon projects or improve their relative attractiveness over high-carbon projects—through a carbon tax, for example.

1

Only one African country, South Africa, has a carbon pricing system

2

Deploying green off-grid solutions at scale to provide universal access to energy

Expanding energy access and keeping energy affordable is key for Africa's development and continued economic growth. Distributed energy resources (DERs) could be critical tools for providing energy access to those who live in remote locations and are not connected to the centralized grid.

Some areas in sub-Saharan Africa, including parts of Nigeria and wealthier residential areas in other countries, already rely on off-grid power generated by fossil fuel. These existing solutions could be retrofitted for renewables.[457] While off-grid diesel generation is highly polluting and expensive over its lifetime, other solutions, such as solar and microgrids, could serve as faster and less costly alternatives without adverse health impacts. However, the up-front costs for off-grid solutions are relatively high, and adding battery storage further increases costs.

Several barriers currently stand in the way of the scale-up of distributed renewables in Africa, including affordability challenges, lack of access to finance, lack of financial incentives for operators, uncertainty of arrival of the main grid, and regulations—such as the inability to charge cost-reflective tariffs. The following three actions could be considered to address these barriers and accelerate the build-out of distributed renewables in Africa.

[455] *South African carbon tax,* IEA, updated June 30, 2020.
[456] "Kenya setting up emissions trading market, says Ukur Yatani," *Business Daily Africa,* May 11, 2021.
[457] Nick Ferris, "Weekly data: Africa's diesel generation boom," Energy Monitor, May 31, 2022.

Lowering financial barriers for rural customers through finance partnerships and cost reduction. To support the affordability of off-grid solutions, the large up-front capital expenditures need to be addressed. Banks and microfinance institutions could partner with solution providers to offer microloans and point-of-sale financing options to households to cover the up-front payment. In addition, home solar and microgrid companies could offer at-scale pay-as-you-go solutions.

Governments, donors, and even utilities could support the deployment of off-grid solutions through rebates or incentives like results-based financing (RBF). With RBF, financing is provided after the delivery of predefined results, such as the installation of a minigrid. This financing helps improve accountability, drives innovation, and shifts operational risks to the private sector. The Nigerian Electrification Project (NEP)—an initiative from the Nigerian government and the African Development Bank with financing from the World Bank to provide off-grid solutions to rural areas—has set the example for implementing RBF. Developers receive a subsidy of $350 per electricity connection upon verification that the installed minigrid has provided reliable electricity for at least three months.[458] The Universal Energy Facility (UEF) is another leading example of using RBF to incentivize scaling up minigrids, solar home systems, and clean cooking solutions across sub-Saharan Africa.[459]

To lower production costs, African governments could reduce customs duties and import tariffs for the major components required to construct minigrids. Procurement pooling, lower negotiation costs, and subsidizing low-quality incumbents could further reduce the costs of minigrids, in turn reducing the up-front investment they require.

Implementing policies and regulations to mitigate the risk of the arrival of the main grid and to support the build-out of off-grid renewables. Utilities and off-grid solar developers could collaborate to bring mini-grids to underserved communities and integrate them with the central grid once consumption exceeds the minigrid's energy supply. For example, Power for All is piloting the Utilities 2.0 project in Uganda, which has successfully mobilized the main electricity supplier Umeme to work with minigrid developers and is currently supplying electricity to 380 connections. Umeme provided its metering system and back-end operations for customer billing and revenue collection and built the distribution network to maintain grid standards.[460] To scale these type of projects, regulatory stakeholders could adopt efficient and standardized processes for site approval and an integrated energy planning approach. Policy makers could also make information on the location and timeline of grid extensions transparent, to help mitigate the risk involved with the arrival of the main grid and ensure a seamless integration.

380

A project in Uganda mobilized an electricity supplier to supply 380 connections

Electricity tariff regulations could also be adjusted to allow developers to recover costs and thus attract further investment. One of the RISE[461] indicators for minigrids is the ability of minigrid operators to charge a cost-reflective tariff. Minigrids could be exempted from tariff regulations, allowing developers and operators to set cost-recovery tariffs, which saves resources of regulatory agencies that they would otherwise spend on approving a large number of small-scale projects and on government subsidies.

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[458] *About the Nigeria Electrification Project (NEP),* Rural Electrification Agency Nigeria.
[459] *Universal Energy Facility,* Sustainable Energy for All.
[460] *Delivering clean and affordable energy to Africa, faster,* Power for All, May 18, 2022.
[461] *Regulatory Indicators for Sustainable Energy, a set of indicators to help compare national policy and regulatory frameworks for sustainable energy,* World Bank and ESMAP, RISE.

$100 million

A $100 million dollar project in the DRC aims to supply power for half a million people

Supporting commercial players to build regional metrogrids to improve energy access and affordability. Regional isolated grid projects (metrogrids) are one upcoming, forward-leaning concept to provide more people with energy access, megawatt-scale power generation and distribution systems that distribute renewable energy independently of the national grid. Metrogrids require the installation of renewable energy technologies, energy storage systems, and a distribution power grid around the city or community. One of the models being tested is Moyi Power, a $100 million solar-power project in the Democratic Republic of the Congo (DRC) that builds three large-scale metrogrids to power half a million people living in three cities in the north of the country.[462] Several players, including the Global Energy Alliance for People and Planet, GridWorks, and BII, plan to develop and finance metrogrids in the DRC. The government has announced many local concessions to secure these solutions across the country.[463]

25

The DRC government is collaborating to develop metrogrids for more than 25 cities in the country

Metrogrids have a larger power distribution potential, are more affordable, and have a lower carbon footprint than diesel minigrids. Over time, as demand grows, metrogrids could easily evolve to become midscale utilities that eventually cover all households in urban and suburban areas. Metrogrids of different cities could be interconnected to improve the resilience and reliability of the energy supply.

Given that the market for metrogrids is still nascent, development finance institutions, donors, and philanthropies could invest in piloting and testing them. The private sector, venture-capital funds in particular, could provide financial and technical support for innovation to drive down costs. African governments could create a supporting regulatory environment to further attract investments and lower early-stake risk. Together with DFIs and philanthropies, governments could also subsidize the scaling up of metrogrids, as they create jobs and local manufacturing opportunities.

3

Establishing infrastructure, supporting environment, and regulations, to build green industries and realize export opportunities

80%

South Africa produces 80 percent of the world's manganese

Africa has vast reserves of minerals critical for the energy transition, such as cobalt, lithium, and copper, and their demand is expected to increase proportional to the global increase of electric vehicles, wind power, solar cells, and other clean technologies. For example, the DRC has the world's largest cobalt reserves (46 percent of global reserves),[464] and 80 percent of manganese, critical to manufacturing cathodes in lithium-ion batteries, is in South Africa.[465] Producers could expand downstream into the material processing, such as the refining of raw materials and production of cathode active materials. The DRC, South Africa, Mozambique, and other countries near raw materials are well positioned for the private sector to lead the creation of material-production hubs that combine extraction with processing. However, there are risks associated with the ESG impacts of mining, such as geopolitical challenges, labor relations, and emissions. The lack of ESG standards may impact the energy transition, by potentially deterring investments and eroding public and local support for mining.

[462] *Gridworks consortium launches Moyi Power - $100m solar-power project in DRC,* Gridworks, June 3, 2021.
[463] *Case Study: Scaling metro-grid electrification in DRC,* Global Energy Alliance for People and Planet.
[464] "Cobalt statistics and information," USGS, 2022.
[465] Nicolas Beukes, Edward PW Swindell, and Herve Wabo, "Manganese Deposits of Africa," *Episodes: Journal of International Geoscience*, Number 39, Volume 2, June 1, 2016.

700,000

Green-business opportunities could create 700,000 jobs in Africa

Another opportunity for Africa is the production and export of hydrogen and derivative products. The continent's endowment of renewable energy resources far exceeds the expected domestic demand for energy. North African countries could use pipelines to transport hydrogen to Europe, having a cost advantage over green hydrogen shipped from Australia, Chile, or Saudi Arabia. Low-cost green hydrogen could also be used as feedstock by local industries such as green steel and ammonia. Due to its abundance of renewables, Africa's young and growing workforce and cheap access to land, locally produced low-carbon materials could be exported at a highly competitive cost.[466] Green business opportunities are particularly attractive and have the potential to create 700,000 jobs by 2030 and up to $2 billion per year in revenue in 2030.[467]

However, Africa still needs to put in place the required regulatory framework, infrastructure, and manufacturing capabilities to localize manufacturing and build export hubs. To capture the value of these opportunities, four actions may be considered.

Creating a supporting environment to build green industries and manufacturing. African governments may consider initiatives to encourage manufacturers to produce locally and expand production along the value chain. For example, governments could set adoption targets and commit to investing in R&D of green industries, such as hydrogen. Tax incentives, such as value-added tax exemptions, tax holidays, and import-duty exemptions could be introduced for green businesses to encourage production and scale-ups.[468] For refining of critical minerals, governments may implement mandates that require secondary or tertiary processing to be exported.

Private companies could put in place programs to train the local workforce, helping them transition from fossil-intensive industries like oil and gas to green businesses. Governments could provide support to businesses, for example by developing skills certifications for new green jobs and developing training institutes.

Expanding and strengthening special economic zones and required infrastructure to support local manufacturing and realize export markets. To unlock the potential of export markets, new special economic zones (SEZs) could be developed to support local manufacturing and employment. For example, battery-active material-production hubs could be built in southern and central Africa close to mining sites of raw materials needed for cathodes in batteries. The DRC, for example, is well positioned to create battery-manufacturing hubs that combine extraction and refining of raw materials with cathode production.

Countries such as Egypt, Ethiopia, Morocco, and South Africa have already set an example for other African countries to build successful SEZs that attract global investors. SEZs could capitalize on domestic comparative advantages and natural endowments of a country. Strategically selecting the site based on proximity to raw materials and export possibilities could boost its growth potential. Additionally, a clear vision in line with national strategies, and readily available performance data, may help accelerate growth and attract investors. Governments, private-sector players, and donors could invest in infrastructure needed for transport and export of the processed goods.[469] For example, new pipelines would be needed for exporting hydrogen from North Africa to Europe.

[466] Lyes Bouchene, Ziyad Cassim, Hauke Engel, Kartik Jayaram, and Adam Kendall, "Green Africa: A growth and resilience agenda for the continent," October 28, 2021.
[467] Eight business opportunities are: manufacture plant-based protein, manufacture cross-laminated timber, assembly of electric vehicles, assembly of electric two wheelers, produce bioethanol, manufacture wind turbine parts, assembly of off-grid solar systems and assembly of mini-grids. See Lyes Bouchene, Kartik Jayaram, Adam Kendall, and Ken Somers, "Africa's Green Manufacturing Crossroads: Choices for a low-carbon industrial future," September 2021.
[468] *Tax Incentives on Renewable Energy,* Clean Energy 4 Africa, November 5, 2021.
[469] *African Economic Zones Outlook 2021,* Africa Free Zones Organisation.

Enhancing ESG standards to ensure safe and sustainable mining and manufacturing practices that benefit local communities. To mitigate risks associated with mining and manufacturing and to create local employment opportunities, African governments could develop ESG frameworks in collaboration with international organizations. These include imposing clear safety and employment standards and measures to combat corruption, but also standards to create value for local communities. For example, local content laws could be enacted that require mining and manufacturing companies to engage local suppliers and maintain a certain threshold of domestic workers in their labor force.

In addition, standards and policies could be implemented to address the gaps in transparency and accountability on ESG topics. Pension funds and capital market regulators could work together to create green taxonomies, green bond guidelines, and ESG reporting regulations. Regulators could create corporate governance codes and learn from best practices, such as the Code for Responsible Investing in South Africa, which formally encourages investors to integrate ESG factors into their investment strategies. Regional champions, such as the Government Employees Pension Fund in South Africa, could set an example for other public and social security funds to build their domestic financial markets on ESG foundations.

70 million tons

Africa could partner with Europe to help fulfill its need for 65 million to 70 million tons of green hydrogen

Proactively building partnerships with countries importing minerals, hydrogen, and green materials. Africa could collaborate with regions and countries that will likely depend on imports of clean energy, such as the EU and Japan, and are seeking to secure supply. Strategic partnerships may include technical and financial assistance to build green industries and the necessary infrastructure. For example, Africa could partner with Europe, which is expected to need between 65 and 70 million tons of green hydrogen per annum by 2050, about 25 percent of its total energy demand. Proactively engaging with Europe could help to secure a demand market, while it may also provide technical and financial support.

4

Expanding gas pipeline capacity and downstream infrastructure to shift to clean cooking and balance the grid

950 million

In sub-Saharan Africa alone, more than 950 million people rely on wood and charcoal for cooking, contributing to GHG emissions

In sub-Saharan Africa, more than 950 million people rely on wood and charcoal for cooking, contributing to deforestation and leading to further GHG emissions.[470] The IEA estimates that about 500,000 people die prematurely each year in sub-Saharan Africa as a result of exposure to biomass smoke.[471] Replacing high polluting fuels with liquefied petroleum gas could be transformative for households, as it is a cleaner alternative and has no health impact.

At the same time, gas could play a role as a transition fuel to allow for flexible and dispatchable power. As the share of renewables increases, dispatchable assets will need to be built out to balance the grid because of the intermittence of solar and wind power. In the medium term, most countries in Africa will likely rely on gas for grid stability—with the exception of the countries in eastern Africa, where geothermal plants are economically viable alternatives. However, it will likely be important to limit investments in gas to necessary assets needed to balance the grid. In many cases, expanding renewables will be a cheaper and more scalable way to expand electrification in Africa.

Africa has vast gas reserves that are largely untapped. More than 25 countries in Africa have recorded gas reserves, accounting for 9 percent of global reserves.[472] However, the lack of

[470] *Too many cooks,* United Nations Climate Change, June 14, 2021.
[471] *Access to clean cooking and premature deaths from household air pollution in sub-Saharan Africa and Asia, 2010-2019,* IEA, 2018.
[472] *Natural gas in Africa: Why fossil fuels cannot sustainably meet the continent's growing energy demand,* Climate Action Tracker, May 2022.

24 billion m^3

Instead of capturing gas, more than 24 billion cubic meters of gas is flared, wasting energy and resulting in GHG emissions

gas pipelines and downstream infrastructure has resulted in stranded gas assets and poor connections between regions. Attracting capital for gas projects is difficult, given that they often do not meet the investment criteria of green investors.

In addition, more than 24 billion cubic meters of gas is routinely flared per year—a result of poor economic incentives to capture gas.[473] Gas flaring wastes energy that could be used to provide electricity to households. It also results in emissions of GHGs and other pollutants that affect the health and livelihoods of people living close to gas-flaring sites and could cause a decline in crop yield. In Nigeria, where more than 10 percent of gas produced is flared, about 2 million people in the Niger Delta live within 4 kilometers of a gas flare and are exposed to severe health risks.[474] To seize the opportunities that gas could bring for Africa, the following three actions could be taken.

Increasing natural gas pipeline capacity and processing infrastructure. Meeting growing gas demand may require the expansion of domestic pipeline capacities. Countries with significant gas reserves, such as Algeria, Mozambique, and Nigeria, could consider developing cross-border gas pipeline infrastructure to connect to regions where gas will be in significant demand. Developing gas-to-power and gas-to-industry hubs could help increase access to electricity and support manufacturing activities. Increasing gas pipeline capacity will not always be the best solution and will need to be weighed against environmental risk, impacts to local population and land use, and the pace of development of local clean alternatives.

Implementing economic incentives to minimize gas flaring. African oil and gas companies can reduce flaring with timely replacement of equipment, increased maintenance routine and frequency, and enhanced recovery technologies, such as predictive maintenance and improved gas processing. However, to adopt these technologies, governments may need to implement economic incentives to capture the gas. For example, a fee or tax on routine flaring could be implemented to encourage oil and gas companies to use or sell the gas instead of releasing it into the atmosphere. Carbon markets may also be an effective means to incentivize companies to minimize flaring. These incentives may need to be coupled with regulations to measure and monitor flare volumes. Governments may also publicly disclose flaring data to guide investors' decision making.

Incentivizing households to replace polluting fuels with gas for cooking. To stimulate the uptake of cleaner cooking fuels, access to LPG can be an attractive option. This would require investments in LPG production, bottling, and distribution infrastructure. Shifting to LPG creates health benefits for households currently relying on carbon-intensive cooking fuels while also creating manufacturing opportunities and a potential source of carbon credits.

Countries could address challenges related to the affordability of the shift to clean cooking by lowering up-front household costs or adopting subsidy schemes to lower prices of LPG and other clean cooking alternatives, such as electric and biogas-based cooking. Community-based training efforts could be implemented to raise awareness about the health benefits of clean cooking technologies compared with their polluting alternatives.

[473] *Global Gas Flaring Data,* The World Bank, 2021.
[474] *The Impact of Gas Flaring on Child Health in Nigeria,* The World Bank, September 14, 2022.

Note: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.

Southeast Asia

Southeast Asia exhibits the predominant characteristics of the "developing, at risk" archetype.[475] Amid population growth and rapid industrialization, Southeast Asia would likely need to scale renewable technologies and accelerate coal decarbonization to move toward a more orderly energy transition.[476]

Countries across Southeast Asia rely heavily on fossil fuels to meet growing demand. Indeed, the region's population has expanded by about 10 percent in the past ten years.[477] Further, Southeast Asia's economy grew approximately 4.2 percent annually from 2010 to 2019.[478] Urbanization and industrialization are also up: the number of people living in cities in the region has increased by 70 percent since 2000.[479] The expansion of lighter industries, such as car assembly manufacturers and clothing factories, contributed substantially to a 75 percent increase in electricity demand by the industry sector.[480] Total energy demand rose by more than 80 percent from 2000 to 2020, and, to meet it, the coal supply grew by a factor of six, from 8 percent to 26 percent of the region's total energy supply in the same period.[481] Despite a reliance on coal capacity, the region holds distinctive opportunities to support the energy transition, including an abundance of minerals that are critical for green technologies and the manufacturing capacity for renewable energy components, such as solar PV modules.

To seize these opportunities and promote a path to a more orderly energy transition, Southeast Asia could consider the following high-priority measures:

Creating the conditions for bankable renewables projects and advancing national and regional plans to minimize new coal development, and improving efficiency of the existing coal fleet

Electrifying and improving efficiency across sectors to temper growing demand[477]

Adapting local economies to take full advantage of the transition, driving employment and socioeconomic growth across the region

Developing standards and practices for emissions transparency to enable carbon tracking and trading for multinational manufacturers in the region

[475] Southeast Asia" refers to Brunei, Cambodia, Timor-Leste, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam.
[476] *Southeast Asia Energy Outlook 2022*, IEA.
[477] Ibid.
[478] Ibid.
[479] Ibid.
[480] Ibid.
[481] Ibid.
[477] Where "light industry" refers to industries that are generally less energy-intensive and are typically more consumer-oriented. Light industries generally rely on lower-heat manufacturing processes.

82%

More than 82 percent of total primary energy consumption in the region is fossil fuel based

Southeast Asia's starting point

The leading energy consumers in the region include Indonesia (30 percent of regional energy demand), Thailand (19 percent), Vietnam (16 percent), Malaysia (15 percent), Singapore (10 percent), and the Philippines (7 percent).[483] Throughout the region, more than 90 percent of total primary energy consumption is fossil fuel based, with oil (41 percent) being the most dominant source, followed by coal (29 percent) and natural gas (20 percent).[484] Power generation is supported mostly by coal (46 percent) and natural gas (29 percent), followed by hydropower (15 percent) and renewables (9 percent).[485] The renewable development speed in the region has been relatively slow, with the exception of Vietnam, which has added 16 GW of solar power since 2018[486] (86 megawatts in 2018 to 16.5 gigawatts to 2020).[487] Across the region, we estimate that a significant increase in renewable capacity would be required by 2030 to stay on track with climate commitments. According to our estimates, annual renewables capacity would need to rise from about 40 GW today in solar to 255 GW and from about 6 GW today in wind to more than 40 GW.

However, the reliance on fossil fuels across the region has resulted in lagging renewable energy sources: across Southeast Asia, only about 40 percent of the region's investment in energy has been allocated to renewable energy sources.[488] As a result, installed renewables capacity also varies significantly across Southeast Asia (for example, 27 percent for Vietnam,[489] 23 percent for Thailand[490], and 12 percent for Indonesia).[491]

Southeast Asia benefits from abundant mineral reserves that are critical for a more orderly energy transition. The region is home to bauxite, nickel, tin, and rare-earth elements, in addition to cobalt, manganese, silicon, and copper.[492] For example, Indonesia is one of the top ten countries for the world's known reserves of copper, nickel, tin, and bauxite.[493] This makes Indonesia, followed by the Philippines, the largest nickel producer globally.[494] Myanmar produces 13 percent of rare-earth elements globally.[495]

About one-third of the emissions footprint for the region (35 percent) comes from the power sector. Other major energy emissions come from industry (about 33 percent), and transportation (about 30 percent).[496] Both are dependent mainly on imported oil (68 percent) from the Middle East, North America, and West Africa.[497]

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[483] *BP energy outlook,* 2022.
[484] *BP energy outlook,* 2022, based on Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam.
[485] *BP energy outlook,* 2022, based on Indonesia, Malaysia, Thailand, Vietnam.
[486] "Opportunities and challenges in expanding wind in Vietnam's electricity mix," IUCN, May 24, 2019.
[487] "EDPR invests $284 million to double its operational renewables capacity in Vietnam; acquires 255 MW solar projects," Energy Central, June 28, 2022.
[488] Douglas Broom, "Southeast Asia's power generation has tripled in 20 years. But is it running out of energy options?" World Economic Forum, June 8, 2022.
[489] Pritesh Samuel, "Vietnam's power development plan draft incorporates renewables, reduces coal," *Vietnam Briefing,* April 29, 2022.
[490] Nguyen Linh Dan, "Vietnam's renewable energy policies and opportunities for the private sector," National Bureau of Asian Research, May 19, 2022.
[491] "Harnessing renewable energy investment sector in Indonesia," Indonesia Ministry of Investment.
[492] *Southeast Asia Energy Outlook 2022,* IEA.
[493] *Enhancing ASEAN Minerals Trade and Investment,* ASEAN, at asean.org.
[494] *Southeast Asia Energy Outlook 2022,* IEA.
[495] Ibid.
[496] *Global Energy Perspective,* 2022, data for Current Trajectory, 2021.
[497] *BP energy outlook,* 2022.

Nationally determined contributions

23%

Countries have committed to a regional target of 23 percent of total primary energy supply coming from renewable sources by 2025

9%

Singapore is on track to reduce carbon emissions by 9 percent in 2030 relative to 2019 levels

Across Southeast Asia, countries have committed to a regional target of 23 percent of the total primary energy supply coming from renewable energy sources by 2025.[498] Of the 11 countries in the region, nine have committed to net-zero emissions or carbon neutrality by 2050.[499] The Philippines lacks any net-zero target.[500] At the November 2022 G-20 summit, Indonesia and international partners including the European Union agreed on a partnership that would accelerate Indonesia's power sector emissions reduction pathway to net zero by 2050, along with a strategy based on the expansion of renewable energies, the phasing down of coal-fired electricity generation, and further commitments to regulatory reform and energy efficiency.[501]

Decarbonization targets and policies vary significantly across the region. Singapore would likely lead decarbonization efforts, as it has made significant progress on deploying renewable projects and developing a widespread carbon tax, thus positioning it to reduce carbon emissions (by 9 percent) in 2030 relative to 2019 levels.[502] All other countries in the region are expected to undergo emissions growth in the same period.[503] Singapore also reflects a different economic context, as it has a much larger and more developed economy ($397 billion in GDP, compared with $19 billion for Laos and $14 billion for Brunei).[504]

Malaysia and Thailand are also front-runners in aggressive policies and targets and are currently projected to undergo emissions growth of 11 percent and 12 percent, respectively.[505] Malaysia has halted building new coal-fired power plants and has released detailed plans to expand renewable energy deployment.[506] Similarly, Thailand issued a moratorium on new coal plants and is accelerating policies on carbon pricing to provide incentives for the deployment of renewable energy.[507]

Countries with high levels of regional economic growth and heavy reliance on coal-fired power generation to meet growing demand face challenges when drafting ambitious policies.[508] For example, the Philippines has not committed to net zero, and, while some coal projects have been discontinued, at least half of the country's planned coal capacity will remain fully operational.[509] As a product of this heterogeneity in economic development, coal reliance, and renewable targets and deployment, countries across ASEAN are on significantly varying paths toward a more orderly energy transition.

Priority measures that could accelerate a more orderly energy transition

Southeast Asia faces several key challenges in realizing a more orderly energy transition. Four critical challenges to solve include: (1) rapidly growing energy demand exerting pressure on finding scalable sources of energy supply, without exclusively relying on coal or fossil fuels; (2) limited development of energy efficiency frameworks and measures and relatively low electrification levels in industry; (3) limited movement toward the full potential of the renewables and cleantech supply chains, notwithstanding significant domestic riches

[498] *Southeast Asia Energy Outlook 2022,* IEA.
[499] Cecillia Zheng, "Which ASEAN countries will be the front-runners to decarbonize their power sectors?" *S&P Global,* August 24, 2022.
[500] Ibid.
[501] "The EU and international partners launch ground-breaking Just Energy Transition Partnership with Indonesia," November 15, 2022.
[502] Ibid.
[503] Ibid.
[504] World Bank Country Data for Singapore, Laos, and Brunei.
[505] Cecillia Zheng, "Which ASEAN countries will be the front-runners to decarbonize their power sectors?" *S&P Global,* August 24,2022.
[506] The Malaysia Renewable Energy Roadmap.
[507] Ibid.
[508] Ibid.
[509] Ibid.

in raw materials and developed manufacturing industry; and (4) limited carbon transparency standards, posing challenges related to compliance with ESG standards and the targets of multinational companies manufacturing in the region.

To meet these challenges and achieve the NDCs of the countries in Southeast Asia, stakeholders could consider the set of near-term, high-priority measures that follows.

1

Creating the conditions for bankable renewables projects and advancing national and regional plans to minimize new coal development, and improving efficiency of the existing coal fleet

90%

Ninety percent of coal-fired power plants that have operated less than 20 years are in Asia

10%

Hydroelectricity, wind, and solar renewables together represent only 10 percent of total power generation across Southeast Asia

Population growth and industrialization are driving a rapid increase in energy demand across Southeast Asia. The regional economy expanded by around 4.2 percent each year from 2010 to 2019.[510] This trend is expected to continue; for example, Indonesia's population of 270 million[511] is forecasted to reach about 312 million by 2040.[512] General living standards and access to electricity will also increase.[513] According to the IEA, three-quarters of the new energy demand in Southeast Asia is likely to be met by fossil fuels in the absence of intentional intervention.[514] Further, 90 percent of coal-fired power plants that have operated less than 20 years are in Asia, many in Indonesia, the Philippines, and Vietnam.[515]

Historically, growing demand has been met largely by fossil fuels because of the local abundance of coal, lower levelized cost of energy[516] (LCOE) of fossil fuels, and widespread fossil fuel subsidies.[517] Consequently, while wind and solar have doubled across Southeast Asia from 2009 to 2020, hydroelectricity, wind, and solar renewables together represent only 10 percent of total power generation.[518] The untapped potential is widespread. For example, Indonesia has used only 5 percent of its potential for geothermal power, and, more broadly, Southeast Asia's hydropower capacity has the potential to double.[519] Nonetheless, some countries lack strong, ambitious targets for renewables deployment. For instance, although Vietnam has committed to "quit coal," the country has not published specific proposals with clear targets for the share of gas, wind, and coal in the country's power mix.[520]

The integration of greater renewable resources also poses challenges given the limited flexibility in the existing grid infrastructure, with 65 percent of the region's 5.5 GW of interconnection capacity running solely between Thailand and Laos.[521] Some countries, such as Brunei and the Philippines, have no interconnection capacity at all.[522]

To create the conditions for bankable renewable projects and minimize new coal development while improving the efficiency of the existing coal fleet, Southeast Asia could consider taking the following four actions.

[510] *Southeast Asia Energy Outlook 2022,* IEA.
[511] *World Development Indicators,* World Bank.
[512] Total Population in Indonesia 1961-2040, Statista, July 5, 2022.
[513] *Southeast Asia Energy Outlook 2022,* IEA.
[514] *Energy Transition Mechanism,* Asian Development Bank.
[515] Ibid.
[516] The levelized cost of energy represents the average cost of electricity generation of a generator over its lifetime (lifetime costs/energy production).
[517] Coal has historically been at an advantage compared to renewables, yet when renewable ranges are restricted to the most competitive projects, the gap between renewables and coal LCOE decreases significantly.
[518] *Southeast Asia Energy Outlook 2022,* IEA.
[519] *Renewable energy market analysis: Southeast Asia,* IRENA, 2018.
[520] Cecillia Zheng, "Which ASEAN countries will be the front-runners to decarbonize their power sectors?" S&P Global, August 24. 2022.
[521] "Can South-East Asian countries learn to share power?" *The Economist,* September 1, 2022.
[522] Ibid.

Mitigating the coal footprint and progressively phasing out coal generation with renewables. Given the prevalence of coal-fired power generation, countries across Southeast Asia may limit further coal capacity-building by establishing coal moratoria and restricting new proposals for coal-fired power plants. To phase-out existing plants, the Asian Development Bank (ADB) has united countries across Southeast Asia, including Indonesia and the Philippines, in the Energy Transition Mechanism (ETM), which seeks to accelerate the transition from coal-based energy through early retirements and conversions of traditional coal plants.[523] The ETM is already running pilots for the retiring and reconversion of five plants and aims to reduce carbon emissions by 200 million tons per year by retiring about 50 percent of the coal fleet of member countries.[524] While the ETM plans to undergo three distinct pilot phases in Indonesia, the Philippines, and Vietnam, the ADB may work with its member developing countries to attract investment from private-sector investors and philanthropies to accelerate the replication and scaling of the ETM model across Southeast Asia.[525] The ADB may also accelerate replication by proactively working with potential countries to conduct the institutional and regulatory assessments necessary to repurpose and reconvert coal plants across Southeast Asia.[526]

31%

The 2021 Malaysia Renewable Energy Roadmap sets an ambitious target for renewables uptake at 31 percent by 2025

Setting widespread, ambitious targets for renewables uptake. To meet the target of supplementing the 23 percent share of renewables in total primary regional energy supply by 2025—a target adopted by all Southeast Asian countries except the Philippines—countries across Southeast Asia may set more specific targets for renewables uptake to incentivize investment. For example, the 2021 Malaysia Renewable Energy Roadmap (MyRER) sets a more ambitious target for renewables uptake—31 percent by 2025 and decarbonization of the electricity sector by 2035—and also outlines key actions for renewable energy development in solar, hydro, and bioenergy.[527] Countries across Southeast Asia may follow Malaysia's example in establishing defined and feasible road maps for renewables uptake. These targets and road maps may emerge from public-private cooperation with major international institutions (such as the Asian Development Bank), private investors, or labs and research institutions.

Rethinking subsidies and regulatory frameworks to make renewables cost-competitive with coal and to incentivize green investments. Reforming and reallocating traditional energy subsidies may incentivize greater deployment of renewable energy resources across Southeast Asia. For example, Indonesia implemented a program that reduced subsidies for kerosene and increased subsidies for LPG as a lower emission "transition fuel." This encouraged the substitution of traditional, kerosene-based cooking fuel with LPG. As a result, kerosene consumption dropped by more than 90 percent in Indonesia.[528] Countries across Southeast Asia, including the Philippines and Myanmar,[529] may advance the Indonesian model and reform subsidies to incentivize the investment in and deployment of lower-carbon and renewable alternatives.[530] In developing clear road maps for shifting subsidies to incentivize renewables investment and development, countries across Southeast Asia may also design social assistance programs—such as cash-transfer programs for low-income households—for the communities that would be most heavily affected by the removal of universal fossil fuel subsidies.[531]

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[523] *Energy Transition Mechanism Explainer: How ETM will support climate action in Southeast Asia,* Asian Development Bank, November 3, 2021.
[524] Ibid.
[525] Ibid.
[526] Ibid.
[527] *Malaysia Renewable Energy Roadmap (MYRER),* Sustainable Energy Development Authority, Malaysia.
[528] *Southeast Asia Energy Outlook 2022,* IEA.
[529] As of 2015, there were 55 million people in the Philippines and 49 million people in Myanmar without access to clean cooking fuels. "Energy challenges for clean cooking in Asia: The background, and possible policy solutions," Asian Development Bank Institute, working paper number 1007, September 2019.
[530] For example, the ADB conducted reform analysis for India, Indonesia, and Thailand and demonstrated that through fossil fuel subsidy reform, these nations can promote economic growth and living conditions. *Fossil Fuel Subsidies in Asia: Trends, Impacts, and Reforms,* Asian Development Bank, 2016.
[531] Ibid.

Ensuring adequate grid flexibility and interconnection infrastructure to link demand centers with high-potential renewable areas. The ASEAN Power Grid (APG) is a project dedicated to scaling multilateral power trading throughout Southeast Asia. To enable greater renewables deployment and economic efficiency through the APG, Southeast Asian countries could increase the flexibility of its power system in order to effectively scale regional interconnection capacity. For example, drafting agreements for data sharing across borders may help build the technical requirements for cross-border trade.[532] Additionally, countries may revise inflexible, fixed, long-term energy transfer agreements across borders, which currently do not differentiate imports and exports on a daily or hourly basis, thus limiting the integration of variable renewable energy sources.[533] Adapting these bilateral transfer agreements to become more flexible and fluid would facilitate trade across borders.[534] Finally, another key enabler for cross-border power sharing is the harmonization of grid codes across the region.[535] Transmission-system operators may coordinate to draft the minimum requirements on a border-to-border basis before scaling to all countries across the region.[536] Aligning grid codes would ensure that the power systems are consistent and compatible for integration.[537]

2

Electrifying and improving efficiency across sectors to temper growing demand

Scaling renewable energy sources, paired with greater efficiency and electrification measures, could close more than 50 percent of the emissions gap between existing policies and the steps needed for sustainable development toward the 1.7°C "achieved commitments" scenario.[538] However, while many countries in the region have stated efficiency targets, there's a wide range of levels of ambition. For example, Brunei seeks to reduce total energy consumption through efficiency policies by 63 percent by 2035, while Indonesia seeks to reduce energy intensity by 1 percent annually by 2025.[539] Although industry drives the growth in final energy consumption across the region, electrification policies and measures, particularly surrounding boilers and other industrial equipment, remain largely limited.

50%

Energy demand in Southeast Asia will increase by more than 50 percent by 2050

The IEA predicts that stated policies will decrease energy consumption by 12 percent by 2050.[540] However, energy demand will increase by more than 50 percent over the same period.[541] Thus, countries in Southeast Asia may need to incentivize and require both efficiency measures and electrification to curb growing demand while decarbonizing the regional economy. To improve efficiency and electrification measures across the region, countries in Southeast Asia may consider taking the following two key actions:

Catalyzing private financing and involvement in the energy-efficiency value chain. To mobilize private finance to develop the energy-efficiency value chain, countries may revise current green bond grant schemes. Many current green bonds are issued toward financing international projects or refinancing loans.[542] Narrowing criteria to only regional projects may help mobilize private finance for renewable energy deployment in ASEAN countries. To do so,

[532] *Establishing Multilateral Power Trade in ASEAN,* IEA.
[533] *Southeast Asia Energy Outlook 2022,* IEA.
[534] Ibid.
[535] *Establishing Multilateral Power Trade in ASEAN,* IEA.
[536] Ibid.
[537] Ibid.
[538] *Southeast Asia Energy Outlook 2022,* IEA.
[539] Ibid.
[540] Ibid.
[541] Ibid.
[542] *Green Bonds for Financing Renewable Energy and Energy Efficiency in Southeast Asia,* Asian Development Bank.

policy makers may designate only domestic projects as "green" under the eligibility criteria for green bond financing.[543] Another potential means to incentivize energy efficiency is to enable the growth of the energy services company (ESCO) model. Within industry, ASEAN is working with policy makers and stakeholders to set the basis for the creation of an ESCO financing model,[544] where energy services companies achieve energy savings as a service at various properties.[545] The widespread adoption of this model, through tax incentives, subsidies, or large pilot programs, could facilitate decarbonization in industry, while also promoting value creation and employment growth for the developing region.

Establishing widespread electrification, including regional mandatory minimum energy performance standards and standards for the electrification of light industries. Electrification of industrial processes that require heat up to 1,000°C largely require equipment such as boilers or furnaces to be exchanged for an alternative piece of electric equipment.[546] In Southeast Asia, many light industries could shift toward electrification through more rigid standards to promote this exchange. For example, standards for the electrification of low-temperature heat pumps and standards for boilers and motor systems may promote decarbonization in light industries. The adoption of regionally aligned, widespread minimum energy performance standards (MEPS), especially in cooling (one of the fastest-growing sectors in the region[547]), may further incentivize electrification. Indeed, electric equipment in the buildings sector is so energy efficient that the lifetime savings of energy costs more than compensate for the higher costs of equipment and the higher price of electricity.[548] Stringent MEPS may also be applied for buildings and equipment that are regularly updated to promote energy efficiency and electrification of end uses.[549]

3

Adapting local economies to take full advantage of the transition, driving employment and socioeconomic growth across the region

Southeast Asia could be a major player in the production of critical minerals for green technologies and the manufacturing of renewable energy components. For example, Malaysia and Vietnam are the second- and third-largest manufacturers of solar PV modules in the world,[550] trailing China's 80 percent share across all the manufacturing stages of solar panels (polysilicon, ingots, wafers, and cell modules).[551]

$200 million

Southeast Asia's minerals-exploration budget decreased from about $800 million in 2012 to about $200 million in 2020

Despite the region's natural endowment of critical minerals that play an important role in the broader energy transition,[552] Southeast Asia has observed a decrease in mineral-exploration investment in recent years.[553] For example, Southeast Asia's minerals-exploration budget decreased from about $800 million in 2012 to about $200 million in 2020.[554] A lack of investment in mining and minerals development threatens the region's ability to scale green energy supply chains and manufacturing capabilities—even though these represent a key

[543] Ibid.
[544] Best Practices for Scaling Energy Efficiency with ESCOSs: Opportunities for ASEAN, ASEAN Centre for Energy, December 9, 2021.
[545] Building Technologies Program, ESCO Financing Summary, U.S. Department of Energy Better Buildings Initiative.
[546] Occo Roelofsen, Ken Somers, Eveline Speelman, and Maaike Witteveen, "Plugging in: What electrification can do for industry," McKinsey, May 28, 2021.
[547] *Southeast Asia Energy Outlook 2022,* IEA.
[548] Occo Roelofsen, Ken Somers, Eveline Speelman, and Maaike Witteveen, "Plugging in: What electrification can do for industry," McKinsey, May 28, 2021.
[549] *Southeast Asia Energy Outlook 2022,* IEA,
[550] Ibid.
[551] Sayumi Take, "China's solar panel supply chain domination cause for worry: IEA," *Nikkei Asia,* July 7, 2022.
[552] Ibid.
[553] Ibid.
[554] Ibid.

1k–1.1k

An estimated 1,000 to 1,100 jobs are needed per GW of renewable capacity manufactured

2.5x

By scaling processing and manufacturing and delivering products to trading partners, revenue from production of minerals could increase by more than 2.5 times to $60 billion by 2050

opportunity to expand both employment and socioeconomic growth. Securing consistent end markets and trading partners is also a key hurdle to scaling renewables supply chains and manufacturing capacity. Finally, an estimated 1,000 to 1,100 jobs are needed per gigawatt of renewable capacity manufactured.[555] Training and upskilling employees presents a challenge to scaling renewable manufacturing as well as to offsetting declines in coal-mining jobs as countries begin to move toward emissions reductions targets.[556]

If Southeast Asia could scale processing and manufacturing ability across renewable-component industries, such as solar PV and EV manufacturing, and deliver these products to trading partners, revenue from the production of minerals could potentially increase by more than 2.5 times, to $60 billion by 2050.[557]

To build out the critical-minerals supply chain and manufacturing capabilities, Southeast Asia could consider prioritizing the following four actions.

Incentivizing investments in mining and material treatment and processing to leverage the available critical-mineral resources. In order to mitigate recent declines in investment in the mining sector, countries in Southeast Asia may engage in joint ventures and partnerships with multinational corporations in order to accelerate the extraction and export of abundant mineral resources. These minerals, including nickel and cobalt, play a crucial role in the technologies needed for the energy transition. Southeast Asian countries may also leverage public-private cooperation to build capacity for geological and mining engineering expertise in order to deliver the resource-mapping necessary to promote further investment.[558] Another potential way to encourage investment is adopting transparent and consistent processes and procedures surrounding licensing and mineral rights to attract investors. The adoption of ESG frameworks related to waste and water management, worker health and safety, and greater transparency may also facilitate more widespread international investment in critical-materials mining during the energy transition.

Scaling up existing renewable manufacturing capabilities to boost international exports and enable a local supply of renewable components. Countries in Southeast Asia may expand downstream processing of mineral resources and scale manufacturing capabilities of renewable components, such as polysilicon, solar PV cells, and EV components. To improve manufacturing abilities, Southeast Asia could potentially de-risk investment through financial and tax policies and frameworks (for example, credit guarantees) and forge partnerships with research institutions and labs.[559] Joint ventures and partnerships, such as Indonesia's 2022 deal with Tesla to build a battery and EV plant, could also accelerate building out local supply chains and manufacturing capabilities.[560] Scaling manufacturing capacity would enable access to a greater local supply of renewable components, thus accelerating the deployment of renewable energy sources in the region.

Promoting regional and international alliances to consolidate trading routes and secure end markets for local raw materials and manufacturing. Southeast Asia could work with regional and international partners to streamline trading routes. Importing countries may seek to diversify their supply of renewables components to mitigate the risk of dependence on a single country. Regional alliances could also collaborate, aggregating demand to drive economies of scale for the shipping and trading of manufactured renewables products from Southeast Asia. For example, ASEAN may continue to work to develop free-trade agreements and a more flexible tariff policy to encourage cross-border trade.

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[555] *Securing clean energy technology supply chains,* IEA.
[556] *Southeast Asia Energy Outlook 2022,* IEA.
[557] Ibid.
[558] "Energy transition mechanism explainer: How ETM will support climate action in Southeast Asia," Asian Development Bank, November 3, 2021.
[559] *Special report on solar PV global supply chains,* IEA.
[560] Danielle Fallin and Karen Lee, "Southeast Asia hopes to become the next EV hub," Center for Strategic & International Studies (CSIS), August 31, 2022.

Rolling out training programs for reskilling and upskilling the workforce. As the first large-scale renewable projects will likely require experienced developers, Southeast Asian countries are presented with the opportunity to retrain and upskill their local workforce on the job. This would help to develop the in-house critical capabilities needed to enable renewables development. Corporations in the region could leverage international partnerships, such as those with renewables developers, to provide the local workforce with the requisite skills for large-field installation of renewables. These partnerships might also work to establish clear employment standards and transparency measures for worker protection across the renewables supply chain. Clean job creation and adaptation would facilitate fostering sustainable economic development, allowing local renewables manufacturing supply chains to develop across the region.

4

Developing standards and practices for emissions transparency to enable carbon tracking for multinational manufacturers in the region

20%

Compared with 2019, nearly 20 percent more companies operating in the Asia-Pacific conducted climate-related disclosures as of 2020

The Carbon Disclosure Project (CDP), which runs the global disclosure system for companies to manage their environmental impact and targets, reports that 3,000 multinational companies operating in the Asia–Pacific region conducted climate-related disclosures as of 2020, which was nearly a 20 percent increase from 2019.[561] In order to reach their targets and comply with ESG standards, these companies must exhibit transparency about the size of the carbon footprint of produced goods or else risk losing export opportunities.

Carbon accounting and markets are limited in Southeast Asia, with the exceptions of Singapore and Indonesia. To build a sustainable and carbon-conscious manufacturing industry, Southeast Asia may need to develop carbon transparency and tracking mechanisms, which could, in turn help develop the region's fragmented carbon markets to protect and foster its growing manufacturing industry.

Southeast Asia may consider taking the following two actions to increase carbon transparency and scale carbon markets.

Leveraging public-private cooperation to prioritize carbon transparency and tracking mechanisms for the manufacturing industry. The establishment of carbon standards represents one of the key steps for countries and industries in the region, not only as a means of tracking yearly emissions but also to provide large international manufacturers in the region with the necessary frameworks and tools to track the carbon footprint of their products and exports. Enhanced emissions transparency could represent a key enabler to maintain and further attract investments from foreign institutions and corporations. The direct involvement and cooperation of these multinational private companies with public institutions and regulatory agencies could lead to the acceleration of carbon transparency definition and roll-out, promote cross-fertilization to other export-heavy manufacturing regions, and strengthen the relations between Southeast Asia and foreign manufacturing investors.

[561] Pratima Digvi, "Asia Pacific's race to net-zero: CDP's regional analysis of 2020 corporate environmental disclosures," May 13, 2021, CDP.

$10 billion

Southeast Asian carbon offsets amount to a potential $10 billion in economic opportunities by 2030

Establishing carbon markets to promote interregional trading opportunities and push green technology uptake. Carbon markets have significant untapped potential in the region, with Southeast Asian carbon offsets amounting to a potential $10 billion in economic opportunities by 2030.[562] Some countries, including Thailand and Vietnam, have launched carbon credit exchanges domestically. As carbon markets grow, Southeast Asian nations may partner with multinational companies to develop and promote a common carbon market, which could reduce costs for green technologies. To establish a common regional trading platform, multinational manufacturers in the region could use international best practices to set standards for transparency. These corporations may also partner with various governments to facilitate ensuring a sufficient supply of standardized credits and transparent pricing to secure investment in scaling green technology.

Amid population growth and rapid industrialization, Southeast Asia would likely need to scale renewable technologies and accelerate coal decarbonization to move toward a more orderly energy transition.

[562] Reema Bhattacharya, "Asia's booming carbon market—the road to net-zero or a minefield of risks?" SPECTR, May 1, 2022.

A more orderly transition will need to be a just transition, one that recognizes the specific challenges of developing countries and to which collective, global, and unified action finds responses.

5 Key stakeholders can accelerate action to promote a more orderly transition

Key stakeholders can accelerate action at this juncture in order to promote a more orderly transition by 2030. This can be best accomplished through coordinated action on a global basis (even though we realize the current challenges that such coordination faces).

Frequently these actions will require investment, shifts in resource allocation and even economic and lifestyle adjustments. Global cooperation will be critical for three reasons. First, clean resources, raw materials, and expertise are not evenly distributed. Second, the economic exposure and available financial resources vary widely across archetypes. Third, the impacts of local actions (or lack thereof) will have uneven consequences that will require balancing and remediation on a global scale, as per the “loss and damage” and Global North and South collaboration discussions during the recent COP27. At the same time, as we have highlighted in chapter 4 of this report, the energy transition will require tailoring to local conditions and needs.

In this chapter, we look at some ways that governments and multilateral institutions, financial institutions, companies, and individuals could each contribute.

Governments and multilateral institutions could focus on mitigating uneven community impacts and risks, while setting long-term signals.

Specific priorities for governments and multilateral institutions would include:

Promoting carbon transparency and standards for fuels and energy intensive products. Carbon-intensity frameworks would need to be material and stable enough to animate consistent action and drive the economics of lower-carbon commodities, such as green hydrogen, methane abatement, biofuels, green steel, and ammonia. Such frameworks would also need to be technology-agnostic, to balance a wide range of fit-for-purpose technologies and measures.

Targeting policy measures to encourage investment across industries. Policy measures to target could include subsidies, grants, at-scale demand signals, and tax incentives, and would inspire stakeholder confidence in their application. These public investments could target early-stage research in scalable technologies or fund the deployment-led innovation that frequently results in learning-curve effects for green energy technologies. Interventions would need to be dynamic enough to be adjusted as technologies become cheaper. Dialogue and collaboration with the private sector can help shape measures that accelerate scale-up of green technologies as well as promote mobilization of key resources, such as domestic labor force and supply chain.

Managing uneven impacts to communities. Managing uneven results of the journey to net zero would need to take into account affordability and the effects on low-income consumers, the alleviation of the economic dislocation of emission-intensive sectors, and the need for investment in R&D and economic development to expand new green industries in hard-hit communities. For instance, compensating mechanisms such as reskilling and redeployment programs could be established for workers affected by the transition.

Evolving energy markets at the same rate as policy matures. Government could consider creating new price signals, such as auctions for energy storage or voluntary or compliance-based carbon markets, or rapidly advancing existing markets—for example, reforming electricity markets to incentivize and reward reliability and performance in a renewables-based energy mix.

Translating net-zero goals into an integrated energy plan that combines emissions reductions, resilience, affordability, and energy security. Long-term planning across sectors, backed up by policy measures, would help send price signals and build market conviction for further investment and new resource development. To avoid stranded assets and ensure continued access to energy, such planning should also provide clarity about the treatment of continued investment in brownfield assets.

Financial institutions could focus on disclosing and measuring their portfolio exposure in the near term and quickly deploying capital in the long term.

Potential measures for financial institutions to consider include:

Rethinking investment horizons and risk-return profiles. Several clean energy projects have a long-term horizon. Financial institutions would benefit from revisiting their approach to underwriting investments and shaping investor returns. For example, financial institutions could consider de-risking lending to drive demand for net-zero technologies as well as accelerating the development of new green financial instruments, such as climate-risk counterparty ratings.

Providing project capital for subscale technologies. Many promising technologies are proven in the lab but fail to scale once developed because of insufficient financing. Financial institutions could consider project capital for new technologies such as storage, EV-charging infrastructure, hydrogen, carbon capture, and electrification.

Exploring financing for underserved sectors and regions. Disadvantaged communities and at-risk regions will be disproportionately affected. Financial institutions should work with local stakeholders in countries and communities that have untapped potential for capital deployment and new energy project development, and where the impact of private financing often be disproportionate. Investors can provide support beyond money, by lending their expertise and guidance to drive the success of local initiatives. While government support is important, it will be critical to catalyze private investments where they are most needed.

Reporting exposure to stranded risks and emissions-intensive sources. Most investors in energy have risk exposure to coal, oil, and other emissions-intensive fuels. Financial institutions could report their exposure to these energy sources and determine action plans for how to manage them and avoid stranded asset exposure. This would require a balanced and nuanced approach, taking into account short-term as well as long-term needs and priorities.

Companies could consider developing net-zero strategies and action plans and embedding energy transition in their decision making.

When it comes to energy providers such as transmission and distribution firms, utilities, developers, asset operators, and OEMs, companies could consider the following:

Developing a strategy for all high-carbon assets. All energy companies will need a point of view on the evolution of stranded-asset risks for their assets and the options they have to retrofit them and improve their emissions profile, which could range from gas pipelines to oil and gas extraction to gas, coal, and oil plants. Actions on fossil assets need to be tied to a clear and robust strategy for clean-energy development to ensure energy security throughout the transition.

De-risking the supply chain. Access to labor and raw materials in the clean energy space will continue to be bottlenecks, from finding qualified technicians to ensuring critical-minerals supplies. Energy companies would need to redesign their projects to reduce risk, diversify their supply chains, and invest in reskilling and partnering to expand their labor pools.

Prioritizing innovation in business models and technologies. The energy transition would challenge the way energy assets are operated, maintained, and developed. Energy companies would need to try new business models and technologies. For example, capital would need to be allocated to new grid technologies to integrate renewables or investments into clean hydrogen, storage, and carbon-capture projects. Companies can work together to share risks and competencies in order to accelerate the scale-up of innovative solutions and find common answers to sustainability challenges.

Developing the manufacturing footprint for clean technologies. Technology manufacturers would see the rapid expansion of the demand for energy-transition-related products, from grid equipment to wind turbines and electrolyzers. As they determine their manufacturing footprint, these companies would need to consider each region's energy needs and policy priorities and their own access to clean and affordable energy.

Companies in energy-intensive industries such as mining, cement, and oil and gas extraction could consider the following:

Setting targets for energy-decarbonization, linked to specific, time-bound initiatives. These could include measures such as green PPAs and energy-efficiency measures that could have immediate and tangible effects on cost and risk reduction in addition to emissions reductions. These measures can help build resilience and secure business stability against market volatility.

Investing in energy supply and developments, usually with partners. Many large energy users could need to have a hand in shaping their energy supply. This might mean forming partnerships to develop, own, and scale clean energy projects, such as renewables or clean hydrogen production, and to develop enabling infrastructure, such as new electricity connections.

Creating an asset transition strategy. Many companies have already built their facilities that will operate in 2050. Their road maps would need to include retrofit plans, business cases, and operational changes that will transition this portfolio to a net-zero world—through, for example, energy efficiency, on-site renewables, electrification, and procurement of cleaner commodities.

Developing a procurement and energy risk management strategy. All large users of energy would need a plan for transitioning their consumption to green sources of energy plus a risk management approach for avoiding as well as handling energy-security and volatility issues as the transition unfolds. Energy hedges, long-term agreements, or development partnerships could play a part.

Individuals have a powerful role at the heart of the transition, particularly as informed citizens.

The cost and benefits of the transition are as complex as they are critical to the prosperity and stability of our world. It is critical for individual citizens to participate in the ongoing dialogue on the effects of climate change and the instruments for avoiding or mitigating it. Only then could individuals make informed trade-offs and decisions be made about the behavioral changes that may be required, such as green product purchasing decisions, more efficient use of energy, and shifting of economic priorities. To manage a transition that combines emissions reductions with energy security and affordability, the role of citizens and the support they provide their leaders can hardly be overemphasized.

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