A Blueprint for the Energy Transition

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CENTER FOR Energy Impact

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Preface

The transition to a net zero energy future is the biggest and most critical peacetime transformation of our economy in history. We are not currently on track to meet the objectives of the Paris Accords. In order to complete this energy transition in the time frame necessary to avoid significant damage to the planet, humanity, nature, and the economy, we need a much bolder agenda underpinned by a shared understanding of what actions are needed and an all-of-society approach to pursuing them.

This publication, developed by BCG's Center for Energy Impact, outlines the firm's views on crucial elements of the energy transition. It sheds light on the unique roles that different actors—policymakers, energy producers, energy users, technology providers, and investors—must play in order to reach net zero. Each essential shift or action that we identify is underpinned by analyses, existing and plausible scenarios, expert conversations, and BCG experience.

The objective of this work is to reduce ambiguity and provide increased clarity on what really matters, building on the best insights and judgment available to BCG. We hope that the blueprint presented here will help guide the decision making of businesses, policymakers, and other stakeholders, consistent with what we consider the key aspects of the energy transition. By keeping this analytical framework in mind as they act, stakeholders can advance the transition while ensuring positive societal, environmental, and economic outcomes, such as the just transition.

Numerous think tanks, research institutions, businesses, and others are performing extensive analyses on many of the topics discussed in this publication. We welcome their engagement and feedback with the aim of improving and revising our work. We consider our blueprint to be a living document and commit to updating it regularly as technology, regulation, and economic and geopolitical realities evolve.

The stakes of this energy transition are enormous—both to decarbonize the planet and to support prosperity and opportunity for all of us whose lives depend on access to secure and affordable energy. The challenges to get there are even larger. To tackle them requires a willingness to reprioritize objectives, shift resources, change incentives, and honestly confront shortfalls. It also requires collaboration between the public, private, and social sectors and across countries. We don't underestimate the difficulty of doing this, but we hope that this report can contribute to building the understanding necessary to align on a bolder agenda.

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A Tectonic Shift

Society has gone through energy transitions in the past—but nothing like this one. The adoption of coal occurred over roughly five decades, and the shift from coal to oil took more than three decades. To limit global warming to 1.5°C above preindustrial levels, we must ramp up renewables and other low-carbon solutions at warp speed. These energy sources must match the maximum shares held by coal (55%) and oil (41%) roughly three times as fast as those commodities did and ultimately should account for most primary energy by 2050—up to 70% in IEA's Net Zero Emissions scenario. This rapid transition remains a massive challenge and appears increasingly unlikely: current policies would permit warming to +2.7°C by 2100. And the speed of the energy transition in sectors such as industrial manufacturing and buildings is woefully insufficient.

Failure to bend the curve dramatically on emissions will have steep costs for the natural world and for the health and livelihoods of people around the globe. Evidence of these impacts becomes clearer every day—and at a concerning pace. We have the tools to get to net zero, but we do not have the policies, proven business cases, and capabilities in place everywhere to massively accelerate the pace of action. All stakeholders, private and public, need to do their part to effectively unlock concrete progress.

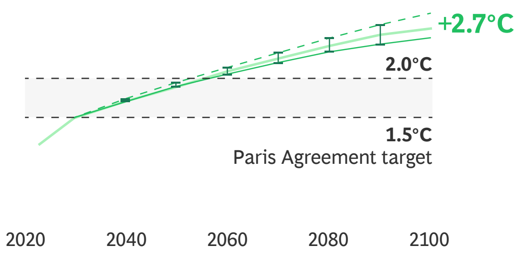
1. Energy is a fundamental driver of economic growth and human prosperity.
2. Society must massively accelerate substitution and abatement of fossil fuel use.
3. We have the technological levers to get us to a net zero energy system.
4. Oil and gas must be phased down rapidly, but selective investments will still be necessary.

1 Energy is a fundamental driver of economic growth and human prosperity.

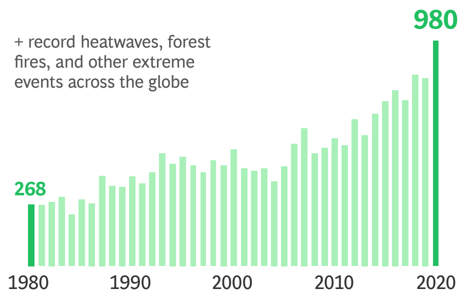
A strong correlation exists between energy access and human prosperity. Nations with “very high human development” (a Human Development Index above 0.8) consume more than 20 MWh of primary energy per capita. Fortunately, we can do more with less energy: over the past three decades, the global energy intensity of GDP has decreased by 34%. Further improvements in energy efficiency are critical, while energy access in developing economies must expand.

Current Policies Will Not Get Us to 1.5°C—and Damage Is Mounting

Global average temperature rise if current policies and actions prevail (°C)[1]



Number of extreme physical events and selected adverse impacts such as record heat waves and forest fires[2]



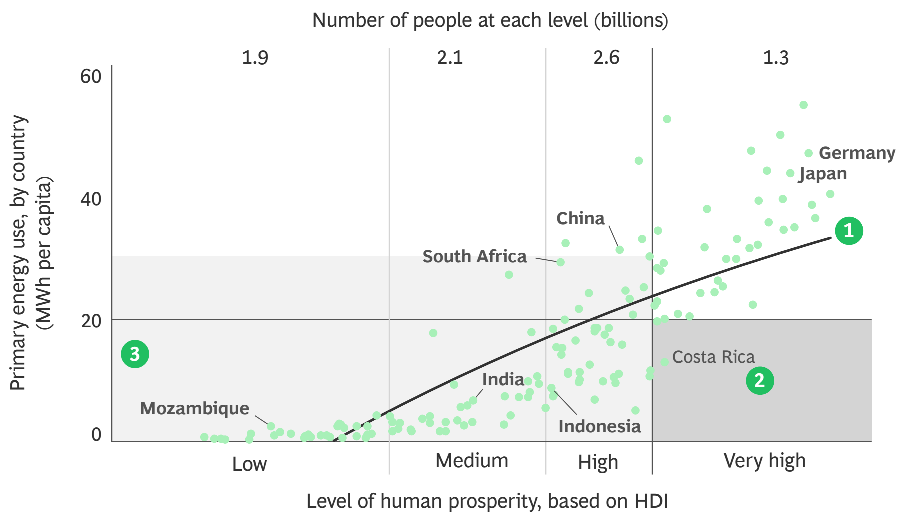
- Global temperatures have already increased by 1.1°C
- Current policies would bring us to 2.7°C by 2100, far beyond the 1.5°C target that countries set in Paris
- Without accelerated action, extreme adverse weather-related events (like the recent record flooding in Pakistan, extended droughts in East Africa, and wildfires on multiple continents) will continue to increase

Sources: World Meteorological Organization Global Climate 2021; PBL; Global Carbon Project; Global Climate Tracker; BCG CEI analysis.

[1]Minimum, maximum, and median (calculated) temperature increases (Climate Action Tracker, “policy and action” scenario, November 2022).

[2]Extreme physical events” are climate or environmental conditions at the extremes of historical measurements.

Societies’ Prosperity Closely Correlates with Availability of Energy



1. Human development and access to energy are deeply intertwined
2. Societies struggle to reach very high levels of prosperity at less than 20 MWh per year of primary energy use per capita
3. More than 775 million people globally still have no access to electricity

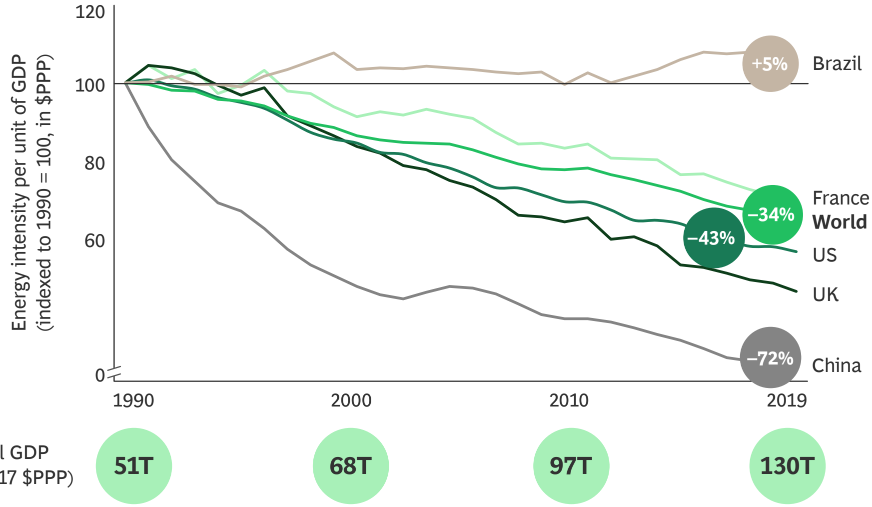
A twofold focus is required:

- Expanding access to green energy to meet demand for the energy-starved
- Reducing wasteful consumption in inefficient uses

Sources: UNDP; EIA; BCG CEI analysis.

Note: Countries with HDI >0.8 and with per capita energy consumption >60MWh are not shown. HDI = Human development index. HDI measures a country’s performance in terms of life expectancy at birth, average years of schooling, and gross national income. Low, HDI <0.55; medium, HDI ≥0.55 but <0.7; high, HDI ≥0.7 but <0.8; very high, HDI ≥0.8.

Energy Consumption Is Already Decoupling from GDP Growth, but Continued Effort Is Essential



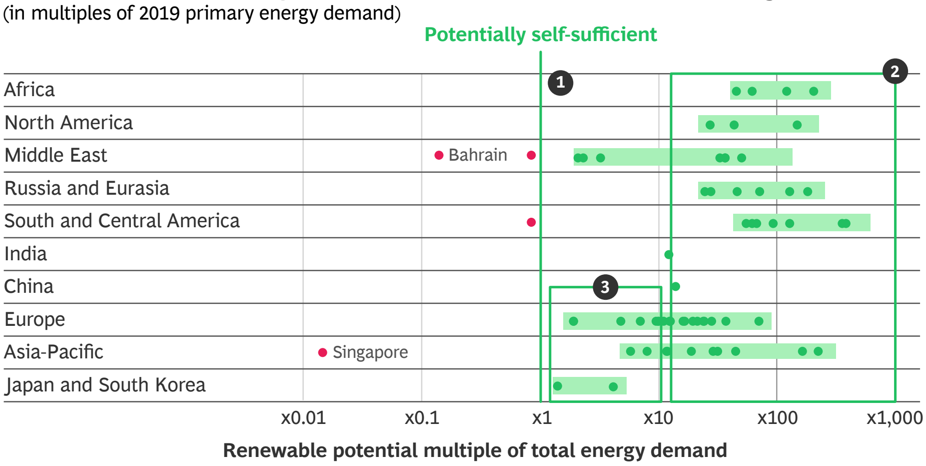
- Global GDP has almost tripled since 1990, while the energy intensity of GDP has decreased by 34%+
- Three changes have driven decoupling:
  - A shift in economic activity from industry to services; for example, in the US, industry's share of GDP decreased from 23% in 2000 to 18% in 2020
  - Technological progress in areas such as energy efficiency and electrification
  - Policy alterations such as fuel efficiency standards
- There is tremendous potential for more efficiency; for example, in the US in 2021, only one-third of primary energy was used, while two-thirds was lost to inefficiencies and energy conversion

Sources: Lawrence Livermore National Laboratory; IEA SDG7 Database 2022; World Bank; BCG CEI analysis.

Note: PPP = purchasing power parity; T = trillion.

The Vast Majority of Countries Have Potential Access to Sufficient Low-Carbon Energy

Combined wind and solar potential for selected countries in different regions
(in multiples of 2019 primary energy demand)



1. Most countries could fully cover their current energy needs with solar photovoltaics and wind
2. For most of the global population, the renewables potential covers current energy-demand tenfold to a hundredfold
3. Some economically advanced countries (such as Japan, South Korea, and many European countries) must manage competing demands on land use, such as for agriculture and for preservation of biodiversity

Sources: Global Solar Atlas; Global Wind Atlas; BP statistical review; BCG CEI analysis.

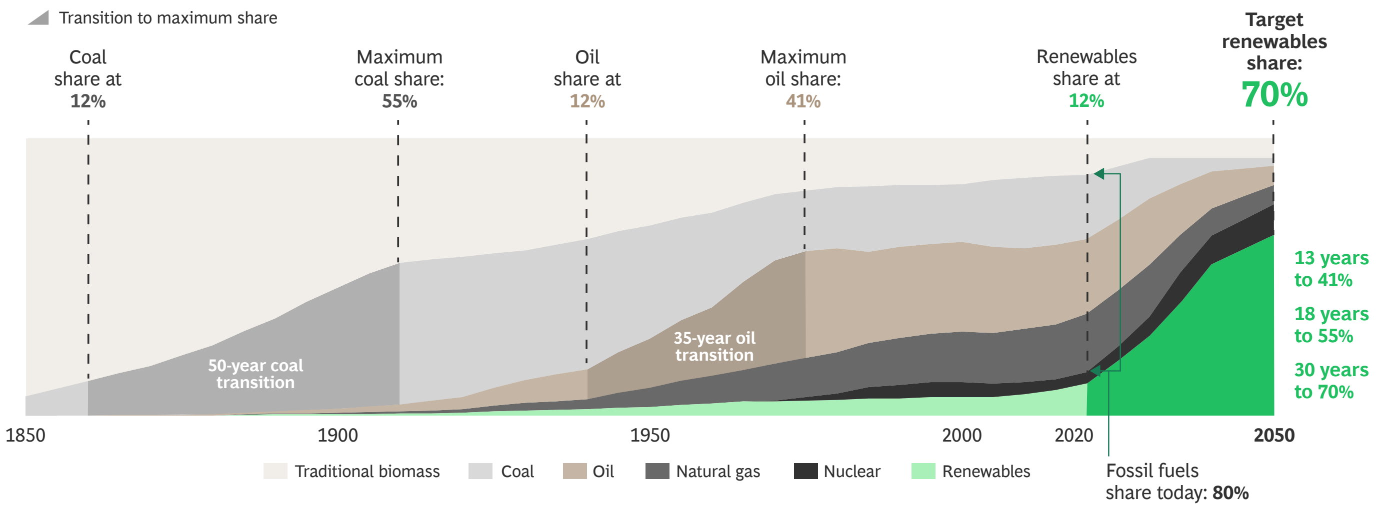
Note: This analysis limits the land area used for energy to a maximum of 10% of land area used for solar and 10% of land area used for wind.

2 Society must massively accelerate substitution and abatement of fossil fuel use.

Fossil fuels represent 80% of energy use and 70% to 75% of GHG emissions globally; coal alone produces over 25% of global emissions. Renewables must rise from 12% of energy supply in 2021 to 50% to 70% by 2050. Solar and wind generation capacity must increase tenfold, and global electric grids must expand by 2.5x—with similar investment levels in both areas. We must also abate emissions from remaining use of fossil fuels, including methane emissions.

The Transition to Net Zero Needs to Happen Roughly 3x Faster Than Previous Transitions

Primary energy supply by energy source[1]



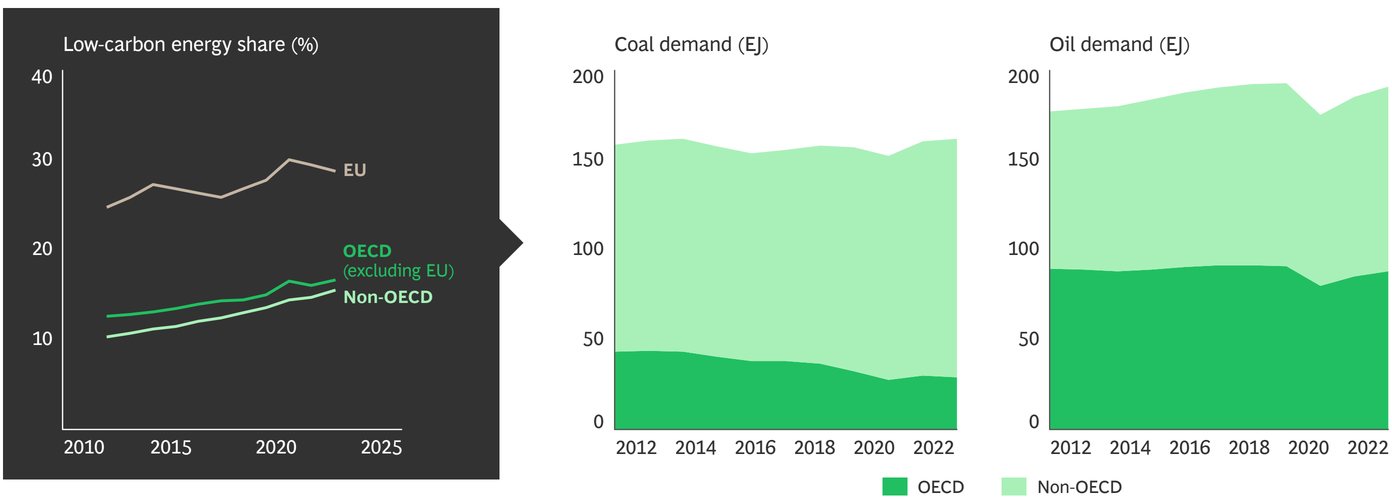
Sources: Vaclav Smil, "Our World in Data" (2017); BP Statistical Review of World Energy; IEA, Net Zero Emissions by 2050; BCG CEI analysis.

Note: Renewables include biofuels, solar, wind, and hydrogen, among others.

[1] 2050 estimates based on the Net Zero Emissions by 2050 scenario from IEA.

Demand for Coal and Oil Has Yet to Peak

Effectively countering climate change requires renewables demand to take share from hydrocarbon demand and for hydrocarbon demand to decline sharply; as yet, global demand for coal and oil has not clearly peaked



Sources: Energy Institute Statistical Review of World Energy; BCG CEI analysis.

Note: EJ = exajoule; OECD = Organization for Economic Cooperation and Development.

We Need to Invest as Much in Our Electric Grids as in New Solar and Wind Capacity

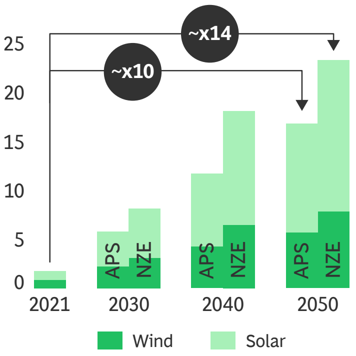
World solar and wind capacity (TW)

Average annual investments:

~$650 billion to $950 billion

Total investments through 2050:

~$20 trillion to $30 trillion



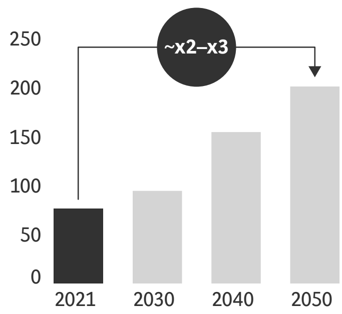
Global electricity grid size in NZE (km millions)

Average annual investments:

~$700 billion to $900 billion

Total investments through 2050:

~$21 trillion to $27 trillion



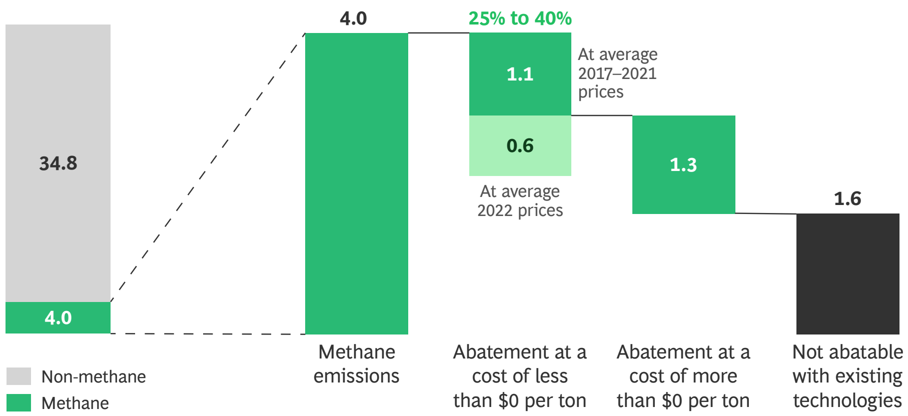
- Total world consumption of electricity is projected to roughly double by 2050
- Methane emissions are responsible for about 10% of long-term energy-related greenhouse gas emissions
- Investments in renewables and in the grid must be made in parallel to avoid generating low-carbon power that is stranded while the grid catches up

Sources: IEA; Bloomberg NEF; BCG CEI analysis.

Note: Total grid investments were calculated on the basis of average annual required investments for the Net Zero Emissions by 2050 scenario from IEA. APS = Announced Pledges scenario from IEA; NZE = Net Zero Emissions by 2050 scenario from IEA; TW = terawatts.

We Must Address Energy-Related Methane Emissions, Which We Can Reduce by 40% at Low or No Cost

Global energy-related emissions and methane abatement potential in 2022 (Gt CO_2e)



- Methane has significantly greater global warming potential than CO_2—from 120x in the first year to 28x over 100 years
- Methane emissions are responsible for about 10% of energy-related greenhouse gas emissions
- 60% of oil and gas methane emissions are abatable with existing technology
- At 2017–2021 prices, a methane emissions reduction of over 25% in the oil and gas sector is possible at negative cost; and at 2022 prices, a reduction of over 40% is possible

Sources: IEA, Global Methane Tracker; BCG analysis.

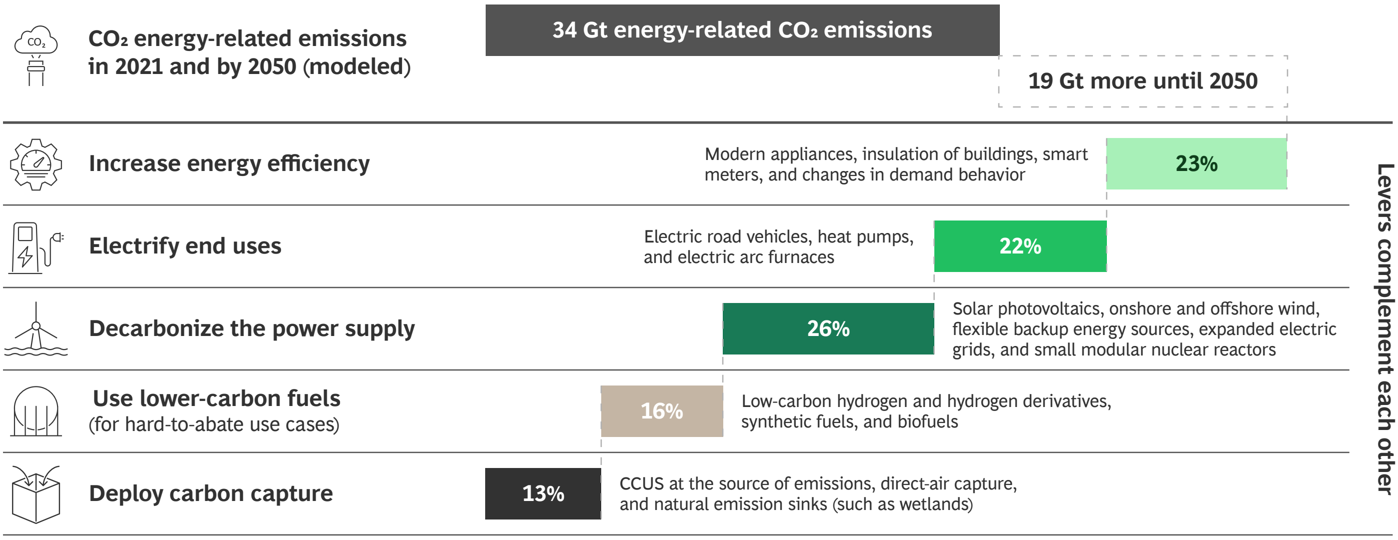
Note: The short-term global warming potential of 1 ton of methane is equivalent to that of 30 tons of CO_2.

3

We have the technological levers to get us to a net zero energy system.

Through 2030, proven technologies such as energy efficiency, electrification of end uses, solar photovoltaics, and wind are mainstays of the transition. In the 2030s, emerging technologies—including grid-scale batteries; new types of nuclear reactors; low-carbon hydrogen and carbon capture, utilization, and storage—will scale, given the right investment and effort. Meanwhile, significant investment in direct air capture is critical in this decade to lower its cost in the decades to come. Longer term, big bets such as fusion could be game changers.

Five Technology Levers Can Get Us to a Net Zero Energy System



Sources: IEA, Net Zero Emissions by 2050; BCG CEI analysis.

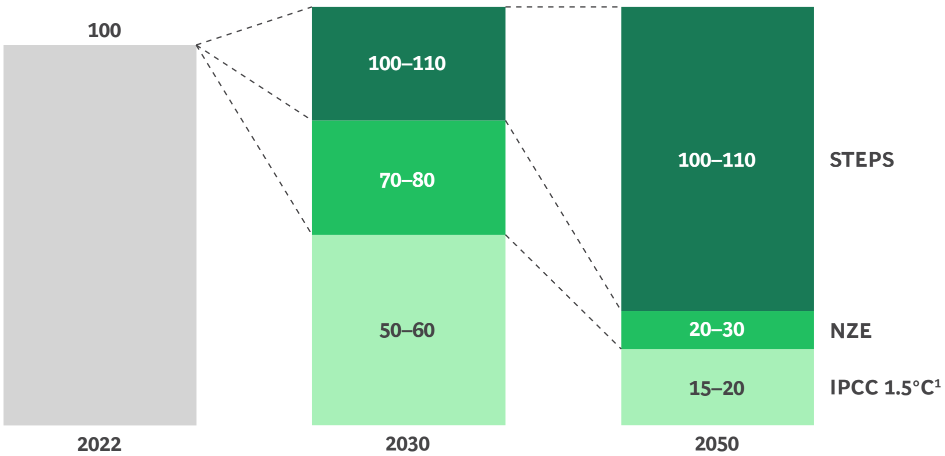
Capex-heavy, low-marginal-cost resources will supply 40% to 65% of global primary energy by 2050, up from 10% today.

4 Oil and gas must be phased down rapidly, but selective investments will still be necessary.

We must swiftly phase out coal. However, most net zero scenarios call for oil and gas supply in 2030 equivalent to 50% to 80% of 2021 supply and 15% to 30% in 2050—particularly for fuel use in hard-to-abate sectors and as feedstock in petrochemicals. Current productive assets will not meet 2030 demand and beyond. We must create conditions that ensure selective investment in the development of the most affordable, least GHG-intensive oil and gas volumes.

Oil and Gas Must Be Phased Down Rapidly, but Selective Investments Will Still Be Necessary

Total primary oil and natural gas consumption (%)



- Most net zero scenarios call for oil and gas supply equivalent to 50% to 80% of 2021 supply in 2030 and 15% to 30% of 2021 supply in 2050
- Current productive assets will not meet 2030 demand and beyond
- We must create conditions that ensure selective investment in the development of the most affordable, least GHG-intensive oil and gas volumes

Sources: IEA; IPCC; BP Statistical Review of World Energy; BCG analysis.

Note: NZE = Net Zero Emissions by 2050 scenario from IEA; STEPS = Stated Policies scenario from IEA.

[1]IPCC pathway 1.5°C without overshoot, at 25th-percentile lowest oil consumption.

The Far-Reaching Implications

The energy transition is critical to preserving a livable planet. It will also drive major economic change—altering the economics of energy systems and markets and remaking the global competitive landscape. But if we successfully accelerate the transition, we can expand access to electricity and greater prosperity to the 775 million people who don't have either today—and enable the even larger number of people who use very small amounts of electricity today to increase their usage.

1. The economics of our energy systems will fundamentally change.
2. We must redesign energy markets to provide the right investment signals.
3. By 2030, the energy transition will require at least $18 trillion in additional capital.
4. The success of the global transition will hinge on four key economies.
5. The transition will reshape the global industrial and competitive landscape.
6. A low-carbon energy supply can break many of the tradeoffs in the energy trilemma.

1 The economics of our energy systems will fundamentally change.

Energy will shift from an extracted to a manufactured resource, with heavier upfront investment but lower operating costs. Energy storage and incentives for customers to shift consumption to off-peak periods will be essential with lower supply-side controllability. Today, electricity storage covers only one to two hours of average consumption in Europe and the US versus over 1,000 hours for oil and gas. And energy transportation costs will multiply, resulting in less global movement of energy.

The Economics of Our Energy System Will Fundamentally Change During the Transition

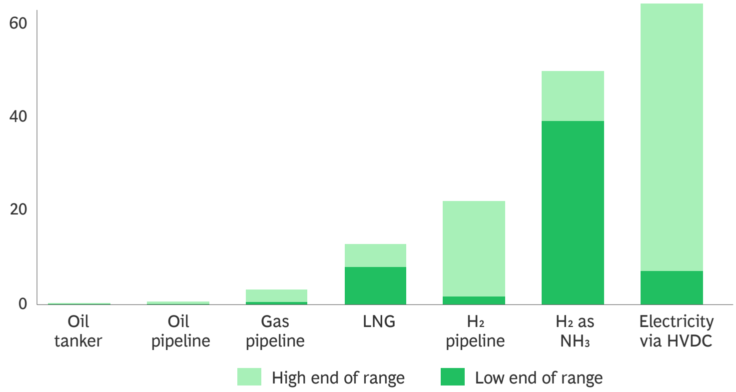
	Drivers	Implications
Resources	**We are moving from opex-driven extracted fuels to capex-driven manufactured resources** Capex-heavy, low-marginal-cost resources will supply 40% to 65% of global primary energy by 2050 (up from 10% today)	**Energy-only markets** based on marginal pricing may not be sufficient to incentivize the investments needed; we must align our market design to this new reality
Supply	**The supply side becomes less controllable, with the share of solar and wind generation capacity increasing rapidly** Solar and wind generation are subject to hourly, daily, and seasonal variations, and conventional midload plants like coal are being phased out	**Supply-side variability will increase,** requiring innovative market design, demand-side response, energy storage, and firm low-carbon generation
Transport	**The cost of transporting energy over long distances will multiply** It is 10x to 30x more costly to transport a unit of energy as H_2 than as oil over 1,000 miles of pipeline	There will be **less global movement of energy** and more interconnected regional markets
Storage	**Energy storage is more challenging as we shift to electricity and hydrogen** Electricity storage in Europe and the US covers less than two hours of average consumption, whereas oil and gas storage covers more than 1,000 hours	**Energy storage** will become more crucial and more expensive

Sources: OPEC ASB charts; ENTSOG; scientific publications; US Energy Information Administration; US Department of Energy; European Commission; IEA; S&P Global; NREL; Statista; desk research; D. DeSantis et al., "Cost of long-distance energy transmission by different carriers," *iScience* 24(12) (2021); BCG CEI analysis.

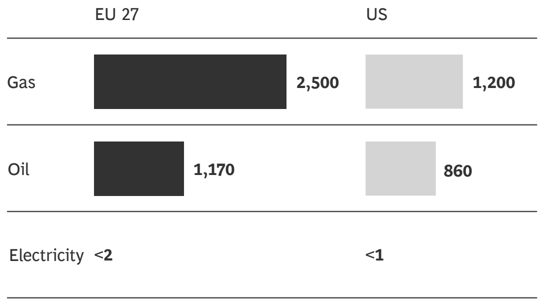
Energy Transport Costs Will Multiply, and Storing Energy Will Become More Difficult and Costly

Transport costs multiply with transition to clean energy

$/MWh/1,000 miles[1]



How long (in hours) can we cover average hourly consumption today?



Sources: OPEC ASB charts; ENTSOG; scientific publications; US Energy Information Administration; US Department of Energy; European Commission; IEA; S&P Global; NREL; Statista; D. DeSantis et al., "Cost of long-distance energy transmission by different carriers," *iScience* 24(12) (2021); desk research; BCG CEI analysis.

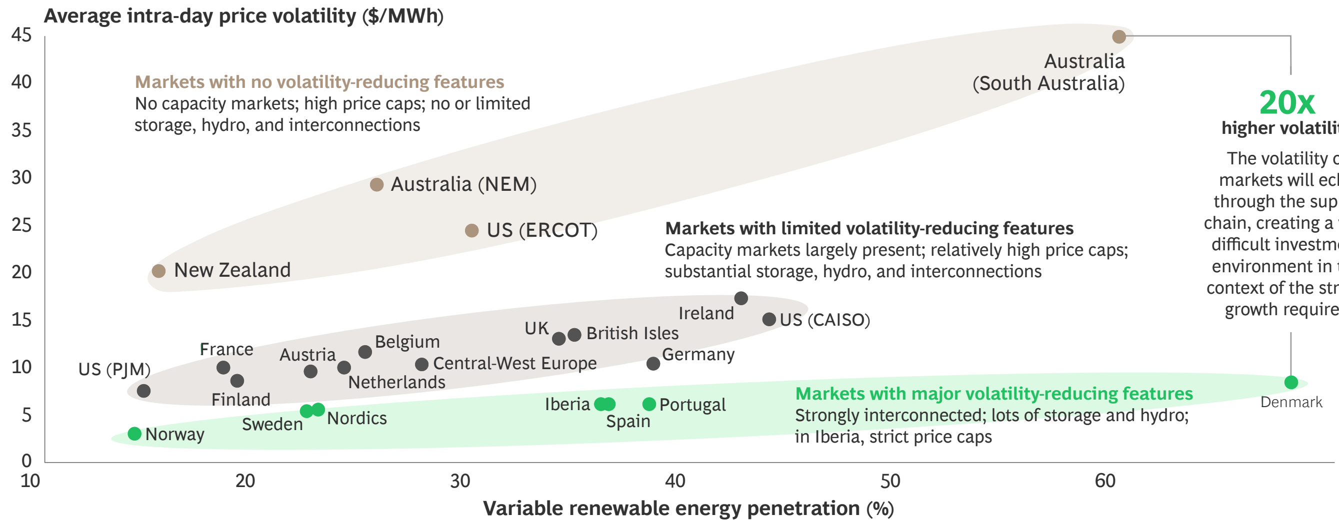
Note: 1 toe = 1 tonne (that is, 1 metric ton) of oil equivalent = 7.33 barrels of oil; 1 barrel of oil = 1.7 megawatt-hour equivalent; 1 mile = 1.60934 km; 1 kg H2 = 33.3 kilowatt-hour equivalent. EU 27 = European Union excluding the UK; H_2 = hydrogen; HVDC = high-voltage direct current; LNG = liquefied natural gas; NH_3 = ammonia.

[1]The costs noted in the left-hand set of bar charts include only the costs of transporting 1 MWh of energy using different energy carriers; it does not aim to compare total costs between these carriers, including production and conversion. For H2, the large range is mainly driven by four elements: onshore vs. offshore, repurposed natural gas pipeline vs. new pipeline, utilization factor, and diameter of the pipeline (with bigger pipelines driving economies of scale). For electricity via HVDC, we observe high variability in costs in completed/planned projects depending on the size of the cable (in terms of GW capacity and voltage levels), and on the assumed utilization and environment (e.g., offshore vs. onshore). The lower bound ($5–$10/MWh/1,000 miles) is most relevant to point-to-point connections over distances greater than 1,000 miles, with cables large enough to transport 5 GW or more at a voltage of 500 kV or more. The upper bound (exceeding $50/MWh/1,000 miles) applies to cables transporting 1–2 GW at a utilization factor of 50% to 60%.

2 We must redesign energy markets to provide the right investment signals.

Cyclicality, increasing volatility, and uncertainty in energy markets put the speed of the transition at risk. Large price swings will occur more frequently, especially in spot and balancing markets. Current market investment signals are insufficient to ensure the needed pace of change and system-level coordination. Uncertainty and risk premiums constrain new investments. But promising efforts to redesign markets are underway—for example, in the UK and the EU.

More Renewables Typically Mean More Volatility—but to Different Degrees, Depending on the Market



Sources: ABB Velocity; AEMO; Australian government, Department of Industry, Science, Energy, and Resources; EIKON; EMI; ENTSO-E; Eurostat; EXAA; IRENA; Nordpool; OMIE; S&P Global; BCG analysis.

Note: Regional positions across individual markets are based on load-weighted average intra-day price volatility and variable renewable energy penetration. Central-West Europe includes Belgium, France, Germany, Austria, and Netherlands; British Isles includes the UK and Ireland; Iberia includes Spain and Portugal; Nordics includes Denmark, Finland, Norway, and Sweden. Calculations reflect hourly day-ahead prices for Europe, hourly average spot prices for Australia, hourly average wholesale prices for New Zealand, and hourly day-ahead locational marginal pricing prices for the different hubs within CAISO, ERCOT, and PJM, averaging the standard deviation for the different zones/hubs within a region (for regions consisting of multiple zones/hubs). CAISO = California Independent System Operator; ERCOT = Electric Reliability Council of Texas; NEM = National Electricity Market); PJM = Pennsylvania-New Jersey-Maryland Interconnection.

Energy Markets Must Evolve in Three Major Ways

We see signs of momentum in frontrunner regions

Holistic system design

- Design energy systems and networks holistically, without shying away from configuring supply and demand in more optimal locations, taking into account demand for and supply of low-carbon electricity and molecules; for example, there are ongoing discussions in the the UK on more granular price signals (even up to nodal pricing), with the goal of better co-locating supply and demand

Electricity market redesign

- Provide price signals to balance supply and demand efficiently in the face of higher penetration of solar and wind (which are located in different places and have different behaviors), and provide investment signals to incentivize the unprecedented investment levels needed
- Consider increasing the pricing of externalities (such as carbon and congestion), increasing the certainty of revenue streams (such as contracts for differences), and setting more granular wholesale prices in time and space; reforms and discussions in the EU market include these elements

Responsive demand participation

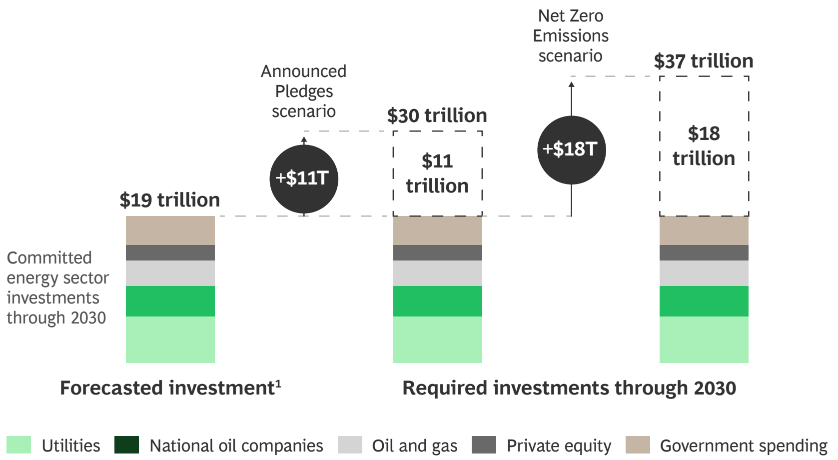
- Unlock more responsive participation by consumers to compensate for increasing supply-side rigidity and storage costs; for example, the EU plans to introduce a “peak shaving” product for demand-side participation in load balancing
- Incentivize efficiency and fuel switching to enable a smooth, demand-led phase-down of fossil fuels

Sources: EU Commission; UK Ofgem; BCG CEI analysis.

3 By 2030, the energy transition will require at least $18 trillion in additional capital.

The transition requires massive new investment of some $37 trillion in energy and industrial infrastructure through 2030. Even if all $19 trillion in planned energy-sector investment is realized, an $18 trillion gap remains, $9.8 trillion of which involves end use, according to BCG analysis. Inflation, supply chain constraints, and higher costs of capital make closing that gap more challenging. Financing the energy transition will require collective action, including through ecosystems of public and private players.

The Energy Transition Requires at Least $18 Trillion More in Investment Through 2030, to Total About $37 Trillion



- Companies and governments have pledged **$19 trillion** in intended investment toward the energy transition through 2030, but much of this amount is contingent on market developments and is not fully committed
- **80%** of this quantity is from the private sector; the remaining 20% is from government spending and subsidies aimed at catalyzing private sector investment
- There is currently an **$18 trillion minimum** capital gap between forecasted investment and required spending

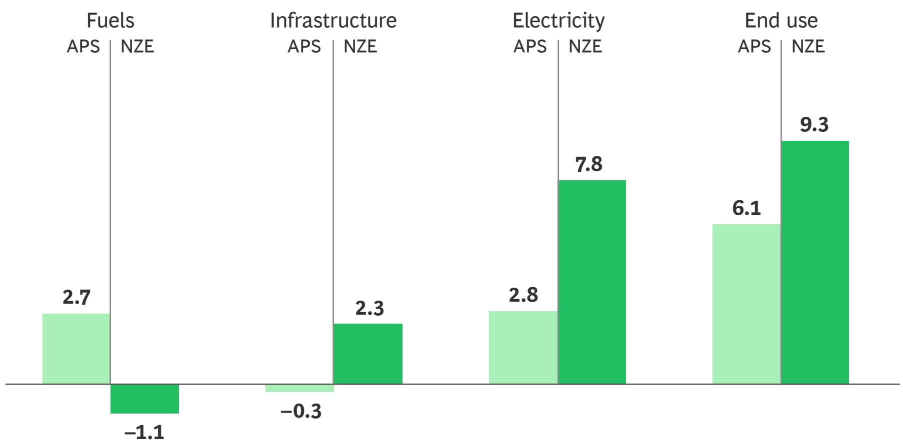
Sources: IEA, Net Zero Emissions by 2050; company-specified targets; modeled assumptions; BCG CEI analysis.

Note: The energy sector capex is modeled capex for the 270 largest energy companies, private equity, and existing direct government investment.

[1]Cumulative, committed investments, 2021–2030, by energy companies, energy-focused private equity investors, and energy-focused venture capital.

The Capital Gap Varies by Category, with End Use and Electricity Having the Farthest to Go

Capital gap ($trillions)



- **90%** of the capital gap is in the end use and electricity categories
- The end use category's **$9.3 trillion** capital gap includes consumer and industrial spending aimed at reducing energy demand and emissions
- The electricity category's **$7.8 trillion** capital gap consists primarily of investments in renewable power

Sources: IEA Net Zero Emissions by 2050; company-specified targets; modeled assumptions; BCG CEI analysis.

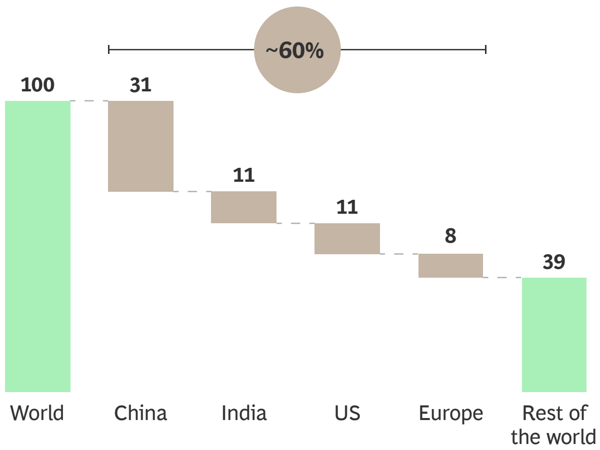
Note: The energy sector stated capex is modeled capex for the 270 largest energy companies, private equity, and existing direct government investment. End-use analysis includes energy sector companies only. However, if all non-energy sectors dedicated 5% of their annual capex to energy-related end use through 2030, this would reduce the end-use capital gap by only about $1 trillion, leaving a material end-use capital gap. Identified gap based on cumulative committed investments for the period 2021–2030 by energy companies, energy-focused private equity investors, and energy-focused venture capital. APS = Announced Pledges scenario from IEA; NZE = Net Zero Emissions by 2050 scenario from IEA.

4 The success of the global transition will hinge on four key economies.

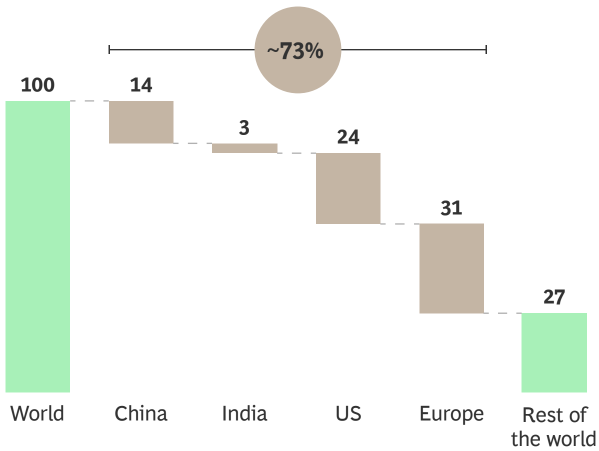
At current trajectories, the US, Europe, China, and India will be responsible for about 60% of global emissions through 2050. These regions must lead on mitigation. Already a leader in low-carbon manufacturing, China can accelerate the transition by reducing its coal use. Notably, action in these four regions has positive ripple effects: as they scale low-carbon technologies, deployment costs for technologies in other markets will also decline.

The Global Energy Transition's Success Through 2030 Will Hinge on Progress in the US, China, Europe, and India

Share of expected energy-related emissions by region, 2030–2050 (%)



Total cumulative past energy-related and industrial process CO_2 emissions by region, 1750–2021 (%)

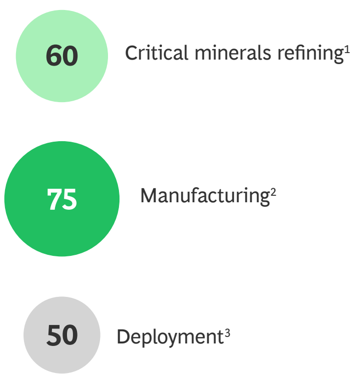


Sources: IEA World Energy Outlook; Global Carbon Budget; World Bank; BCG CEI analysis.

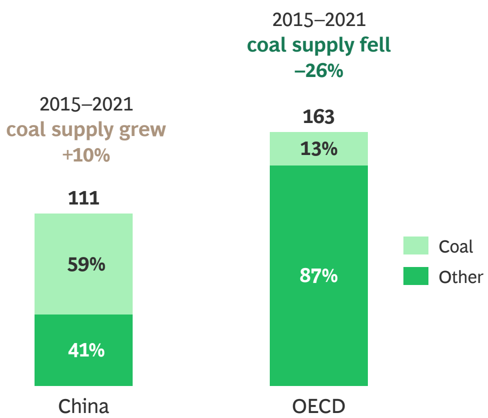
Note: Based on BCG's base case scenario. Europe includes the UK and Turkey. Because of rounding, not all bar segments add up to 100%.

China Will Play a Key Role in Driving the Global Energy Transition

China's share along the clean tech value chain in 2021 (%)



Total primary energy supply in 2021 (GJ/capita)



- China is a leader in low-carbon manufacturing, but it is a laggard in reducing coal generation
- Pairing China's innovation in clean tech with reduced demand for coal can accelerate the pace of the transition

Sources: Desk research; IEA, "The Role of Critical Minerals in Clean Energy Transitions" (2022); IEA, "Solar PV Global Supply Chains" (2022); IEA, "Global Supply Chains of EV Batteries" (2022); IEA WEO; BCG CEI analysis.

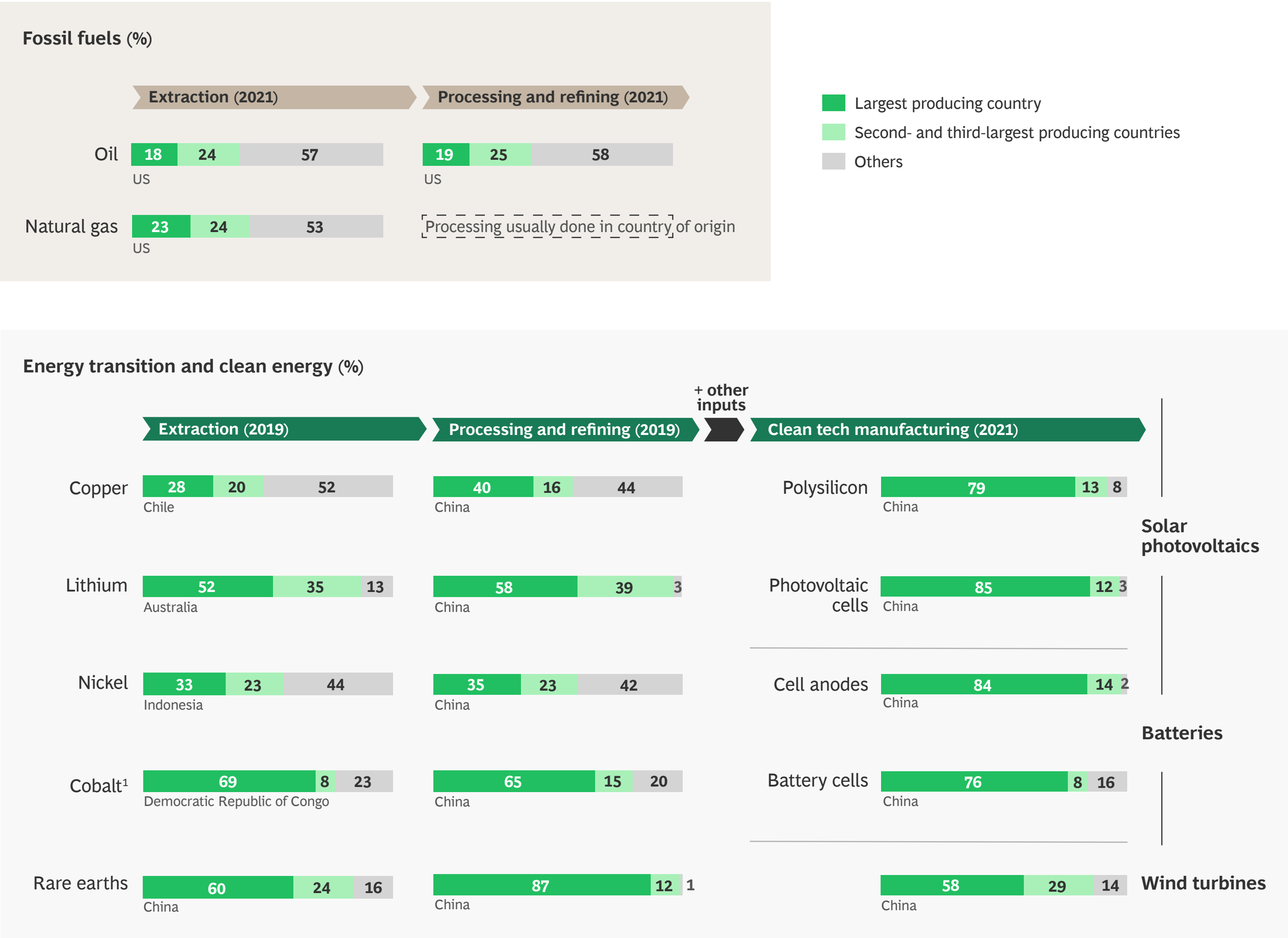
Note: GJ = gigajoules; OECD = Organization for Economic Cooperation and Development.

[1]Includes copper, lithium, nickel, cobalt, and rare earths. [2]Includes solar (polysilicon and cells), wind, and batteries (anodes and cells). [3]Includes solar, wind, and batteries.

5 The transition will reshape the global industrial and competitive landscape.

New centers of low-cost, low-carbon energy will emerge. Industries in which energy accounts for a sizable share of overall costs—for example, ammonia production, data centers, aluminum, pulp and paper, and steel manufacturing—could be leading candidates to relocate to such centers. Without structural action, many current industrial centers could become uncompetitive and might need to repurpose. Already, high energy prices have put base chemical manufacturing, such as ammonia production, in Europe at a disadvantage.

The Transition Depends on Concentrated Value Chains; More Diversification Could Lower Security-of-Supply Risks



Sources: IEA; BP; BCG CEI analysis.

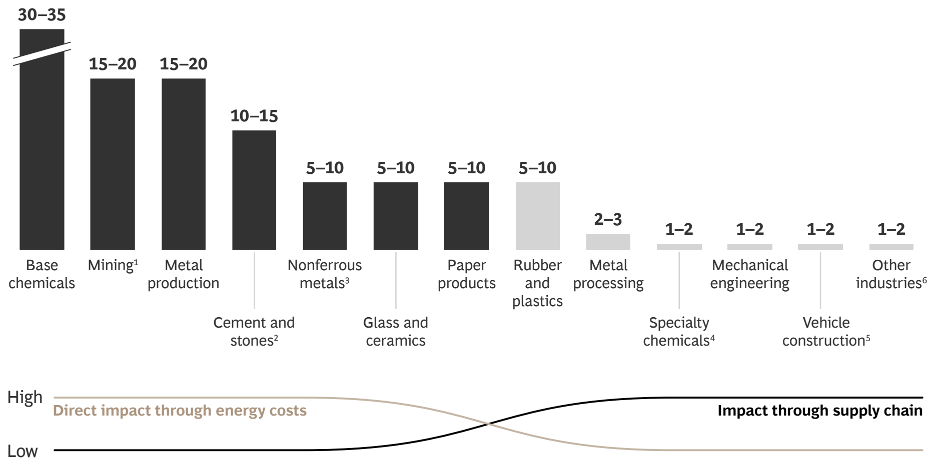
Note: Because of rounding, not all bar segments add up to 100%.

[1]Although 69% of the world's cobalt is extracted in the Democratic Republic of Congo, China owns a large portion of that country's cobalt extraction.

The Global Industrial Landscape Will Change as New Centers of Low-Cost, Low-Carbon Energy Emerge

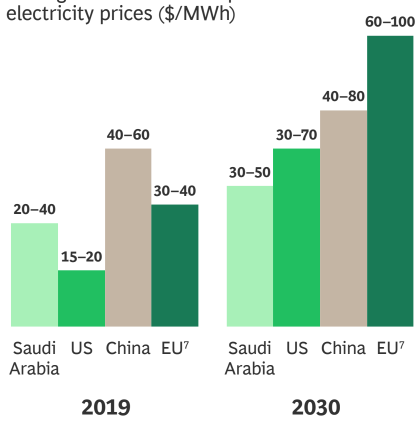
The heaviest electricity users are the most likely to relocate to the most competitive regions for energy supplies in the future

Energy intensity (2019–2020, energy feedstock costs as a percentage of revenue)



Regions have access to energy at vastly different costs

Average observed and expected electricity prices ($/MWh)



Sources: Destatis; Energiebilanzen; Refinitiv Eikon; Aurora Energy Research; Rystad; Nymex; Enerdata; International Center for Energy; International Energy Agency; BCG CEI analysis.

Note: Specific energy intensity depends on company size and tariff. Energy price ranges based on external scenarios and wholesale-price experts.

[1]Coal, stones, earth, and other. [2]Processing of stones and earth. [3]Includes foundries. [4]Includes pharmaceuticals. [5]Includes battery production. [6]E.g., extraction of crude oil and natural gas, food, tobacco, textiles, wood, printed matter. [7]Electricity costs in Germany were used for EU estimates.

6 A low-carbon energy supply can break many of the tradeoffs in the energy trilemma.

Actions that make energy systems more sustainable tend to make them more independent, more secure, and—on average—more economically sound. Investing in a low-carbon energy supply can avoid many of the tradeoffs inherent in the energy trilemma (the challenge of ensuring energy sustainability, affordability, and security) and, ultimately, build public support for decarbonization. Because initial costs and benefits will be distributed unequally across society and across regions, ensuring a just transition is vital.

Over Time, Investing in a Low-Carbon Energy Supply Can Break Many of the Tradeoffs of the Energy Trilemma

For example, in the North Sea, by 2030, each additional gigawatt of offshore wind deployed has the yearly potential to...

Sustainability
...mitigate emissions of fossil fuel generation by up to
~1.5 million to 4 million tons of CO_2

Affordability
...reduce supply costs vs. fossil fuel generation by up to
~€350 million to €450 million[1]

Security
...reduce fossil fuel imports by up to
~10 full LNG carriers or >10,000 coal wagons

Sources: WindEurope; Wood MacKenzie; Orsted; ACER; BCG CEI analysis.

Note: Assuming an offshore wind capacity factor of 50%. The lower bound of impact in each estimate is for combined-cycle gas turbines; the upper bound is for coal. LNG = liquefied natural gas.

[1]Based on 2030 European projections for levelized cost of electricity (average of Wood Mackenzie [2021] and BCG's proprietary levelized cost of electricity model) with comparison to coal as the upper bound and comparison to natural gas as the lower bound.

Second- and Third-Order Effects of Actions Taken in One Region Can Intensify the Trilemma in Other Regions

During the 2022 energy crisis, fossil-fuel prices rose sharply, and power prices rose indirectly as well, affecting countries in different ways

Developed economies
Could secure energy supplies and accelerate their transition away from fossil fuels

70%
of the LNG spot market is likely to be acquired by key EU countries from 2023 to 2025

Developing economies
Had to choose between security and a lower carbon footprint

Second-order effects of LNG reroutes to Europe

4x planned increase in Pakistan's coal-fired capacity after a loss of trust in the reliability of the LNG supply when global markets tightened

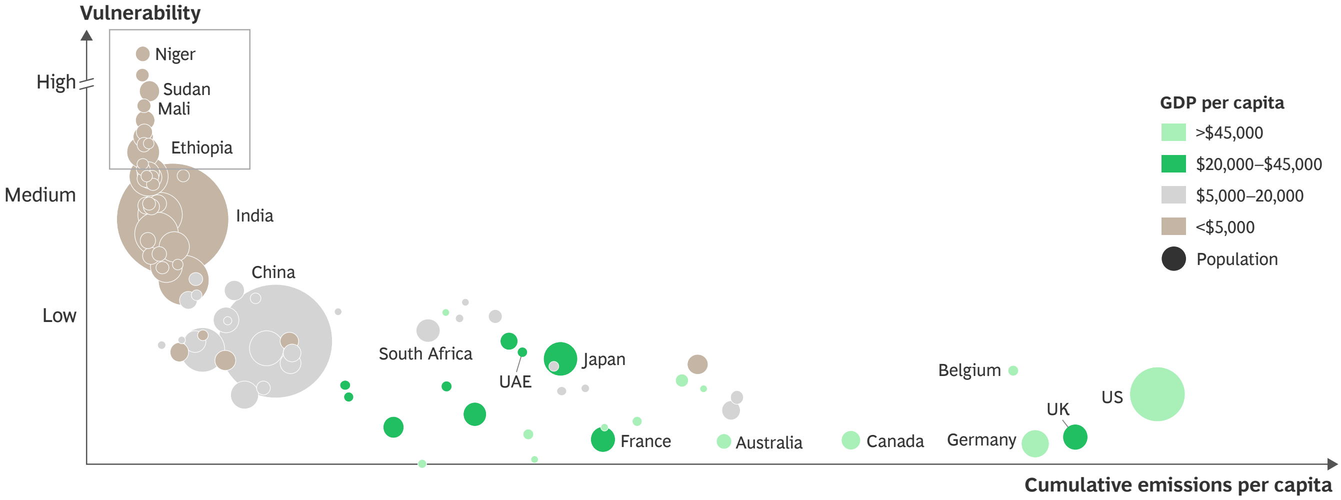
2/3 of Bangladesh's LNG-fueled power supply was unavailable during crisis, leading to blackouts

Sources: Reuters; BCG CEI analysis.

Note: LNG = liquefied natural gas.

The Poorest Countries Have Contributed Least to Climate Change but Are the Most Vulnerable to Its Impacts

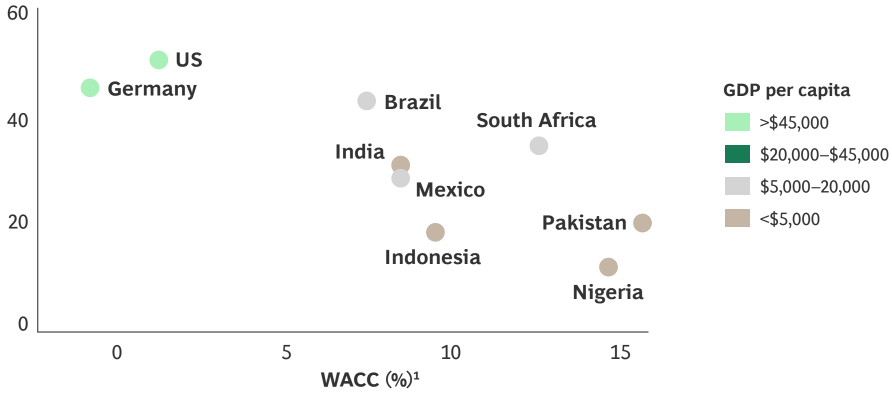
Cumulative CO_2 emissions vs. climate change vulnerability



Sources: World Risk Report, United Nations University Institute for Environment and Human Security (UNU-EHS); World Bank; Our World in Data; BCG CEI analysis.

Note: Bubble size represents population size. Population, GDP data, and cumulative emissions are as of 2020. Vulnerability relates to social, physical, economic, and environmental factors that put people or systems at risk of harm from climate change.

The High Cost of Capital Makes Financing the Energy Transition Harder for Developing Economies



- Developing economies have significantly less ability to finance energy transition investments than developed economies do
- The higher cost of capital in developing economies constrains renewable energy investments, which typically require high upfront capital costs
- For renewables, the higher cost of finance negatively impacts the cost of renewable energy produced, increasing the competitiveness of fossil investments
- In most developing economies, public spending as a share of total GDP is low, limiting their ability to offset low private investment with public spending

Sources: International Monetary Fund; IEA Cost of Capital Observatory; BCG CEI analysis.

Note: Countries with available data in the IEA Cost of Capital Observatory. WACC = weighted average cost of capital.

[1]Indicators of economy-wide cost of capital for debt (government bond + debt risk premium), nominal values, 2020.

The higher cost of capital in developing economies constrains renewable energy investments.

Action Across the Energy Ecosystem

Private and public sector leaders seek greater clarity about the concrete actions they can take today to accelerate the energy transition through 2030 and beyond. Our work sheds light on opportunities and imperatives for all players. They must not only push ahead on these specific steps, but also simultaneously craft a vision of a green, resilient economy and private sector that mobilizes the support of their stakeholders.

Policymakers

Large Energy Consumers and Energy Infrastructure Providers

Energy Producers and Suppliers

OEMs and Low-Carbon Technology Companies

Investors and Financial Institutions

Policymakers

As the toll of climate change becomes increasingly visible to citizens, public sector leaders need to build public support for action. That action should leverage the full power of market forces while maintaining the ability to course-correct. To achieve this result, they should prioritize actions on six fronts:

Close the Cost Gap

The energy transition will cost consumers in the short to medium term but pay off in the long term.

Many green products and technologies are still more expensive than gray alternatives when externalities are not priced in. (We currently price only 18% of global emissions from a carbon markets perspective.) Policymakers can level the playing field by taking steps to make non-green offerings more expensive (for example, through tax policy, carbon pricing, or removal of subsidies) or by making green products more cost competitive (for example, through incentives or public R&D funding). Recent developments are encouraging—particularly in the US, with its passage of the IRA, and in the EU, with its Green Deal Industrial Plan. The challenge now is to proceed to implementation, designing the appropriate regulations and disbursement mechanisms and alleviating bottlenecks.

Get Granular

Governments must set the stage for predictable, steady progress toward net zero.

Granular year-by-year deployment targets are critical to delivering on ambitious 2030 and 2050 goals. Stakeholders must coordinate these targets across industries and value chains. In some cases, government guarantees can advance efforts to achieve those targets.

Redesign Energy Markets

The energy system needs unprecedented levels of low-carbon investment.

Energy markets must evolve in three primary ways. First, planners must design energy systems and networks holistically and not shy away from configuring supply and demand in more optimal locations, when possible. Second, they must redesign electricity markets to provide the price signals needed to efficiently balance supply and short-term demand, and to incentivize an unprecedented level of investment. To this end, policymakers can enhance today's market signals—for example, through carbon pricing and guaranteed revenue streams or subsidies. Third, energy markets must encourage energy consumers to modulate the timing of demand, including by shifting consumption toward off-peak hours.

Dramatically Cut Planning and Permitting Times

Large investment is needed, most notably to increase low-carbon energy supply and grid expansion.

In theory we have access to plenty of low-carbon energy. But time-consuming planning and permitting processes can severely impede rapid progress. Policymakers can streamline these processes to power rapid progress, particularly in expanding electric grids. Of course, instituting such procedural innovations entails overcoming major barriers, including potential pushback from public opinion.

Rethink Liability Frameworks

New low-carbon technologies are critical, but funding them carries some risk for investors.

Newer technologies—such as hydrogen and carbon capture, utilization, and storage—raise questions of liability uncertainty. For example, it may be unclear who should pay in the event of CO_2 leakage. Potential financial risks of this sort, which can be massive, are slowing or even halting investment decisions. Updating and implementing redesigned liability frameworks can unleash significant investment.

Ensure a Just Energy Transition

The costs and benefits of the transition must be equitably shared.

During the energy transition, some traditional jobs will disappear and many new ones will emerge. Governments must ensure an equitable distribution of the positive and negative impacts of these changes across geographies and society. Ultimately, such equity will be critical to gaining and maintaining popular support for the transition. Advanced economies should also offer technical and financial assistance to emerging economies in support of their efforts to plan and deliver just transitions.

Large Energy Consumers and Energy Infrastructure Providers

The emerging energy system will be more complex than its predecessor, requiring energy consumers and infrastructure providers to play a larger role. They must take three interlinked actions:

Lock in Green Energy Supply and Infrastructure

Demand for low-carbon energy may outstrip supply.

Large energy consumers should ensure that they have reliable access to low-carbon energy (for which there will be real competition) and to required infrastructure such as hydrogen and CO_2 networks and long-distance electricity transmission. Timing matters because there is risk that end-use conversion and transmission and distribution infrastructure will lag creation of new low-carbon demand.

Design Capital Expenditure Plans with a Long-Term View

Investments in heavy assets should take into account the pace of scale-up in demand.

To avoid falling behind, heavy industry players must make capital expenditure decisions that are economic over the long term, even if the investments do not yield high returns in the short term. At the same time, they must bear in mind the risk of stranded assets created by an accelerated transition.

Build and Support Low-Carbon Ecosystems

Given the scale of investment needed, companies cannot go it alone.

Business cases for many large investments in low-carbon production, infrastructure, and offtake assets have significant interdependencies, both between stakeholders and in the timing of investments. Consider hydrogen. In order for hydrogen markets to develop, end users must convert to its use, transport must be built out, low-carbon power must become widely available, and electrolyzers must be built on a large scale—all in the right order over time. Clearly, collaboration (including public-private partnerships) across sectors and along the entire the supply chain is critical in this process.

Energy Producers and Suppliers

Energy producers and suppliers must aim for flexibility and resilience as they decarbonize. To achieve this, they should pursue these priorities:

Ensure a Responsible and Resilient Supply of Oil and Gas

As demand for fossil fuels declines, the risk of price shocks and volatility will increase.

To minimize those risks and avoid the added costs of stop-start investment cycles, energy producers and suppliers must arrange for a reliable supply of oil and gas. At the same time, they have an obligation to reduce fossil-fuel-related GHG emissions—in the short term through methane leak elimination, and in the short and medium terms through Scope 1 and Scope 2 emissions reductions and carbon capture, utilization, and storage. In parallel, they must invest aggressively in direct-air capture R&D and in pilots at scale to ensure the technology's viability.

Lead on Low-Carbon Energy Production

Building out a new energy system requires massive capital and expertise.

Producers and suppliers can leverage strong balance sheets and their technical and operational know-how to help orchestrate complex energy systems and ecosystems. Individually, players need to clarify their strategy—for example, whether they will operate as a pure play or as an integrated energy provider.

Develop Tailored Energy Supply Portfolios

Different markets will need different mixes of low-carbon energy sources.

In some regions, green fuels may be a good fit; in others, using renewable energy to meet higher levels of electrification may be more suitable. Producers and suppliers can develop business cases and roadmaps that reflect those differences, and they can work with policymakers to shape regulations that support the right mix.

Design the Right Solutions

Customers will need flexible, integrated hydrocarbon and low-carbon energy solutions.

As customers transition from fossil fuels to low-carbon energy in their operations, energy producers must help them find pathways to transition effectively over time and avoid disruptions. For example, energy producers can offer industrial manufacturers heat as a service, independent of whether the source of the heat is fossil fuels or renewable energy. This will enable the manufacturers to reduce their carbon footprint while also limiting their need to invest in new assets or processes.

Plan for Volatility

Customers should not bear the entire burden of increased price volatility customers.

Not all customers, particularly residential or small commercial, are well equipped to absorb large increases in price volatility. As in many other industries, large swings in producers' supply costs need not be passed on to customers. Energy suppliers should understand customer preferences regarding volatility and design innovative products that match those preferences.

OEMs and Low-Carbon Technology Companies

If the low-carbon energy system is to scale successfully, manufacturers and tech players must secure and diversify their supply chains and push for standardization. To advance the transition, they should adopt the following measures:

De-risk and Diversify Supply Chains

The energy transition hinges on global value chains, so ensuring resilient supply is key.

Both OEMs—including all producers of equipment along the low-carbon supply chain—and low-carbon technology companies should ensure that their supply chains are robust and do not rely too heavily on suppliers in any one country. This means diversification, not decoupling.

Monetize the Power of Scale

The benefits of producing on a large scale can accelerate the transition.

OEMs should push for scale in low-carbon technologies to bring down costs and, ultimately, prices. In doing so, they should take advantage of supportive policies—for example, the Production Tax Credit in the IRA in the US.

Balance Innovation and Standardization

There is a clear path to scale in emerging low-carbon value chains.

Technological advances can help OEMs and low-carbon tech companies lower costs and improve efficiency. For example, the power generation capacity of the average operational wind turbine has quadrupled over the past two decades. As technologies mature, however, players should establish standards to drive industrialization. The right standardization can provide opportunities to lower costs in the medium term—not only for the component manufacturing industry, but also for the downstream value chain. Conversely, a lack of standardization might require endless, costly modifications, such as (in the case of wind power OEMs) continuous upsizing and alteration of vessels and other logistics for installing offshore wind.

Investors and Financial Institutions

The energy transition is impossible to achieve without a step-change in levels of investment in low-carbon solutions. To drive that outcome, financial players should take these steps:

Engage with Regulators and Governments

We need to unlock unprecedented levels of investment.

Investors and financial institutions can work with the public sector to install long-term investment signals, including standards for measuring emissions and verifying that companies have taken certain decarbonization actions. Doing so will promote a more level playing field and a more accurate valuation of the externalities that exist today, ultimately increasing the pace and overall coordination of capital spending.

Do Not Lose Sight of Infrastructure Investments

The success of the energy transition will depend on new networks and infrastructure.

Investors and financial institutions must identify sound investments in networks and other shared infrastructure to ensure that sufficient low-carbon production is built. From now until 2050, the global electricity grid alone will require investments totaling more than $21 trillion. Larger connected zones, including for electric grids or hydrogen networks, will eventually yield lower commodity costs.

Consistently Integrate Carbon into Decision Making and Asset Valuations

New approaches are necessary to close the energy transition investment gap.

Investors must systematically embed consideration of carbon in their decision making process. This assessment should encompass regulated carbon costs, internal carbon costs, indirect carbon costs (related to Scope 3 emissions), and value created through the company's decarbonization efforts (such as demand for the resulting low-carbon alternatives).

Apply a Programmatic Approach in Financing

Funding green projects piecemeal is slow and limits the agility of funded companies.

Investors and financial institutions need to move beyond financing individual projects and instead directly finance companies that are deploying low-carbon technologies. This will enable those companies to move capital between projects as situations for each evolve.

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For Further Contact and Content

If you would like to discuss this report, please contact the authors. If you would like additional energy transition insights, please visit our topic page on bcg.com.

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