Key messages

- When a crisis strikes, such as that surrounding global energy, middle-income countries should seize the opportunity to instigate the needed restructuring and reallocation. For example, the global energy and climate crises have spurred rapid progress in the development and deployment of low-carbon technologies.
- In middle-income countries, the rate of adoption of key clean energy technologies is growing more rapidly than in high-income countries, but levels of adoption by firms and households remain significantly lower, particularly for solar energy, wind energy, and electric vehicles.
- Incumbents in high-carbon industries, which tend to be state-owned enterprises in middle-income countries, erect barriers to the entry of low-carbon technology because they have the strongest incentive to maintain the status quo and limit competition from low-carbon energy providers.
- Middle-income countries run the risk of becoming stranded nations—not because of anything inherent in the scaling up of low-carbon technologies and the winding down of fossil fuels, but because of (1) outdated policies and rules of thumb that limit the growth of value-creating enterprises and the exit of unproductive ones; (2) limited improvements in human capital and the mobility of workers; and (3) a refusal to let go of state control of productive assets that are being decommissioned ahead of time.

Destruction: To be expected, managed, and mitigated

The Republic of Korea’s financial crisis in 1997–98 had paradoxical economic impacts on innovation, restructuring, and growth. Before the crisis, large family-owned industrial conglomerates, chaebols, enjoyed almost unrestrained market power and expansion thanks to excessive debt financing. They were then able to drive rival firms and small industries out of business by adopting predatory tactics, suppressing technological improvements, and persuading government to restrict new entry or open market policies. Therefore, the crisis, although triggered by external events, was largely a product of internal problems related to a weak system of corporate governance, a dysfunctional financial system, and poor labor relations.¹

The crisis triggered major reforms and a comprehensive restructuring of the financial sector and the chaebols. Nearly 500 nonviable financial institutions closed, including two-thirds of
commercial banks, and 15 of the 30 top conglomerates went bankrupt. The collapse of many chaebols made room for venture capital–backed firms, which led to the rapid growth of the information and communication technology (ICT) sector. The ICT boom—spurred by new technologies such as mobile phones, thin film transistor liquid crystal displays, and broadband and wireless internet—kick-started an unusually swift recovery in 1999, with economic growth of 10.3 percent. The reforms and restructuring led to long-term innovation-led growth and contributed to Korea’s transition to high-income status. Overall, then, it took a crisis to lay bare the need for economic reforms and drive the reallocation of economic activity toward more productive, more innovative firms.

The destruction of outdated arrangements—enterprises, jobs, technologies, private contracts, policies, and public institutions—is essential to create value through investment and reallocation, infusion, and innovation. But in many countries these destructive forces are weak during boom times, with crises playing a disproportionate role in driving the process of resource reallocation. In some cases, downturns can serve as times of cleansing in which older, less-productive firms die, making way for newer, more productive firms. As Joseph A. Schumpeter (1942, 113), writing in the aftermath of the Great Depression, argued about crises:

> They are but temporary. They are the means to reconstruct each time the economic system on a more efficient plan. But they inflict losses while they last, drive firms into the bankruptcy court, throw people out of employment, before the ground is clear and the way paved for new achievement of the kind which has created modern civilization and made the greatness of this country.

One of Schumpeter’s key observations is that the process of creating new industries does not go forward without sweeping away the existing order. For example, over the last 30 years in the United States, on average nearly 16 percent of jobs in the private sector have been destroyed each year. Literature on firm exit—stemming from seminal work by Hopenhayn (1992)—reveals that the exit of low-productivity firms contributes substantially to raising aggregate productivity. For example, the Great Depression (1929–39) ushered in a permanent structural change toward mass production and automation in the motor vehicle industry through the exit of smaller, less productive plants and the need for surviving plants to innovate—a process that likely would have taken much longer without the crisis.

Financial crises also spur readjustments of new technologies. For example, the financial crisis of 2007 accelerated skill-biased technological change. More recently, during the COVID-19 crisis economic activity was reallocated toward more productive firms, with reallocation effects higher than before the pandemic.

In the context of energy, the oil price shocks in the 1980s played a major role in accelerating investments in energy efficiency and the development of cleaner energy technologies. One impact of the oil price shocks was an increase in the relative cost of fossil fuels. Another was new policy support for less energy-intensive activities. More recently, the global financial crisis of 2007–09 coincided with a significant increase in the uptake of renewables. Renewable energy use grew rapidly in the United States, China, and Germany in part because of the stimulus programs governments enacted to address the crisis.

This chapter focuses on the process of creative destruction being accelerated today by two crises—the climate crisis and the 2022–23 global energy crisis triggered by the Russian Federation’s invasion of Ukraine. In this context, this chapter explores three questions:

- **How is the energy crisis building momentum for change?** The global energy crisis spurred rapid progress in the development and deployment of low-carbon technologies. It also triggered reshaping of the climate policy landscape in 2022 and 2023. Developed nations such as the United States...
and European Union (EU) member states introduced a wide variety of incentives for producing and deploying low-carbon technologies. In September 2023, the leaders of the Group of Twenty (G20) agreed to triple renewable energy capacity by 2030. Although fossil fuels have shaped the world’s economy and economic geography for over a century, low-carbon technologies favor new trends: urban agglomerations and new spatial clusters; the use of highly skilled workers to develop, modify, adapt, apply, and maintain new technologies; and the entry of younger firms in the private sector. Entrants are instigators of change.

- Who are the antagonists blocking creative destruction in energy markets? Incumbents may resist change. Many incumbents in the energy market have the strongest incentive to maintain the status quo and limit competition from low-carbon energy providers. High-carbon firms tend to lobby against pro-environmental regulations. Power purchase agreements (PPAs) with long time horizons and inflexible terms that create “lock-ins” impede change. These agreements often lock in polluting assets, resulting in significant inertia in energy systems.

- Do middle-income countries run the risk of becoming stranded nations? Yes, they do. But stranding is not driven by anything inherent in the scaling up of low-carbon technologies and the winding down of fossil fuels. It is the result of outdated policies and rules of thumb that limit the growth of value-creating enterprises and the exit of unproductive ones; limited improvements in human capital and mobility of workers; and not relinquishing state control of productive assets now being decommissioned ahead of time. To be sure, workers displaced from the transition will need targeted and time-bound support, but it is not a panacea for avoiding difficult reforms.

The climate and energy crises could trigger restructuring and reallocation

Disruptions are accelerating the diffusion of innovative lower-carbon technologies

Today, two crises—the climate crisis and the global energy crisis—are combining to drive rapid progress in low-carbon technologies (box 6.1). Four technologies—solar panels, wind turbines, lithium-ion batteries, and electrolysers used for green hydrogen—have been shown to follow “learning curves,” as formalized by Wright’s Law: costs fall as a power function of cumulative deployment due to the positive effects of learning by doing or increasing returns to scale in the unit’s production. Since the first commercial use of solar panels in 1958, their costs have fallen by more than three orders of magnitude. This technology is therefore in a category that has been characterized by exponential rather than linear growth, along with computer processing power, Ford’s Model T cars in the 1900s, and DNA sequencing. Figure 6.1 compares the cost trajectories of solar and wind power with other technologies that have undergone rapid cost declines. Critically, this pattern is in sharp contrast to that of fossil fuels, whose prices have stayed broadly constant when adjusted for inflation over the last century.

Diffusion of these technologies, although slow for many decades, recently accelerated. Analysis of 700 million online job postings from 35 predominantly advanced economies reveals that after very modest growth beginning in 2014, the share of jobs related to low-carbon technologies increased by more than 50 percent from 2021 to 2022 (figure 6.2, panel a). Growth was rapid in three-quarters of the countries studied in Asia, Europe, and North America, but stronger in Europe. Driving this growth were electric vehicles (EVs), solar energy, insulation, EV charging, heat pumps, and wind energy. In 2022, openings related to low-carbon technologies grew rapidly in almost every industry,
**Box 6.1  The diffusion of low-carbon technologies as defined and measured in this chapter**

This chapter defines low-carbon technologies in line with the Y02 classification of patents related to “climate change mitigation technologies” adopted by the European Patent Office. Low-carbon technologies are defined as “technologies or applications which can be considered as countering the effects of climate change.” This classification has seven main categories: energy, greenhouse gas capture, buildings, industry (including agriculture), transport, waste management, and wastewater management. Some examples of the technologies included under these categories are:

- **Upstream energy supply technologies**: renewable energy, combustion technologies with the potential to mitigate carbon emissions, energy storage technologies, decentralized energy, efficient electrical power generation technologies, and smart grids.
- **Downstream end-user technologies**: energy-efficient lighting, energy-efficient heating, energy-efficient appliances, heat pumps, electric vehicles, electric vehicle charging, hybrid vehicles; technologies related to processing of metals and minerals and lowering emissions in agriculture (such as solar water pumping and greenhouses); and technologies related to solid waste management, biopackaging, and bioplastics.

Detailed microdata on the adoption of these granular technologies across a wide range of countries, regions, industries, and firms are not yet readily available. In the absence of such data, this chapter relies on a growing literature that takes advantage of real-time data sources and uses text analysis to infer the spread of new technologies through their footprint in the demand for new technology-related tasks or skills in online job postings. Where possible, the chapter also complements these measures with country-level measures of specific technologies and data on energy intensity and carbon intensity at the country and industry levels. Finally, it also incorporates recent granular firm-level data on green technology adoption from the World Bank’s Firm-level Adoption of Technology (FAT) survey.

a. See, for example, Acemoglu et al. (2022); Goldfarb, Taska, and Teodoridis (2023).

...but were particularly pronounced in manufacturing, electricity, heat supply, and construction. Mentions of low-carbon technologies in the shareholder meetings of the world’s largest firms also doubled in 2022 (figure 6.2, panel b).

Countries have responded to high energy prices and energy security stemming from the invasion of Ukraine with energy conservation measures, fuel switching, and accelerated deployment of cleaner energy technologies. The energy intensity of the gross domestic product (GDP) is now 3.5 percent below levels before the pandemic in 2019—a rate of decline considerably higher than the 2 percent decline three years after the onset of the 2008 financial crisis. Emissions from natural gas also fell by 1.6 percent in 2022.
In light of policy changes, the International Energy Agency (IEA) revised its forecast for renewable capacity additions for 2023 and 2024, raising it by 38 percent from its expectations before the war, in December 2021. Countries more dependent on imports of natural gas before the war were more exposed to the price shock and increased hiring for jobs related to low-carbon technologies.

The global energy crisis also spurred a reshaping of the climate policy landscape in 2022 and 2023. The United States saw a historic shift in climate policy with passage of the Inflation Reduction Act (IRA) in late 2022, which introduced a wide variety of incentives for producing and deploying low-carbon technologies. The IRA could have large impacts on power sector investments and electricity prices, lowering retail electricity rates and resulting in negative prices in some wholesale markets. It could also significantly hasten the adoption of renewable energy in the United States, increasing renewable penetration by about 13 percent by 2030, and it could spur adoption in other countries as the higher US investment drives capital prices lower. The European Union also made substantial shifts in climate policy in 2022 and early 2023. These included the REPowerEU strategy to end the bloc’s reliance on Russian fossil fuels through lower fossil fuel use; the Green Deal Industrial Plan, which aims to boost low-carbon manufacturing and industry in Europe; and an increase in the bloc’s binding renewable energy target from 32 percent to 43 percent. China has also pushed its scale-up of renewables and is now on track to meet its 2030 renewable energy generation target five years ahead of time, by 2025.

This acceleration of the clean energy transition is driving the emergence of new spatial clusters and jobs (map 6.1). Evidence extending the work of Bastos et al. (2023) to analyze 1 billion online job postings across 86 countries over the last decade reveals that in 2022 alone 3.3 million new job openings were related to low-carbon technologies—just under 2 percent of jobs posted online in 2022. In absolute terms, new openings have been highest in the United States, Europe, and China (figure 6.3, panel a). The new spatial clusters emerging in terms of low-carbon technology jobs are Catalonia and Madrid in Spain, home to major solar industries; Guangzhou, Beijing, Shanghai, Suzhou, and Shenzhen in China, home to China’s largest EV and clean energy manufacturing hubs; Rhône-Alpes and Île-de-France (the Paris region), home to France’s largest clean energy clusters; and California, the clean energy pioneer in the United States.
Figure 6.2 The diffusion of low-carbon technologies is rapidly accelerating

a. Share of jobs related to low-carbon technologies in 35 countries

Source: Bastos et al. 2023.
Note: Panel a displays the share of online job postings in 35 countries that mention low-carbon technologies (LCTs) as defined by the Y02 classification of patents adopted by the European Patent Office. See Classification of Patents: Climate Change Mitigation Technologies (dashboard), European Patent Office, Munich, https://www.epo.org/en/news-events/in-focus/classification/climate-change. Panel b displays the share of shareholder meeting transcripts from publicly listed firms that mention these technologies.
Innovation is also driving the creation of start-ups and capital flows (figure 6.3, panels b and c). In 2021, about 1,500 new clean energy start-ups were listed on Crunchbase, drawing on IEA data covering 40 countries, and about one-fourth of the start-ups were in middle-income countries. Of these, more than half were in China and one-third in India, although growth has been most rapid in India, with a tripling of start-up creation over the last decade. Globally, total clean energy financing passed US$1 trillion for the first time in 2022.

These shifts are triggering a reallocation of economic activity across countries, regions, industries, occupations, and firms. Just as fossil fuels have shaped the geopolitical map over the last two centuries, the clean energy transformation will alter the economic geography of manufacturing and global trade and the landscape of international trade policy. Access to fossil fuels has fundamentally shaped the world’s economic geography for nearly a century, with heavy industry close to coal beds and petrochemical plants near petroleum fields. The trade in fossil fuels has been a driving component of global trade and geopolitics for decades, with fuel exports accounting for 11.7 percent of total merchandise exports globally in 2019. However, this picture is starting to change—and more rapidly than had been imagined as the following shifts occur:

- **Shifts between countries and between regions within countries.** Low-carbon technologies and fossil fuels tend to be produced in different countries, and low-carbon technologies favor countries where manufacturing capabilities are already in place. Even within some countries, a spatial reallocation of production and jobs is under way. In China, for example, although fossil fuel jobs have been highly concentrated in the inland provinces highly reliant on coal mining, low-carbon technology jobs are growing in the manufacturing hubs on the east coast. Spatial disparities...

Source: WDR 2024 team analysis extending Bastos et al. (2023) to 86 countries.
will be altered and potentially intensified because the geographical determinants of low-carbon energy sources differ from those of fossil fuel–based economies, and technological innovation is likely to occur most rapidly in centers of research and agglomeration.

- Shifts between industries. Because low-carbon technologies are generally being mass manufactured, the low-carbon transition is

**Figure 6.3** Low-carbon innovation is driving the emergence of new spatial clusters, start-ups, and financing

*Figure continues next page*
driving a reallocation of economic activity across industries from extractives to manufacturing and ancillary services. Jobs are most likely to be in the manufacturing, construction, and sales industries, but low-carbon technology jobs are growing rapidly in the high-skilled white-collar industries able to develop, modify, adapt, apply, and maintain new technologies.

- **Shifts between occupations.** The manufacture of low-carbon technologies is more skill-intensive than that for the high-carbon alternatives, resulting in a reallocation of economic activity between occupations and skill types. Jobs are also more likely to be filled by younger, college-educated white-collar workers, whereas high-carbon jobs are more likely to be occupied by older blue-collar workers.

- **Shifts between firms.** Low-carbon technologies are more likely to be adopted by new entrants, exporters, private firms, and firms that use research and development (R&D) more intensively. Low-carbon technology job postings are also highly concentrated in multinational firms and their supply chains. By contrast, high-carbon jobs are more likely to be in older firms and state-owned enterprises.

The energy transition is also shaping a new global trade and industrial policy landscape, which is disrupting the last three decades of trade policy coordination. After decades of such coordination, which yielded significant growth dividends, the world’s major economies now have divergent climate and trade policy approaches. The IRA in the United States, the Net-Zero Industry Act in the...
European Union, and the growing number of similar policies globally increasingly include local content requirements and other reshoring efforts to support local industries. Although the previous waves of middle-income countries transitioned to high-income status against the backdrop of trade policy coordination, today’s middle-income countries will need to navigate a more complex landscape in which key trade rules have not yet been agreed on.

**Productive incumbents and new entrants are driving the diffusion of cleaner technologies**

**Diffusion of upstream clean energy technologies in middle-income countries**

As the costs of low-carbon technologies decline, growth using cleaner energy sources and energy efficiency technologies is for the first time a possibility in today’s middle-income countries. Currently, these countries’ rate of adoption of key low-carbon energy technologies is, in fact, growing more rapidly than that of high-income countries, but levels of adoption remain significantly lower. In levels, middle-income countries are still lagging on the deployment of three key low-carbon energy technologies—solar energy, wind energy, and EVs—compared with high-income countries (figure 6.4). In 2021, the average share of electricity generated from wind and solar power in middle-income countries was about half of that in high-income countries (respectively, 4.1 percent versus 9.5 percent for wind and 2.7 percent versus 5.3 percent for solar). The uptake of EVs in middle-income countries also remains about half as much as that in high-income countries (measured as number of EVs per million inhabitants). But today in middle-income countries, the average growth rates of key clean energy technologies have overtaken those of high-income countries.

Research for this Report found that after controlling for income, countries with higher rates of deployment of solar and wind energy have more favorable renewable energy policies and a more favorable regulatory environment (captured by a higher value on the Regulatory Indicators for Sustainable Energy, or RISE, Index); higher carbon pricing (as measured using the net effective carbon rate of the Organisation for Economic Co-operation and Development, OECD); and lower fossil fuel reserves. Countries with higher solar potential (measured using the World Bank PVOUT Index) also have higher solar deployment rates.

**Diffusion of downstream low-carbon energy technologies in middle-income countries**

Adoption of low-carbon technologies by firms and households in middle-income countries remains far more limited than in high-income countries. In 2021, the emissions intensity of energy consumption in middle-income countries was 49 percent higher than that in high-income countries, while energy consumption per unit of GDP was 2.5 times higher. Measures of downstream technology adoption across a wide range of countries are not readily available, but emissions intensity within narrowly defined industries can serve as a proxy for technology adoption. On average, of 63 middle-income countries, two-thirds (41) have higher carbon intensity across industries—in terms of direct emissions that are owned or controlled by a company (Scope 1 emissions)—than the high-income country average, while about one-third (22) have lower carbon intensity.

Firms in middle-income countries vary widely in their adoption of low-carbon technologies, even within narrowly defined industries. Firms’ overall management practices and technological sophistication, skill intensity, and international orientation are correlated with their adoption of low-carbon technologies and energy-saving practices. In Argentina, for example, firms’ capacity to adopt more advanced low-carbon technologies has been shown to be correlated with their share of skilled workers. Exporters usually have lower emissions intensity relative to nonexporters. Foreign-owned firms generally have better environmental performance, as has been shown for Côte d’Ivoire, Mexico, and República Bolivariana de Venezuela.
Figure 6.4 The rate of adoption of clean energy technologies is growing more rapidly in middle-income countries than in high-income countries, but the level of adoption is lower.


Note: Comparing middle- and high-income countries, panels a and b display the shares and growth rates of wind energy and solar energy, respectively, in electricity generation, and panel c the number of battery electric vehicles per million inhabitants. HICs = high-income countries; MICs = middle-income countries.
Production of low-carbon technologies is concentrated in a few middle-income countries

Substantial manufacturing or innovation in low-carbon energy technologies is occurring in only a handful of middle-income countries with competitive manufacturing sectors. In terms of production, only one middle-income country—China—is competitive in all three key low-carbon technologies in terms of breadth (across the full value chain from raw materials, processed materials, subcomponents, to the end product of the supply chain) and depth (a high average market share) (figure 6.5). By contrast, other middle-income countries have either depth or breadth and typically only in one product. For example, countries with well-established manufacturing sectors such as India and Türkiye show a high breadth of export competitiveness in the production of wind turbines. Middle-income countries with large mineral deposits (such as Brazil and Russia) have high depth in the export of critical minerals for EVs.

Patenting for low-carbon technologies is also highly concentrated in just a handful of countries, with China in the lead, according to data from the International Renewable Energy Agency (IRENA). Over the last two decades, China has filed the largest number of such patents, followed by the United States, Japan, Korea, and Germany. Such patenting has been very limited in other middle-income countries, with the second-highest middle-income country, Brazil, filing only 2 percent as many patents as China over the last 20 years.

Costa Rica and China are global front-runners in terms of job creation related to low-carbon technologies. In 2022, Costa Rica accounted for about 8 percent of all online job postings related to low-carbon technologies and China for 5 percent—just below the global maximum of 8 percent for Denmark (figure 6.6). Five other countries have exceeded the high-income country average: Brazil, Georgia, Senegal, South Africa, and the Dominican Republic. In terms of emerging spatial clusters in 2022, 28 of the 30 cities with the largest number of new online job postings related to low-carbon technologies were in China. Only Bangalore and São Paulo were the other middle-income country cities in the top 30. These sectors and jobs are clustered both within and across countries. For middle-income countries to successfully seize the opportunities of the green economy, the right policy mix, financing, regulatory environment, and infrastructure need to be in place.

Incumbent state-owned enterprises, legacy policies, and path dependence—all block creative destruction

Incumbents in high-carbon industries erect barriers to entry of low-carbon technologies

The low-carbon transition will create winners and losers—and the losses are more concentrated than the gains, resulting in a political economy prone to inertia. Although 80 percent of the global population lives in a country that imports fossil fuel, fossil fuel revenues are highly concentrated. In 18 countries, fuel exports account for more than 50 percent of total merchandise exports; seven countries generate 90 percent or more of their export earnings from fossil fuel exports. Fossil fuel resources are more concentrated than renewable resources. Within countries, the losses to fossil fuel companies are also highly concentrated. Studies have shown that the concentrated nature of the losses from the low-carbon transition, compared with the distributed nature of the gains, makes the clean energy transition particularly prone to obstructionism by entrenched interests. Moreover, the incentives for lobbying are asymmetric. Incumbents, as a tightly defined group of actors, have a greater incentive to mobilize, and they face lower coordination costs. Smaller firms and individuals, by contrast, are more dispersed and face higher coordination costs. This results in political inertia, as has been evident from the persistent difficulty in phasing out fossil fuel subsidies globally.

Incentives, both explicit and implicit, that favor higher-carbon industries and production processes over lower-carbon ones are higher in
Figure 6.5  Clean energy technology value chains are still dominated by high-income countries and China

Source: Rosenow and Mealy 2024.

Note: Each panel measures countries’ competitive dominance across traded products in a given supply chain in terms of two key measures. Breadth represents a country’s export competitiveness across the raw materials, processed materials, subcomponents, and end products of the supply chain. Depth measures a country’s export competitiveness in terms of its average market share across supply chain products. The sample includes countries whose total number of value chain products with a revealed comparative advantage exceeds 1.
middle-income countries than in high-income countries. Middle-income countries, particularly energy exporters, have significantly lower carbon prices. Consumer fossil fuel subsidies in middle-income countries totaled over US$800 billion in 2022, of a global total of US$900 billion. Estimates of explicit consumer and producer fossil fuel subsidies in 2022 from the International Monetary Fund (IMF) also show that middle-income countries account for 65 percent of the total. Fossil fuel subsidies have a sizable fiscal cost and exacerbate air pollution, contributing directly to premature deaths.

Middle-income countries also score lower on the RISE Index, particularly on the components of providing incentives and regulatory support for renewable energy and planning for the expansion of renewable energy. In addition, middle-income countries generally provide highly polluting industries with higher corporate tax incentives. Such incentives are particularly high in the Middle East and North Africa, as measured by the World Bank’s Global Corporate Income Tax Incentives Database.

Incentives that support incumbent firms and energy sources, as well as major barriers to entry in power markets, also severely limit private innovation in middle-income countries. Over the last 35 years, many countries have introduced competitive markets in parts of the
electricity system to reduce costs and improve reliability. In many middle-income countries, however, power markets remain a monopoly: a state-owned entity operating under a vertically integrated utility. This state-owned entity carries out all functions in the electricity sector, including generation, transmission, distribution, and retail supply. Such an arrangement has generally hindered competition, and in many countries it has resulted in the inefficient use of resources. In addition, in many middle-income countries the first generators dispatched are often not those with the lower marginal prices (that is, power dispatch often does not follow merit order), serving as a barrier to the penetration of renewables with rapidly declining costs. Generally, the shift to more competitive market structures has lowered costs and enabled more innovation and penetration of renewables.\(^{44}\) In addition, the fact that energy supply technologies tend to be big, complex, expensive, and slow to develop and that new entrants must sell into entrenched markets dominated by incumbents severely limits incentives for private innovation.\(^{45}\)

Power purchase agreements with long time horizons and inflexible terms that create “lock-ins” also impede change in energy systems. PPAs are widely used to procure power by establishing a contract between a seller of power and a buyer, often a utility. If well-structured, PPAs offer certainty for buyers as well as sellers, protecting them from volatility in energy prices by locking in the price buyers pay for electricity for decades to come. This kind of long-term certainty offers sellers a steady source of revenue and improves the chances of securing low-cost financing. However, by their very nature, when used to generate power in emissions-intensive ways, such as coal-fired power, these agreements lock in polluting assets, often for decades at a time, resulting in significant inertia in energy systems. Against the backdrop of the rapidly declining costs of clean energy technologies, inflexible PPAs with “take or pay” clauses are also resulting in economically—and environmentally—suboptimal energy systems choices.

**High-carbon inertia curtails innovation, slows planning, and locks in behavior**

A wide body of literature has now demonstrated that patents for low-carbon technologies “build on the shoulders” of earlier developments. Thus patenting is path-dependent, meaning that innovations are more likely to follow existing innovations, which can impede innovations in new technologies at an early stage.\(^{46}\) This literature has generally pointed out the need for initial subsidies to jump-start the innovation process and correct for the positive externalities that result in under-investment in R&D on low-carbon technologies, as well as the need for carbon pricing to correct for the negative externality of carbon emissions.

Inertia in keeping up with, and planning for, exponential progress in low-carbon technologies has also slowed the changes needed in energy systems. The rapid technical progress in a range of low-carbon technologies described earlier has generally outpaced the expectations of leading agencies and energy-economy models. For example, for many years the IEA forecasted linear growth in the supplies of solar under its business-as-usual scenarios, even as supplies continued to rise exponentially. Not only the IEA but historically most energy-economy models have underestimated the deployment rates for renewable energy technologies and overestimated their costs, as outlined by Grubb et al. (2021) and Way et al. (2022). The reason is that most national energy-economy models and large-scale global integrated assessment models label energy technology cost developments as exogenous. However, energy systems investments are often large and indivisible (lumpy)—that is, they are not easily divided or sold in parts—and they are made over long time horizons, often spanning multiple decades. Thus such downside forecast inaccuracy has deterred investments in low-carbon technologies and resulted in inertia in planning.

Studies have found that peer effects and social learning are important factors in decision-making related to climate change.\(^{47}\) Preferences
on technology adoption or social change are not cast in stone, but they change in response to decisions made by peers. The result is inertia in adoption initially and then rapid adoption later once a critical mass of peers adopts the technology. Similarly, the production of low-carbon technologies is subject to external economies of scale, which lead to lower production and operating costs for all companies in the industry. These, in turn, can increase profitability and competitiveness. However, these cost reductions do not occur until a sufficient number of industry players or scale is reached—meaning costs are higher for first movers.

**Legacy transmission networks built to serve large fossil fuel plants slow diffusion of low-carbon energy**

Because of the market structure of electricity generation and transmission, the deployment of clean energy technologies is more challenging and more complex than that for other technologies. Variable renewable energy sources provide energy only at certain times of the day or in certain seasons. Such intermittency poses challenges for their integration into power systems, particularly before electricity storage is fully developed. Integration also requires new approaches to demand-side management. The scale-up of the electrification of transport and buildings, which will increase the demand for electricity, also depends on the reliability of the power system. Scale-up requires accurate forecasting and forward planning. All these aspects of the energy transition create barriers and necessitate strong systemwide coordination and institutional capacity.

Legacy transmission networks built to serve large fossil fuel plants, along with outdated regulations, also create barriers to entry in middle-income countries. Typically, legacy networks have been designed for traditional energy sources for which generation can be located close to the source of demand (map 6.2). However, the renewable generation capacity for wind and solar must be built at the decentralized sites where these natural resources are found. Thus networks to transmit power are critical for the scale-up of power transmission lines

**Map 6.2 Limited or outdated electricity transmission networks serve as barriers to the entry of renewable sources**

Source: Arkolakis and Walsh 2023.

Note: The map displays electricity transmission networks in 2023. The two insets focus on areas of particular interest due to the geographic disparities in coverage of transmission networks in these regions.
variable renewable energy. Because electricity transmission has elements of a public good that often result in its underprovision, transmission networks in many countries are not keeping pace with the ambitions of governments or the plans of firms. This inertia in transmission networks serves as a major barrier to the energy transition in many middle-income countries. In addition, outdated regulations related to the siting of renewables or permitting for rooftop solar also create inertia, hindering diffusion.

**Destruction without creation: The risks of becoming stranded nations**

**Preservation worsens obsolescence; dynamic firms and mobile people are needed**

The low-carbon transition poses a major risk of accelerating the obsolescence of capital, skills, and industries. It is a form of directed technical change away from carbon-intensive production processes. In perfectly competitive markets, the associated reallocation of labor and capital would have minimal transition costs because workers and capital would smoothly and quickly adjust by switching jobs, moving to areas with growing demand, and supporting expansion of greener firms. In practice, however, search complications, costs to acquire human capital, or ties to particular geographic areas may give rise to significant transition costs. Higher social, occupational, and geographic mobility facilitates the rapid movement of people out of declining industries and into expanding ones, which in many countries requires a move to another geographic location. Likewise, dynamic enterprises and low barriers to entry can lower transition costs within countries.

Meanwhile, fossil fuel resources that cannot be burned and fossil fuel infrastructure no longer used risk becoming “stranded assets.” Stocks of unburnable carbon (such as coal reserves) could become stranded resources if their future value becomes lower than their current expected value. This disconnect could lead to overly high investment in and maintenance of infrastructure that supports, and is supported by, the burning of fossil fuels, which later becomes stranded capital. In middle-income countries, coal-fired power plants are the most exposed to the risk of becoming stranded and may have to be retired 10–30 years earlier than they did in the past. Several expectations influence whether assets become stranded. They include expectations about the implementation of climate policies, about technological progress, and about legal action against high emitters. Stranding could occur based on today’s projections of fossil fuel production solely due to the current rate of technological change, which is faster than expected. The extent of stranding will depend on how policy choices today shape expectations about the future, along with efforts today to facilitate the reallocation of resources from sunsetting industries to growing ones. Efforts by countries, industries, or firms to preserve sunsetting industries longer than is economically viable rather than reallocating resources to expanding ones risk increasing transition risks and obsolescence.

Overvalued assets also pose the risk of a carbon bubble in financial markets. The scale of the fossil fuel industry is large enough to potentially trigger broader financial crises. The exposure to correlated risks within and across portfolios, with many potentially stranded assets at risk of being devalued simultaneously, alongside the underexposure to assets in low-carbon technologies with potentially higher returns, also pose systemic risks that could affect the financial system as a whole. If undermanaged, this instability could result in policy swinging away from transition to protecting the financial system more broadly. Ensuring an orderly transition and clarity in direction is necessary to limit the potential of this crisis.

These financial risks are heightened in countries with more vulnerable financial systems. Countries more dependent on resource revenues would be particularly exposed, limiting their
capacity to respond to the shock. The degree to which sectors are linked within the economy is also associated with the exposure of the financial system, with greater links acting to potentially multiply the effects of an initial shock, creating ripples through the wider economy, and exposing financial systems to further pressures.  

Countries with rich reserves of critical green minerals will also need to ensure they avoid repeating the mistakes of past natural resource booms and contracting “Dutch disease” or a green “resource curse.” The transition is also expected to significantly increase the demand for minerals that are critical inputs in low-carbon technologies such as lithium, cobalt, copper, and rare essential earths. This demand could present countries with large reserves of such minerals, such as Chile, the Democratic Republic of Congo, and Namibia, with a potential economic opportunity. However, critical minerals are often located in regions characterized by poor labor and environmental standards and considerable political fragility and corruption. Thus these increases in demand could contribute to a proliferation of problematic mining practices and conflict. The failure of many hydrocarbon exporters to use export revenue to diversify their economies, which now renders them vulnerable to the transition, should serve as a cautionary tale to mineral exporters. To avoid another resource curse, revenue from a higher demand for minerals could be used to support investment in education, infrastructure, and the development of economic sectors that are higher in value added.

Infusion of global technologies and diversification will be crucial for middle-income countries

Andres et al. (2023) have compiled a list of traded “brown products,” whose use is likely to decline if the world is to mitigate climate change. They then explore which countries are most at risk of seeing their productive capabilities “stranded.” They find that, on average, brown products tend to be less complex than green products. Although countries that export technologically sophisticated brown products, such as internal combustion engine vehicles, could find it relatively easy to transition, those with exports highly concentrated in a few low-complexity brown products (such as commodities) have fewer opportunities for diversification. Of the top 10 countries facing the greatest risk of such “brown lock-ins,” as measured by an index constructed by these authors, six are middle-income countries. Panel a of figure 6.7 displays the 10 middle-income countries most exposed: Iraq, Libya, Angola, Equatorial Guinea, Azerbaijan, Nigeria, Algeria, Turkmenistan, Timor-Leste, and Gabon.

Middle-income countries with a high degree of specialization of physical, institutional, and human capital in declining sectors that cannot be easily transitioned to new opportunities face the highest risks. The production of some carbon-intensive products is similar to the production of green ones—for example, there is a high degree of overlap in the manufacture of internal combustion engine (ICE) vehicles and electric vehicles. In general, the risk of brown lock-ins is negatively and significantly associated with the ease of transitioning to green or overall non-brown products. This risk is displayed in panel b of figure 6.7, which shows the correlation between the Brown Lock-in Index and the Transition Outlook, also constructed by Andres et al. (2023) to measure a country’s ease of transitioning from brown to green products.

Workers with obsolete occupations and skills will need support to avoid stranding

The energy transition will lower the demand for workers who extract and refine coal, natural gas, and oil. Employment in these activities tends to be disproportionately occupied by workers without a college education. Workers at legacy suppliers of electricity, such as the coal-fired power plants that are now being retired, will also be affected. At risk as well are those employed in energy-intensive manufacturing industries such as basic chemicals, nonmetallic minerals, and primary metals, and in industries like ICE
Figure 6.7  Most of the countries currently “locked in” to declining brown industries are middle-income countries

a. Brown Lock-in Index for top 10 highest-risk middle-income countries

b. Brown Lock-in Index versus Transition Outlook for middle-income countries

Source: WDR 2024 team analysis based on Andres et al. (2023).
Note: Panel a displays the Brown Lock-in Index for the 10 middle-income countries with the highest index values. See BLI (Brown Lock-in Index) (dashboard), Green Transition Navigator, London School of Economics and Political Science, London, https://green-transition-navigator.org/. Panel b displays the correlation between the Brown Lock-in Index and the Transition Outlook for all middle-income countries. The Brown Lock-in Index measures the risk that a country will be locked in to carbon-intensive industries. A higher index value indicates greater risk. The Transition Outlook measures a country’s ease of transitioning from brown to green products. A higher value indicates greater ease of transitioning. See Green Transition Navigator (dashboard), London School of Economics and Political Science, London, https://green-transition-navigator.org/. For country abbreviations, see International Organization for Standardization (ISO), https://www.iso.org/obp/ui/#search.
vehicle manufacturing. Park et al. (2023) explore fossil fuel jobs in China and how their economic geography compares with that of low-carbon technology jobs. In China, fossil fuel jobs are concentrated around Shanxi and in the north of China, whereas low-carbon technology jobs are concentrated in the cities on the east coast and particularly in the south, demonstrating the challenge for workers to transition (map 6.3).

Recent research on job transitions has demonstrated the challenge of transitioning workers out of high-carbon jobs.59 Using microdata representing more than 130 million online work profiles, Curtis, O’Kane, and Park (2023) explore transitions away from carbon-intensive production technologies. They find that in 2021 only 0.7 percent of workers who transitioned out of a carbon-intensive job found work in a green job. Conversely, the vast majority of workers obtaining green jobs do not come from carbon-intensive industries, but from a wide range of other industries and occupations (such as sales manager, software developer, and

Map 6.3 Low-carbon technology jobs in China are growing in manufacturing hubs on the southeast coast, whereas fossil fuel jobs are close to coal mines

a. Share of online job postings related to low-carbon technologies, 2019

b. Share of fossil fuel jobs, 2019

Share of online job postings related to low-carbon technologies (%)

0 7.90

Share of fossil fuel jobs (%)

0 3.75


Note: In panel b, the share of fossil fuel jobs in 2019 is based on data from China Statistical Database, National Bureau of Statistics of China, Beijing, https://www.stats.gov.cn/english/.
marketing manager). On average, 20 percent of transitions out of carbon-intensive jobs are into other carbon-intensive jobs, whereas transitions into manufacturing are the most common, accounting for more than 25 percent of all transitions out of carbon-intensive jobs. Although in some US states, such as California, the rates of transition from dirty to green jobs are relatively high, in others, such as West Virginia, the rates of green transitions are low even though these states have a high density of existing carbon-intensive jobs.

In conclusion, middle-income countries will need to amplify the forces of creation, weaken the forces of preservation, and manage the forces of destruction to advance technological progress. The chapters that follow focus on policies that these countries can implement to help them achieve these goals.

Notes

3. Crises do not always benefit reallocation and have also been shown to have “sullying” effects, leading to the exit of otherwise productive firms or high-quality jobs, with long-lasting scarring effects (Haltiwanger et al. 2021).
14. Climate and low-carbon competitiveness are also now covered in a wide number of new US policies, including the CHIPS and Science Act of 2022 and Infrastructure Investment and Jobs Act of 2021.
17. Jones (2023); Xue (2024).
18. This is similar to the IEA’s finding that clean energy jobs now account for about 2 percent of all jobs globally (IEA and IFC 2023).
19. Several smaller cities and those in middle-income countries are experiencing sizable job creation from low-carbon technologies. For example, 5 percent of online job postings in 2022 in Rio de Janeiro were by low-carbon technologies, while in small provincial cities in China, such as Ningde, home to one of China’s largest battery manufacturing clusters, 8 percent of all online job postings were related to low-carbon technologies.
20. Crunchbase is a US-based company that provides information about start-ups using data sourced from investors and community contributors, such as start-ups themselves. Although it includes companies in more than 200 countries, it may underrepresent start-ups in emerging markets that are funded only domestically and do not have a global presence. Thus they do not choose to list themselves and are not disclosed by investors. For more information, see Dalle, den Besten, and Menon (2017).
22. Park et al. (2023).
24. See, for example, Saussay et al. (2023).
27. Bastos et al. (2023).
28. “Net zero” refers to the balance between the amount of greenhouse gas produced and the amount removed from the atmosphere. It can be achieved through a combination of emissions reduction and removal.
29. In the five years before the COVID-19 pandemic (2015–19), the growth rates in the share of electricity generated from solar and wind energy were higher in middle-income countries than in high-income countries. The average growth rate in middle-income countries was about 13 percent for wind and 44 percent for solar, compared with 11 percent and 16 percent, respectively, for high-income countries. The average growth rate of EVs per capita in middle-income countries over the five years preceding the COVID-19 pandemic was in line with that of high-income countries, but in 2021 it was more than twice as high in middle-income countries than in high-income countries.
32. This emissions intensity could also reflect the composition of products produced within these industries, so it is an imperfect proxy.
33. Albornoz et al. (2009).
34. See, for example, Holladay (2016); Richter and Schiersch (2017).
38. See, for example, Kwon, Lowry, and Verardo (2023); Srivastav and Rafaty 2022; Stokes (2020).
40. Agnolucci et al. (2023); Agnolucci, Gencer, and Heine (2024).
References


