

9

Capitalizing on Crises



Key messages

- The climate and energy crises are providing an opportunity for middle-income countries to infuse global technologies domestically and become producers of green intermediates for global markets. By doing so, they will help reduce the cost of decarbonization worldwide.
- To accelerate the diffusion of technologies, middle-income countries will need to improve their investment climate so that contestable markets will give domestic incumbents an incentive to upgrade their technology. Alongside these efforts, high-income countries will need to reduce the scope of industrial policies that protect domestic incumbents and prevent middle-income countries from accessing technologies and markets.
- Middle-income countries should assess viable investment opportunities for renewable energy technologies and the cost of capital.
- To reduce emissions intensity, middle-income countries will need to create a market for renewable technologies, take into account their own natural resource endowment, and optimize the choice of technologies.

Using crises to destroy outdated arrangements

To ensure it has the appropriate balance of investment, infusion, and innovation, a country must pursue the destruction of outdated arrangements—enterprises, jobs, technologies, private contracts, policies, and public institutions. In many countries, however, the forces of destruction are weak during boom times.

Because middle-income countries will need to recalibrate their mix of investment, infusion, and innovation, crises are, in a sense, a necessary evil because they weaken the forces of preservation that maintain the status quo. Today, the climate crisis is one of the most pressing challenges facing not only the global economy, but also humanity at large.

To effectively tackle the climate crisis, middle-income countries will need to direct

investment, infusion, and innovation toward reducing greenhouse gas emissions, bringing them to net zero.¹ In support of climate action, more than 140 countries have set a net zero target, covering about 88 percent of global emissions.² This chapter explores what it will take for middle-income countries to capitalize on the climate crisis to overcome structural stasis and advance decarbonization both locally and globally.

Low-carbon sources of energy such as wind and solar are technologically sophisticated and benefit from increasing returns to scale in production and deployment. Thus middle-income countries have an opportunity to infuse global technologies domestically and become producers of green intermediates for global markets, thereby reducing the cost of decarbonization worldwide. To accelerate diffusion of such technologies, these countries will need to improve their investment climate so that contestable markets give domestic incumbents the incentive to upgrade. Alongside these efforts, major Group of Twenty (G20) and Organisation for Economic Co-operation and Development (OECD) countries will need to reduce the scope of industrial policies that protect domestic incumbents and prevent middle-income countries from accessing technologies and markets. Indeed, the globalization of protectionist industrial policy poses the risk of slowing down the globalization of decarbonization. Global coordination of the use of *green* industrial policy will ensure that industrial policy does not hinder the climate transition of or penalize low- and middle-income countries.

Middle-income countries could also diffuse low-carbon technologies at home by building green to meet their significant demand for infrastructure systems. For example, one-third of projected urban growth will occur in large middle-income countries such as China, India, and Nigeria by 2050, and three-quarters of the world's urban infrastructure that will exist in 30 years has not yet been built.³ By building green, investments in middle-income countries can help reduce emissions at a lower cost than in high-income countries that would have

to retrofit green.⁴ But there is a challenge—despite the falling cost of green infrastructure and potential for high economic returns in middle-income countries, capital does not flow from high-income to low- and middle-income countries to undertake these infrastructure investments.

Finally, where capital costs are high, low-carbon energy may be unaffordable. Moreover, the intermittency of variable renewables and high storage costs pose risks to energy security if not managed well. Middle-income countries will need flexibility in choosing emissions-reducing strategies.

Globalizing decarbonization

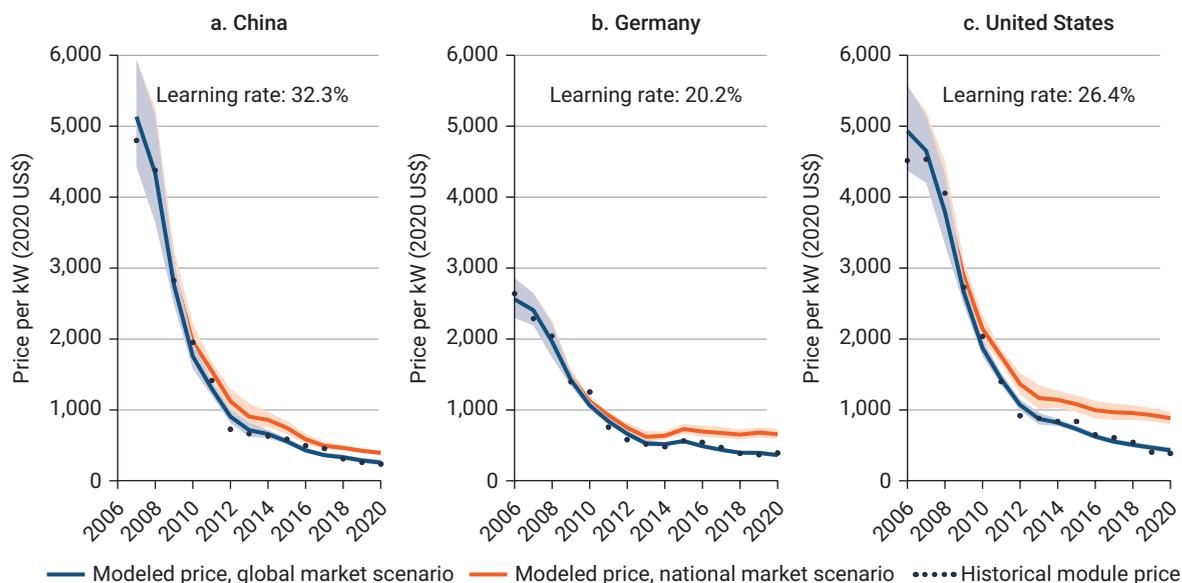
Upgrade and compete through global low-carbon value chains

Izmir, Türkiye, a vibrant city of nearly 4.5 million people on the Aegean Sea, has been historically significant for more than 5,000 years. Its settlement goes back to the third millennium BCE. Now it is poised to become a significant producer and exporter of intermediate products in Europe's wind energy value chain. Thirteen factories produce towers, blades, gearboxes, and generators, and 80 percent of the production from this value chain is exported—primarily to Europe. Türkiye is increasing its competence and competitiveness in the wind turbine value chains, as well as developing capabilities in a broader range of technically sophisticated green products (so-called green complex products).

As this example suggests, middle-income countries could join global low-carbon energy value chains by supplying intermediate products, thereby reducing the cost of green energy faster than would be possible through national efforts alone. Moreover, through their participation, middle-income countries can infuse global knowledge into their own industries and subsequently increase their “economic complexity.”⁵

An example is the solar photovoltaic (PV) industry (figure 9.1). From 2008 to 2020, the globalized market for PV modules saved PV installers in China US\$36 billion, those in the United States

Figure 9.1 Use of globalized value chains for solar panels results in faster learning and lower global prices



Source: Helveston, He, and Davidson 2022.

Note: The figure displays the estimated module prices for global versus national market scenarios for 2006–20. The dots represent historical module prices, and the two solid lines reflect the modeled prices using global (blue) versus national (orange) market scenarios. In each modeled curve, the learning rates are held constant by country, and the prices of silicon follow historical global trends. The global market scenario uses global capacities, and the national market scenario uses a weighted sum of national and global capacities that reflects a gradual transition to fully domestically supplied markets over a 10-year period. The shaded uncertainty bands represent 95 percent confidence intervals from the estimated learning models, which were computed using a simulation. kW = kilowatt.

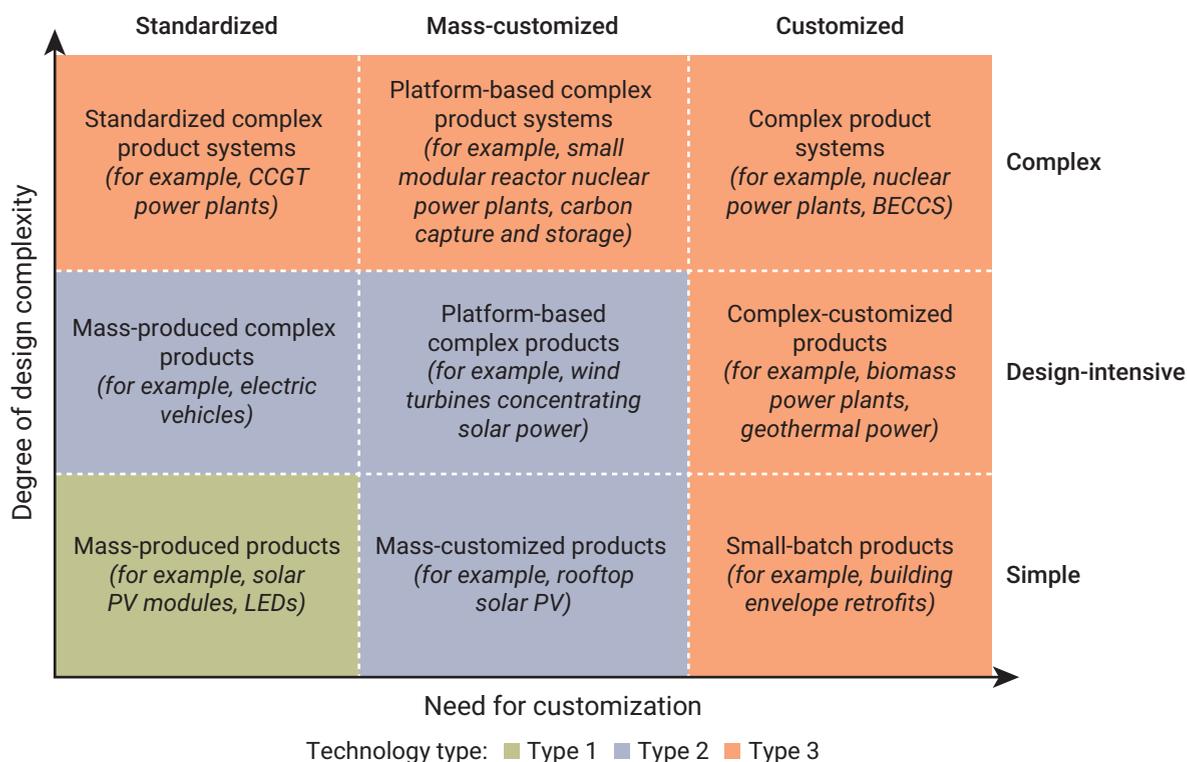
US\$24 billion, and those in Germany US\$7 billion when compared with the cost of having domestic manufacturers supply an increasing share of installed capacity over a 10-year period.⁶ China produced about 80 percent of solar PV cells and modules globally in 2023. From 2020 to 2023, China’s PV module prices plummeted to US\$0.15 per watt, or to more than 60 percent lower than the US price of US\$0.40 cents per watt. It succeeded by *infusing* global technologies through start-ups backed by foreign finance, international collaboration among researchers, and licensing and the mass production of technologies developed in foreign labs.⁷

As highlighted in chapter 6, four technologies—solar panels, wind turbines, lithium-ion batteries, and electrolyzers used for green hydrogen—follow

Wright’s Law (learning curves): 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 production of technologies.⁸ By contrast, more complex technologies and those that require a greater level of customization to local environments (type 3 technologies in figure 9.2) tend to “learn” more slowly. Small “granular” technologies (type 1 and type 2 technologies in figure 9.2) can diffuse much more rapidly. Middle-income countries can create value by becoming suppliers in global value chains of type 1 and type 2 technologies.

To date, however, participation by most middle-income countries in value chains producing low-carbon energy technologies has been limited. These value chains are highly concentrated,

Figure 9.2 Middle-income countries can support global decarbonization by becoming global suppliers of “granular” (type 1 and type 2) energy technologies



Source: Malhotra and Schmidt 2020.

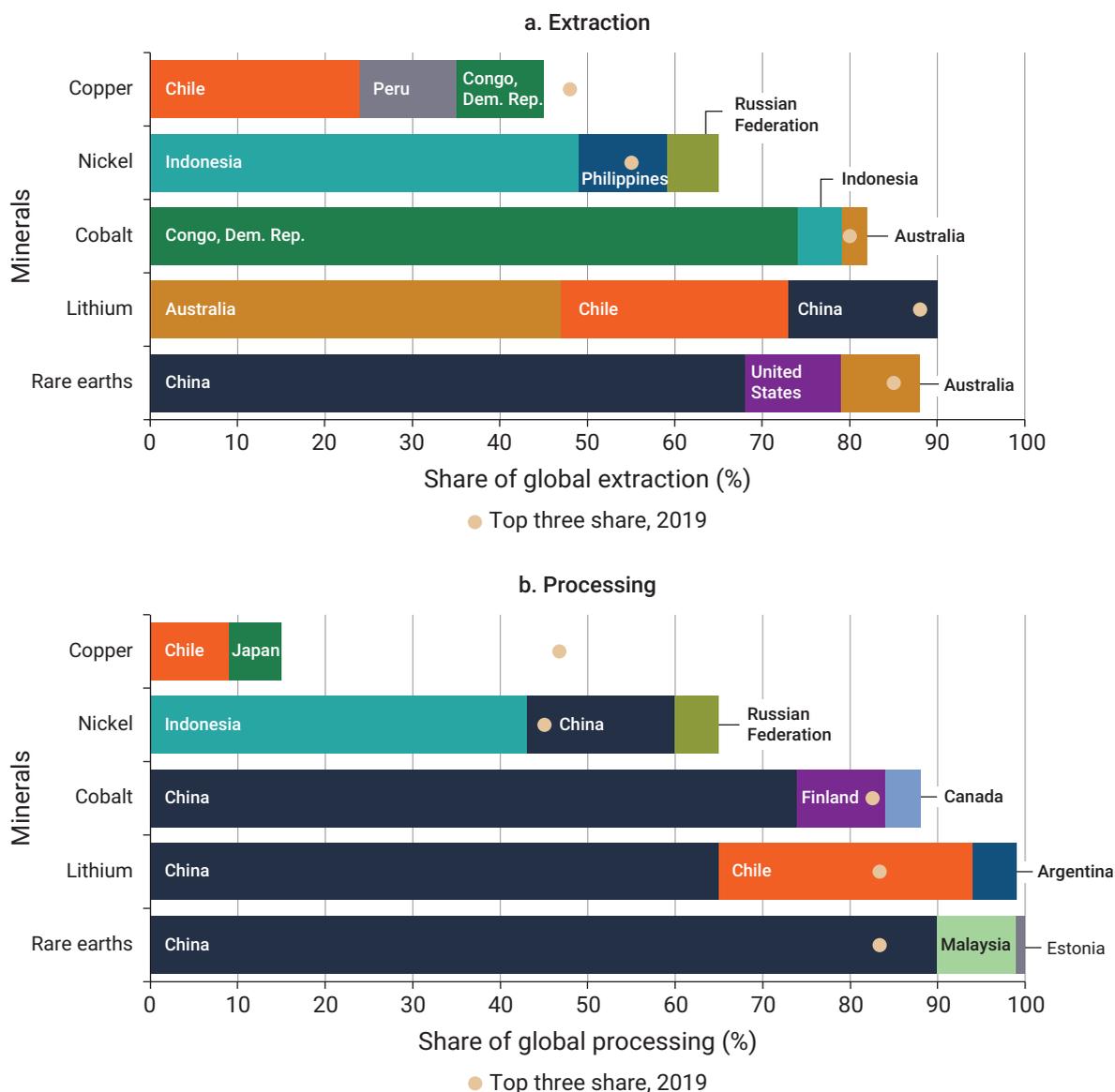
Note: Type 1 technologies, such as solar photovoltaic (PV) modules and efficient light emitting diode (LED) lighting, are simple to assemble and distribute at scale (although individual components may exhibit complexity) and have rapid learning rates and scale economies. Type 2 technologies, such as wind turbines and electric vehicles, involve relatively more complex designs and move toward scalability more slowly, although they include standardized components, have the potential for scale economies and increasing replication, and have learning cycles of a few years. Type 3 technologies, such as nuclear power, require extensive customization and involve a high degree of complexity. They are susceptible to cost overruns and have limited scope for rapid learning by doing. BECCS = bioenergy with carbon capture and storage; CCGT = combined-cycle gas turbine.

as discussed in chapter 6. Many inputs into clean energy value chains are also highly concentrated. For example, the Democratic Republic of Congo supplies 74 percent of cobalt, China 68 percent of rare earth elements, and Indonesia 49 percent of nickel. Australia accounts for 47 percent of lithium mining, and Chile for 24 percent. Processing of these minerals is also highly concentrated, with China refining 90 percent of rare earth elements and 65 percent and 74 percent, respectively, of lithium and cobalt (figure 9.3).

One pathway for middle-income countries is to improve their firm capabilities and

overall technological sophistication (as discussed in chapter 6). Middle-income countries tapping into manufacturing opportunities for clean energy technologies are typically those already competitive in manufacturing or exporters of high-technology products.⁹ Research conducted for this Report shows that the share of online job postings for all disruptive technologies is highly correlated with the share of online job postings related to low-carbon technologies.¹⁰ This finding suggests that countries experiencing a rapid diffusion of all emerging disruptive technologies are also witnessing a rapid diffusion of low-carbon technologies.

Figure 9.3 Extraction and processing of critical minerals for the clean energy transition remain highly concentrated in certain countries

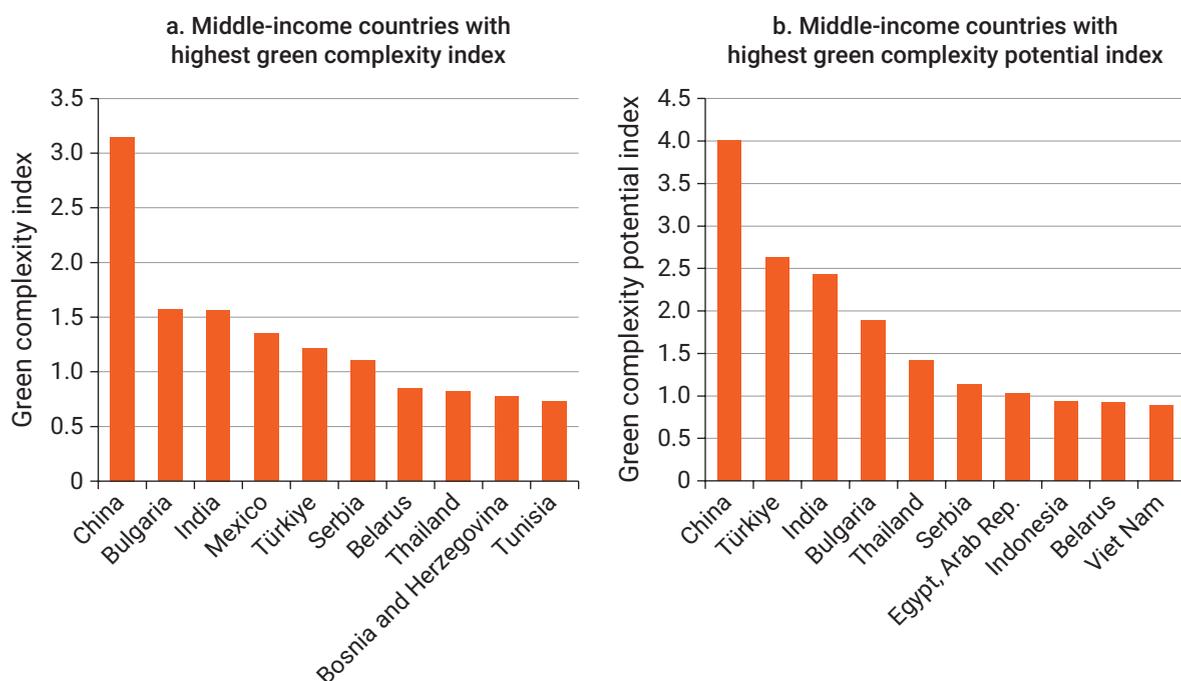


Source: IEA 2023a.

In fact, low-carbon production has been higher in countries with greater overall competitiveness.¹¹ The green complexity index—which measures a country’s current ability to export green complex products competitively—reveals that middle-income countries currently able to competitively

export a wide range of green complex products include China, Bulgaria, India, Mexico, Türkiye, Serbia, Belarus, Thailand, Bosnia and Herzegovina, and Tunisia¹² (figure 9.4, panel a). The green complexity potential index measures countries’ potential to export green, technologically sophisticated

Figure 9.4 Many middle-income countries have untapped potential to manufacture green products



Source: WDR 2024 team based on Mealy and Teytelboym (2022).

Note: Panel a shows the green complexity index (GCI), which is aimed at capturing the extent to which countries are able to competitively export green, technologically sophisticated products. A country is considered to be *competitive* in a product if its revealed comparative advantage for this product is greater than 1. Panel b shows the green complexity potential (GCP) index. This index aggregates the information contained in each country's green adjacent possible (GAP)—which is aimed at identifying the green diversification opportunities for each country—into a single, comparable metric. The GCP index measures each country's average relatedness to green complex products in which the country is not yet competitive.

products in the future, and it reveals that many middle-income countries have untapped potential to export green complex products. China, Türkiye, India, Bulgaria, and Thailand have the highest untapped potential based on other products they are currently manufacturing (figure 9.4, panel b). Türkiye, for example, has high potential in the value chains for wind turbines and electric vehicles. Although production is growing rapidly, these industries could become even greater drivers of growth.

Only if middle-income countries are able to join low-carbon value chains can they effectively contribute to global decarbonization and realistically aspire to tilting their own markets green.

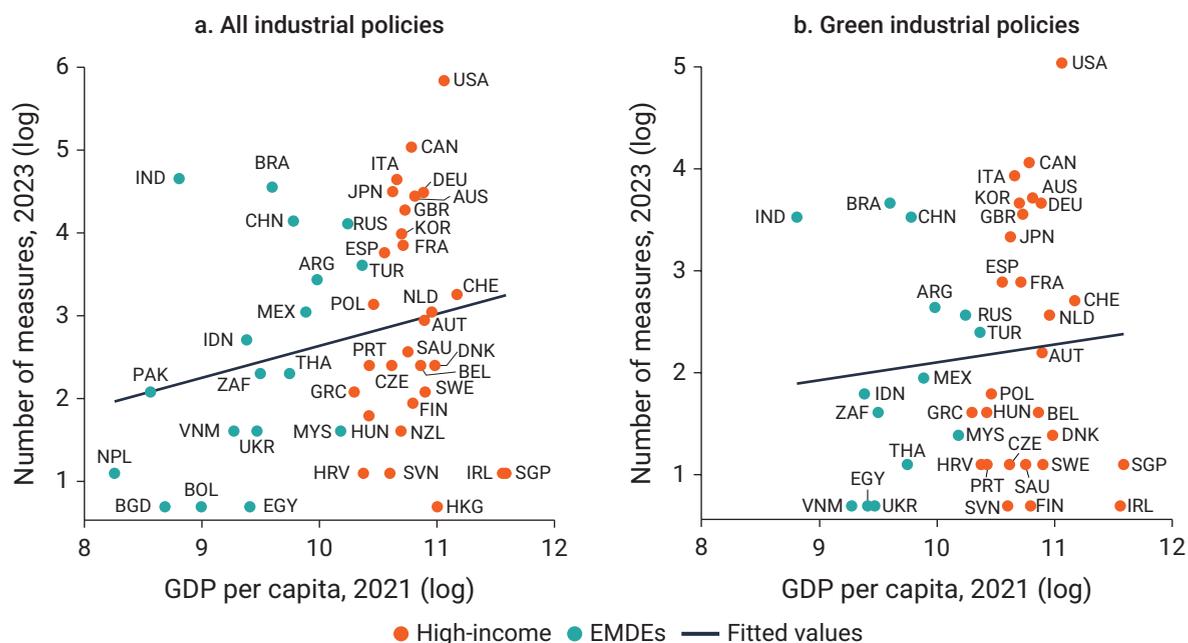
Resist uncoordinated and protectionist industrial policy

In the climate context, there is a strong case economically for countries to use industrial policies to support far-from-market low-carbon technologies. Furthermore, countries are faced with legitimate concerns about energy security and the need for politically feasible climate policies, which warrant certain unique considerations in making energy-related trade policy. Nevertheless, to ensure a successful low-carbon transition, it is essential to implement well-coordinated, balanced industrial policies that avoid protectionism and minimize market distortions.

Research using the New Industrial Policy Observer (NIPO) reveals the significant implementation of new industrial policy measures in 2023, particularly by high-income and large middle-income countries (figure 9.5, panel a).¹³ For industrial policies targeting low-carbon technologies specifically, a similar pattern holds (figure 9.5, panel b). Policies in the NIPO classified as potentially trade distorting and that target low-carbon technologies have been spearheaded by a few large G20 countries. These include the European Union’s Green Deal Industrial Plan, the US Inflation Reduction Act (IRA), Japan’s Green Growth Strategy, and the Korean New Deal. However, green industrial policies are rapidly

spreading across low- and middle-income countries. Many middle-income economies are designing and deploying state-led projects to foster green industrialization. Notably, the Arab Republic of Egypt, Kenya, Morocco, Namibia, South Africa, and Tunisia have launched initiatives to support the development of green hydrogen. This shift introduces significant challenges, often imposing a “development tax” whether or not countries engage in industrial policies. For example, policy response options for International Development Association and other low-income countries are typically limited to nontariff measures (NTMs) due to financial constraints and World Trade Organization (WTO) commitments. Subsidizing

Figure 9.5 All industrial policy implementation and green industrial policy implementation are correlated with GDP per capita



Sources: Panel a: Barattieri, Mattoo, and Taglioni 2024. Panel b: WDR 2024 team analysis replicating Barattieri, Mattoo, and Taglioni (2024) for green technologies only.

Note: The vertical axis in both panels is the log of numbers of all potentially trade distorting measures from the New Industrial Policy Observer (NIPO). The horizontal axis in both panels is gross domestic product (GDP) per capita in 2021 based on WDI (World Development Indicators) (Data Catalog), World Bank, Washington, DC, <https://datacatalog.worldbank.org/search/dataset/>. Panel b includes all NIPO policies classified as targeting low-carbon technologies, hydrogen, or critical minerals, according to NIPO definitions. EMDEs = emerging market and developing economies. For country abbreviations, see International Organization for Standardization (ISO), <https://www.iso.org/obp/ui/#search>.

their own industries can divert funds from essential public services, and NTMs can strain economies, potentially leading to impoverishing growth and a global race to the bottom.

Such policies may also risk slowing down knowledge transfer and the diffusion of low-carbon technologies. Policy makers in the world's major economies must therefore coordinate on the appropriate use of green industrial policies. Indeed, they should consider that the energy transition has outcomes that extend beyond its effects on climate, but also on technology diffusion and the economic development of middle-income countries.

To support middle-income countries as they move toward global decarbonization, policy makers will need to update global trade policy rules to clearly define the appropriate use of green subsidies, export controls, and import controls. Such reforms are already being discussed and designed at the WTO level. The Villars Framework 2.0 has also detailed various potential reforms of the WTO to bring the international trading system into harmony with a global “commitment to a sustainable future.” These reforms include, among others, carefully distinguishing between subsidies that benefit sustainability and subsidies that impair it. Other possibilities include modifying existing agreements with supplementary clauses in much the same way that Articles 20 and 21 of the General Agreement on Tariffs and Trade (GATT) were used to carve out exceptions.¹⁴ Such clauses could acknowledge that countries may need to nurture emerging domestic industries if they are to achieve a transition with energy security, but the use of subsidies should also be restricted to specific circumstances, such as the commercialization of far-from-market low-carbon technologies.

Expanding low-carbon infrastructure

To achieve the United Nations' Sustainable Development Goals (SDGs) related to infrastructure and stay on track to limit climate change

to 2 degrees Celsius, low- and middle-income countries will have to undertake investments of 4.5 percent of their gross domestic product (GDP) each year.¹⁵ Additional investments will be needed to provide safe water and sanitation, as well as reliable electricity and transport to meet the rising demand based on growing incomes.

Many of these investments can provide double dividends by enhancing living standards and mitigating greenhouse gas (GHG) emissions. For example, city developers that integrate land use and transport plans can enhance economic productivity while reducing GHG emissions.¹⁶ Designing buildings with emissions and energy savings in mind is likely to be more cost-efficient than retrofitting, the dominant practice in high-income countries.¹⁷ Similarly, scaling up investment in energy production and distribution, as well as transportation systems in low- and middle-income countries, can provide important benefits in structural transformation and economic productivity.¹⁸

Considering the development and decarbonization potential of these investments, investment opportunities in middle-income countries appear to be untapped. By leveraging multilateral resources, private capital in high-income countries could alleviate the shortage of infrastructure in low- and middle-income countries, help achieve the SDGs, and contribute to economic growth, as suggested by the World Bank and International Monetary Fund, along with regional development banks.¹⁹

Research conducted for this Report provides the first set of estimates on “investment potential” in renewable energy in middle-income countries by examining the expected rates of return and cost of capital.²⁰ Capital costs constitute the largest part of life cycle costs in renewable energy projects. In middle-income countries such as Brazil and India, the cost of capital can even account for 50 percent of the levelized cost of energy for solar PV.²¹ For fossil fuel-based power generation, fuel costs and other operational costs make up the largest proportion of costs.

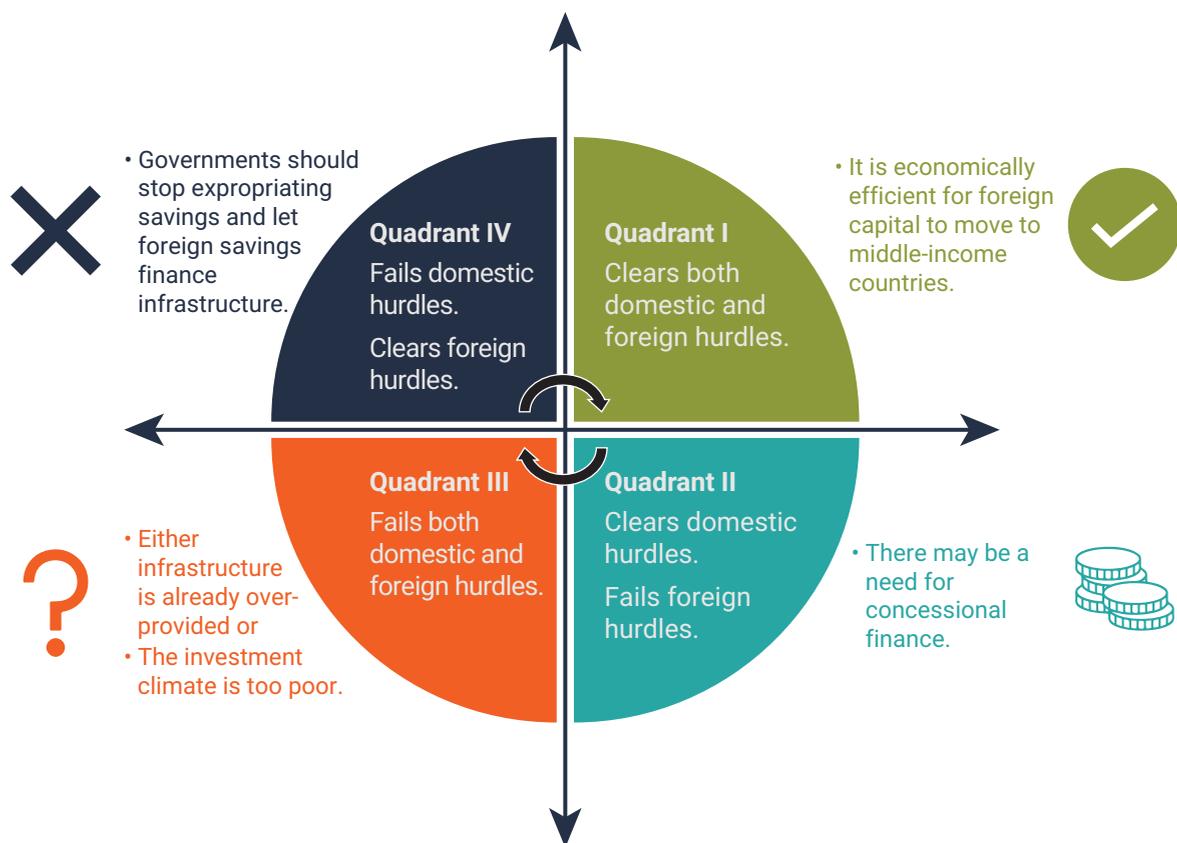
To assess whether investing in a renewable energy technology in a middle-income country would be an efficient use of domestic and foreign savings, this study compares a middle-income country's social rate of return on infrastructure with its social rate of return²² on private capital and the social rate of return on foreign capital:

- If a middle-income country's infrastructure is scarce, its social rate of return on infrastructure will exceed its social rate of return on private capital—that is, its

ratio is greater than 1. The vertical axis in figure 9.6 clears such a domestic hurdle, so that to the right of the axis it is economically efficient to invest in low-carbon energy infrastructure.

- If a middle-income country's infrastructure is scarce relative to that of a wealthier country, it becomes economically efficient for capital to move toward the middle-income country. Above the horizontal axis, the hurdle for foreign investment is cleared.

Figure 9.6 Countries must clear hurdles for both efficient domestic investment and foreign investment in renewable energy



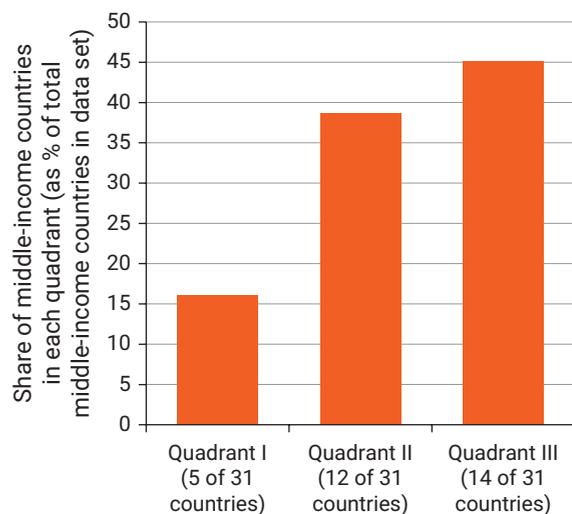
Source: Gardner and Henry 2023.

Note: For a middle-income country, the dual-hurdle framework sorts each country-infrastructure observation into one of four quadrants according to whether it clears the hurdle for both efficient domestic investment and foreign investment. The framework allows evaluating whether investing in the infrastructure of a given developing country would be an efficient use of developing country (domestic) and developed country (foreign) savings.

The unit cost of installing renewable energy and country-specific rates of return to capital are calculated using evidence from a new meta-analysis to derive the output elasticity of renewable energy together with data from the World Bank Private Participation in Infrastructure (PPI) database²³ as well as country estimates from the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), the World Bank Electricity Planning Model (EPM), and renewable energy auctions.²⁴ The following insights then emerge from the framework (figure 9.7):

- Quadrant I in figure 9.6 comprises countries in which the return on infrastructure clears both the domestic and foreign hurdles—that is, the minimum rate of return that an investor needs to proceed with a project. Five of 31 middle-income

Figure 9.7 In many middle-income countries, it is economically efficient to expand renewable energy



Source: Lall and Vagliasindi 2024.

Note: The sample includes 31 middle-income countries. In quadrant I countries, the return on infrastructure clears both the domestic and the foreign hurdles. In quadrant II countries, the economic rate of return on infrastructure clears the domestic hurdle but falls below the foreign hurdle. In quadrant III countries, the economic rate of return on renewable energy clears neither the domestic nor the foreign hurdle.

countries in the study pass both hurdles, including Ecuador, Jordan, and Malaysia.

- Quadrant II comprises countries in which the social rate of return on infrastructure clears the domestic hurdle but falls below the foreign hurdle. Although these countries would benefit from additional investment in renewable energy, it is not efficient for foreign savings to finance it. These countries can tap into domestic savings, and there may be a role for concessional foreign financing due to the global co-benefits in GHG reductions. This category includes 12 of 31 middle-income countries, including Brazil, Cambodia, China, Colombia, and India.
- Quadrant III comprises countries in which the social rate of return on renewable energy clears neither the domestic nor the foreign hurdle. Additional investigation is warranted for these countries. On the one hand, a country with a vibrant private investment climate (and therefore a high social rate of return on renewable energy) may be well endowed with capital in renewable energy. Thus the marginal benefit of installing another unit is not an efficient use of either local or foreign savings. On the other hand, a country may have a poor investment climate that leads to low social rates of return on private investment, even as it remains relatively undercapitalized in renewable energy.

Assess financial returns and cost of capital for renewable energy

For investments that add value in economic terms, investors—domestic or foreign—will want to know whether they can cover their cost of capital and secure sufficient revenue over an extended period to access finance on reasonable terms. Investors use the cost of capital to assess project risk. Costs vary among countries, with the spread often determining the competitiveness of renewable energy.²⁵ Investment risk

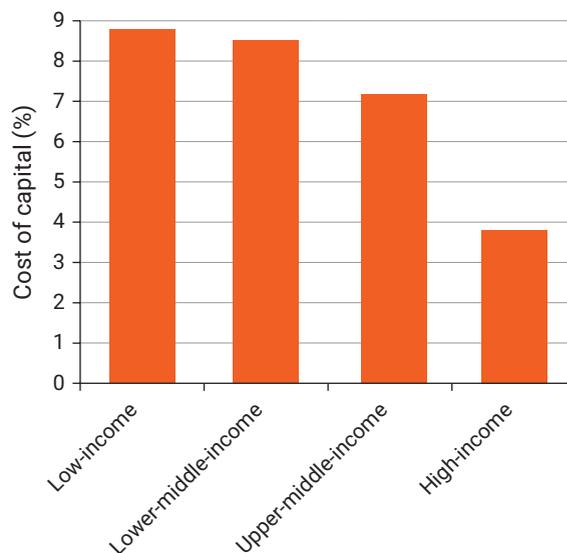
also varies according to type of renewable technology.²⁶ Rotating equipment such as a wind turbine is prone to more wear and tear than a photoelectric system such as solar PV, thereby raising operating costs and increasing uncertainty about the costs of repairing the components of wind turbines.²⁷ Country-specific and technology-specific investment risks can vary over time²⁸ due to specific policy or cost changes in a technology or economywide variations in interest rates.²⁹

Before entering long-term commitments, investors consider the level of risk in a country, such as macroeconomic stability and political uncertainties.³⁰ Where cash flow depends on payments from a state-owned enterprise, the credibility of the specific policy framework matters.³¹

The cost of capital for low-carbon technologies affects the investment decisions of both financial institutions and private corporations. Data on the cost of capital in 45 countries using solar PV or wind technologies reveal that the cost of capital in middle-income countries is twice that in high-income countries, averaging 3.8 percent in high-income countries, but 7.2 percent in upper-middle-income countries and more than 8.5 percent in lower-middle-income countries³² (figure 9.8).³³ The high cost of capital has material implications for affordable energy. For example, for a representative solar PV project or onshore wind project, the total cost of electricity increases by 80 percent if the cost of capital is 10 percent rather than 2 percent.³⁴

The high cost of capital in many low- and middle-income countries could increase the cost of renewables by 50 percent or more. The Energy Transition Risk and Cost of Capital Program of the Oxford Sustainable Finance Group tracks the cost of capital across equities, syndicated loans, corporate bonds, and accounting data, and it has revealed a significant variation in trends across regions.³⁵ In European countries, the cost of capital for low-carbon electric utilities is significantly lower than the cost for high-carbon ones. In North America, the cost of debt and equity for low-carbon electric utilities is comparable to that for high-carbon ones.

Figure 9.8 In low- and middle-income countries, the cost of capital for renewables is high



Source: IRENA 2023.

Note: Data are for 2021 and 2022.

The trends in middle-income countries such as China are the opposite: low-carbon electric utilities have a higher cost of debt than high-carbon ones. In other emerging markets, such as Latin America and Asia, utilities focused on renewables are subject to a higher cost of capital. And there is a clear divide in the cost of capital between OECD and non-OECD countries, with average cost of debt in 2021 of 3.9 percent for OECD countries compared with 4.7 percent for non-OECD countries.

Accelerating reductions in carbon emissions will require reducing the cost of capital for low-carbon technologies. Addressing technology risk, development risk, and pricing risk can help incentivize investors—utilities, banks, or other institutions—to invest in renewable projects. Derisking requires a whole-of-economy approach. It depends on licensing, policy stability, and social acceptance, along with technical, market, and regulatory risks.³⁶ Derisking not only makes renewable energy projects less expensive, but also reduces the amount of public finance needed to support these projects.

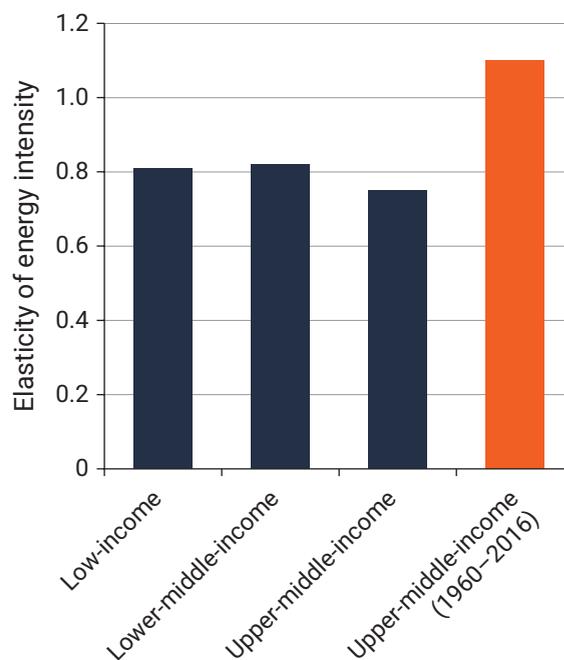
Decoupling economic growth and emissions

Middle-income countries aspire to grow their economies and achieve living standards closer to those of high-income countries. But economic expansion in middle-income countries could lead to a significant surge in the demand for energy if efficiency is not improved.³⁷ A country does not, however, need to grow at the expense of steps to reduce emissions if it can reduce both the amount of energy required to fuel its economy and the carbon emissions per unit of energy used by the economy. Growth has become less energy-intensive (figure 9.9). Most notably, the amount of energy needed to fuel the economy (per unit of GDP) is much lower for today's upper-middle-income countries than for upper-middle-income countries in the past. In other words, there is evidence that leapfrogging is advancing over time as middle-income countries move closer to the technology frontier.

Economic growth is also accompanied by structural and spatial transformations that help reduce the carbon emissions of an economy. The carbon emissions of the global economy—a combination of energy intensity (energy consumed per dollar of GDP) and carbon intensity (carbon emissions per unit of energy)—have declined globally from about 0.69 million tons of carbon dioxide (CO₂) per billion dollars of GDP in 1980 to 0.46 million tons in 2018 (figure 9.10).³⁸ In particular, China's drop in carbon intensity is globally material because China is the world's largest emitter.³⁹ More broadly, the carbon emissions per unit of GDP over time of upper-middle-income and lower-middle-income countries have declined, even when supply chain emissions are taken into account. A recent study covering 137 countries also finds that countries with higher GDP per capita have lower energy intensity. Furthermore, countries with a high level of energy intensity experience a stronger reduction in energy intensity.⁴⁰

Past oil crises motivated high-income countries to lower energy intensity and to accelerate

Figure 9.9 Today's upper-middle-income countries are more energy efficient than upper-middle-income countries in the past

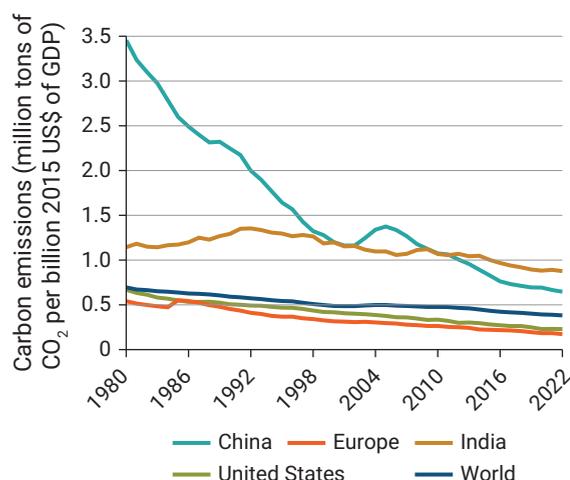


Source: WDR 2024 team calculations based on data from Fetter (2022).

Note: Elasticity of energy intensity refers to the energy used per unit of gross domestic product (GDP). Estimates of the elasticity of energy intensity in the long run are based on a fixed effect dynamic response lag model covering 136 countries over the period 1960–2017 (34,800 observations), including log price index, two lags of end-user energy consumption, dummies for structural breaks in data series, and country-sector fixed effects. Values of the elasticity of energy intensity can be interpreted as follows: if GDP increases by 1 percent, energy consumption increases only by 0.75 percent in upper-middle-income countries that achieved upper-middle-income status as of 2017, compared with 1.1 percent in upper-middle-income countries that achieved upper-middle-income status within the period 1960–2016.

innovation and research into renewables. Those measures substantially compensated for the increase in these countries' emissions arising from a growing economy (figure 9.11). Today, a combination of reductions in carbon emissions and improvements in carbon efficiency are offsetting the increase in emissions stemming from economic and population growth. By contrast,

Figure 9.10 Carbon emissions per unit of GDP have been declining worldwide



Source: WDR 2024 team analysis based on adapting from and updating Pindyck (2021). Carbon emissions data are from Energy Institute (2023). GDP data are from WDI (World Development Indicators) (Data Catalog), World Bank, Washington, DC, <https://datacatalog.worldbank.org/search/dataset/0037712>.

Note: Carbon emissions, the product of energy intensity and energy efficiency, are measured in million metric tons of carbon dioxide (CO₂) emissions per billion 2015 US dollars of GDP. GDP = gross domestic product.

economic growth is the key driver of emissions in middle-income countries, and those emissions more than outweigh the reductions in emissions from lowering energy intensity and improving energy efficiency. The effect of economic growth on emissions is especially strong in upper-middle-income countries. According to projections from the Network for Greening the Financial System, if middle-income countries continue their current policies, there is an 83 percent chance that even if today’s high-income countries achieve their 2050 net zero goals, global emissions will exceed the remaining carbon budget required for limiting the change in global warming to less than 2 degrees Celsius by 2050.⁴¹

In deciding how to “decouple” emissions from a growing economy, middle-income countries will need to consider their country’s concerns with energy security and access to reliable energy.

Although low-carbon and renewable energy can improve energy security by reducing price volatility through lower exposure to fuel price shocks during supply disruptions, energy from these sources cannot be produced consistently throughout the day. Because electricity systems must always be balanced—that is, ensure that the supply of electricity is meeting the demand at all times—countries will have to consider a balanced mix of energy sources in which low-carbon and renewable sources cannot provide 100 percent of the supply and to incentivize energy-intensive users to adopt energy-conserving technologies. What can these countries do to reduce energy intensity and accelerate energy efficiency?

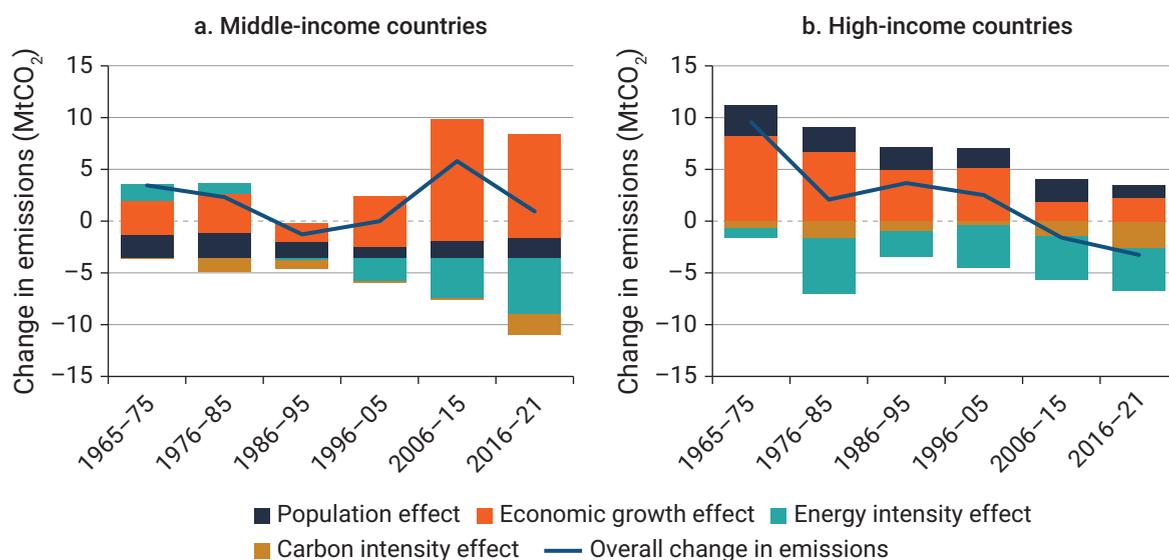
How middle-income countries can reduce energy intensity

In 2022, middle-income countries were experiencing energy intensity (energy consumption per unit of GDP) 2.5 times higher than that in high-income countries. The first set of insights on middle-income countries’ adoption of energy-saving technologies is now available through the World Bank’s Firm-level Adoption of Technology (FAT) survey of seven countries—Bangladesh, Brazil, Cambodia, Chile, Ethiopia, Georgia, and India.

Adoption of energy-saving technologies varies significantly across the countries sampled for the FAT survey. For example, the primary green building certification, Leadership in Energy and Environmental Design (LEED), reflects the level of technologies used in buildings.⁴² Research suggests that firms operating in green-certified buildings use 8 percent less energy than those in noncertified buildings.⁴³ The adoption of the LEED certification varies significantly. The highest adoption rates are in Brazil and Chile, where more than 20 percent of firms are LEED-certified. In Bangladesh, 7 percent of firms are certified, whereas less than 3 percent of firms in Georgia and 1 percent in India are LEED-certified.⁴⁴

Scale economies matter in the adoption of energy-saving technologies. Technologies such

Figure 9.11 High-income countries have succeeded in reducing overall emissions by curbing energy intensity



Source: WDR 2024 team analysis based on data from GCB (Global Carbon Budget) (data hub), Future Earth, Fort Collins, CO; University of Exeter, Exeter, UK, <https://globalcarbonbudgetdata.org/#>.

Note: Decomposition according to the Kaya identity, which states that the overall change in emissions (blue line) is the sum of four factors: population; gross domestic product (GDP) per capita (economic growth); energy intensity (energy used per unit of GDP); and carbon intensity (emissions per unit of energy consumed). The analysis is based on a global sample of 182 middle- and high-income countries and a time horizon since 1965, which allows the analysis to incorporate major crises, including the oil price shocks in the 1970s. MtCO₂ = million tonnes of carbon dioxide. One tonne is equal to 1,000 kilograms.

as advanced end-of-pipe treatment entail large installation costs, making adoption more likely among larger firms. Competition also matters. In Georgia, markets with a higher concentration have lower energy efficiency (concentration measured as the average price markups of the top 25 percent of firms in the markup distribution within their sector-size group and municipality). In addition, of firms with similar capital intensity, entrants are more energy-efficient than incumbents. In Argentina, for example, firms with a higher share of skilled workers are better able to adopt advanced green technologies.⁴⁵ Exporters also tend to have lower emissions intensity than nonexporters.⁴⁶ And foreign-owned firms generally perform better on environmental standards, such as in Côte d'Ivoire, Mexico, and República Bolivariana de Venezuela.⁴⁷

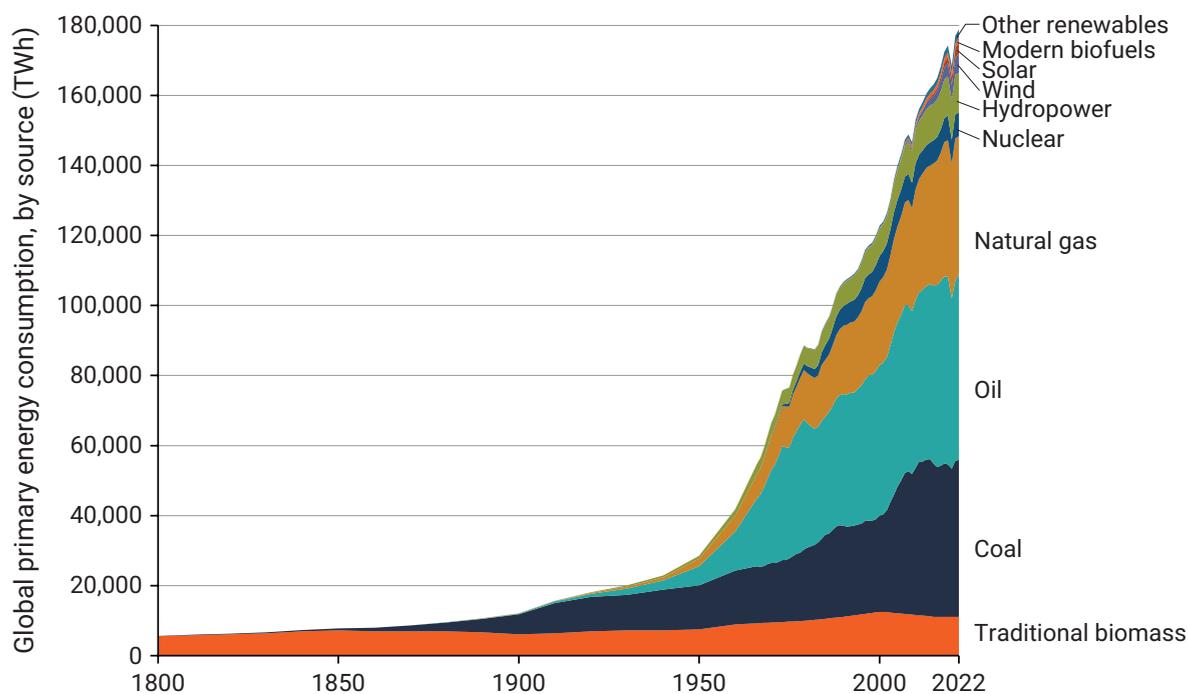
Such evidence indicates that market contestability, as well as opportunities for value-adding firms to grow, is compatible with adopting energy-saving technologies. As for renewable energy, firms' adoption of energy efficiency technologies has been hampered by the high up-front costs of acquiring the technology, lack of access to accurate information about the technology and its costs and benefits, and low returns from early adoption of technologies that require a large network of users.⁴⁸ Policies that improve the efficient allocation of resources by subsidizing technology adoption, to the extent that environmental benefits are not fully captured by adopters, or ease the financing constraints that prevent technology adoption are important in decoupling emissions from economic growth.

There is reason to be optimistic that ongoing energy price increases will encourage firms and other users to reduce energy intensity. In the long term, countries spend 5–9 percent of GDP on energy, and increases in energy prices tend to be fully compensated by higher efficiency.⁴⁹ In the short term, however, price shocks may pose a cost to an economy, so complementary policies may be needed to compensate for economic and welfare impacts. Governments can help provide firms that use energy intensively with access to energy-conserving technologies and finance for adoption as part of a reform program. Proactive programs that offer a mix of information, finance, and support can encourage changes in production technology and investment in energy-saving equipment.

How middle-income countries can reduce emissions intensity

Access to reliable, affordable energy is an important consideration for growing middle-income countries, which must choose the appropriate mix of energy sources that reduce emissions while ensuring stable energy supplies. Moving across energy sources is a slow process. Despite commitments by high-income and low- and middle-income countries, fossil fuels continue to account for more than 75 percent of global energy consumption (figure 9.12). Although there has been significant growth in renewable energy in recent years—particularly wind, solar, and hydroelectric power—the relative contributions are still small.

Figure 9.12 The world is slowly transitioning away from fossil fuels



Source: WDR 2024 team analysis of data from Our World in Data (dashboard), Global Change Data Lab and Oxford Martin Program on Global Development, University of Oxford, Oxford, UK, <https://ourworldindata.org/>; Statistical Review of World Energy (dashboard), BP, London, <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>.

Note: TWh = terawatt-hour. One terawatt-hour is equal to 1 trillion watt-hours, or the amount of power generated by a 1-terawatt generator running for one hour.

Create a market for technologies

To hasten the expansion of today's low-carbon technologies and support research and development (R&D) to create new technologies in the future, should government policies in middle-income countries subsidize development of specific technologies? This Report has highlighted that most middle-income countries would benefit from infusing global technologies, not innovating prematurely, before the necessary complements are in place. To promote energy efficiency, middle-income countries need a cluster of technologies that affect energy production, storage, and consumption.

Policy should be directed at creating markets for low-carbon technologies. This would include removing subsidies for fossil fuel-related technology (see chapter 8) so that low-carbon technologies can compete on a level playing field. Furthermore, middle-income countries need complementary investments in transmission infrastructure, as well as interoperability standards. As in China, demand-side “pull” may be needed to create a market for these technologies. Sectoral policies such as government feed-in tariff programs⁵⁰ were particularly significant in creating a market for renewable energy, first in Germany in the 1990s, followed by Italy, Spain, the United States, China, and India by the 2010s. Notably, as technologies have matured, feed-in tariffs have been replaced by more cost-efficient procurement methods, such as auctions (for example, in Brazil, India, South Africa, and, more recently, the Middle East and North Africa and Sub-Saharan Africa). Auctions have achieved record lowest prices per unit of electricity.

Consider resource endowment

A country's likelihood of switching from energy sources related to fossil fuels depends heavily on its resource endowment. For example, if solar radiation is not sufficiently powerful, the market value of producing such renewable energy would be low and would not justify the switch for an incumbent firm or energy company. But irradiance is not the full story in measuring the

solar potential of a region—it is also influenced by temperature (the higher the temperature, the less efficient is the solar potential), the type of terrain, the extent and type of mountains and hills, and so on. Taking these factors into account, the solar potential of each location within a country can be computed—the so-called PVOUT, the ratio between energy obtained (in kilowatt-hours, kWh) and installed power (in terms of kilowatt peak, kWp). This ratio serves as an assessment of the efficiency and productivity of solar plants in each region.

To switch to a renewable energy source, a country must have the potential to create an abundant supply of that energy. Meanwhile, countries with a rich endowment of fossil fuels may find it more difficult to embrace an energy transition due to the forces of inertia and the uneven playing field from fossil fuel subsidies.

Optimize the choice of technologies

Multiple sources of low-carbon technologies offer a myriad of possibilities for alleviating the heavy reliance on fossil fuels. Among the options are emerging and next-generation technologies, including, on the supply side, carbon capture, utilization, and storage (CCUS), carbon capture and storage (CCS), green hydrogen, blue hydrogen, and carbon removal technologies (DACCS and BECCS),⁵¹ and, on the demand side, hydrogen technologies in transport (hydrogen fuel cell trucks, aircraft) and industry (green steel). According to a comprehensive modeling exercise focusing on Europe and Central Asia, these new technologies have a critical role to play in the energy transition.⁵² Their growth rates will need to replicate the rapid rates of solar and wind energy to stay in line with climate targets,⁵³ as most net zero modeling of these new technologies indicates. But they are not on such a trajectory now.

Although the multiple sources of low-carbon technologies offer countries options for weaning off carbon and other fossil fuels, infrastructure constraints related to generation, transmission, and storage, as well as limits on the availability

of renewable resources, present challenges. Renewable energy sources depend on geographic location, climate, and weather. Thus regions have different needs for and availability of specific renewable sources. Moreover, connecting renewable sources to the electricity grid is a major issue in terms of cost and efficiency. Currently, there is a bottleneck in transmission lines because the existing transmission grids are supporting conventional energy resources. Legacy power grids that have been in place for several decades occupy the routes and land needed to set up additional power lines supporting renewable sources.

Middle-income countries may be able to partially leapfrog legacy grids located near large fossil fuel power plants in urban areas. But it may be difficult to leapfrog to a grid that is entirely powered by wind and solar plus energy storage—at least not while also expanding electricity access and driving economic growth. Even in advanced countries such as the United States, transmission lines need to increase by at least 25 percent over the next decade. Expanding distribution for

power through renewable sources requires not only investments in new transmission lines, but also in renovating legacy lines to integrate them smoothly in new frameworks. As long as energy storage options remain both economically and technically limited, the appetite may increase for other technologies to maintain baseload energy supplies. Examples are natural gas and hydro technologies, as well as other technologies at different levels of maturity (ranging from geothermal to green hydrogen), along with fuels such as nuclear power. Box 9.1 discusses the role of alternate technologies as system stabilizers.

In view of the high cost of capital, the risk of intermittency, and the high storage cost for low carbon energy, middle-income countries will need flexibility in managing how they go about reducing their own emissions, while expanding energy access and maintaining security. Furthermore, to support global decarbonization, they will need to ensure coordination on the use of *green* industrial policy so that it does not limit their participation in low-carbon value chains.

Box 9.1 Technologies that can act as “stabilizers” of energy supply

Different technologies can play different roles as stabilizers of energy supply.

Hydropower. In addition to being a low-carbon source of energy, hydropower is a dispatchable and flexible technology. Hydropower with storage is currently one of the most cost-effective low-carbon solutions for integrating large-scale variable renewable energy capacity. For example, 1 megawatt of hydropower in Bhutan and Nepal can help integrate 5–6 megawatts of variable renewable energy in India and Bangladesh. There is an urgent need to scale up investment in rehabilitating and upgrading the existing hydropower installed capacity as well as restoring the current reservoir storage capacity. By 2030, more than 20 percent of the global hydropower infrastructure is expected to be more than 55 years old, the age at which major electromechanical equipment needs to be rehabilitated and upgraded. The risk-return profile and long gestation period of large hydropower projects has resulted in the limited participation of private financing in hydropower projects. Only 27 percent of the added hydropower installed capacity from 2011 to 2020 was privately owned—a rate that is even lower for large hydropower projects.

Geothermal. Geothermal power is one of the cleanest energy resources. It is also associated with some of the lowest land use of any energy technology, including other

(Box continues next page)

Box 9.1 Technologies that can act as “stabilizers” of energy supply (continued)

renewable sources. Although traditionally a baseload source of electricity, geothermal power can offer flexibility because plants can run continuously or adjust quickly to match demand and supply. Adopting appropriate pricing structures that recognize geothermal power’s up-front costs can increase the flexibility in generating and dispatching geothermal power. Geothermal energy and heat pumps can also play a key role in enhancing the stability and flexibility of the grid, particularly with the rise of renewable energy sources.

Hydrogen. Hydrogen has a role to play in storing energy and providing grid flexibility, as well as serving as a fuel in sectors in which carbon emissions are hard to abate. The cost of renewable hydrogen production depends on the cost of renewable power and the capital cost of equipment—notably, electrolyzers^a—as well as on the financing cost represented by the cost of capital. In today’s best locations and under optimistic assumptions, the production cost can be as low as US\$3 per kilogram, although this level cannot serve as a benchmark for low- and middle-income countries due to lower-quality renewable resources and high capital costs of equipment. For example, the cost of an electrolyzer system varies significantly, from less than US\$500 per kilowatt in China to as much as US\$2,000 per kilowatt elsewhere.^b Electrolyzer costs are expected to fall rapidly in the coming years, and so future projects will benefit from large-scale electrolyzers that will be cheaper. Although the current investment in hydrogen is significantly less than that in mature renewable energy technologies such as wind and solar, hydrogen technology has seen strong inflows of early stage capital as well as high levels of national funding in recent years in Europe and the United States. Regions with abundant solar and wind endowments, especially in Africa, can provide cheap green hydrogen for both domestic use and export. Demand for green hydrogen can also reciprocally boost investments in renewables and provide a salient business case for investment in renewables while facilitating electrification in some middle-income countries.

Natural gas. The use of natural gas reduces emissions if it displaces coal and if fugitive emissions are sufficiently low. Natural gas can empower industrial development as a chemical feedstock, fertilizer component, direct energy source, and electricity provider. However, switching from coal to natural gas does not help to shift or avoid path-dependency. It can lead to a carbon lock-in—that is, a long-term reliance on the built fossil fuel infrastructure.^c Wealth losses from stranded gas reserves could be significant. Estimates range from US\$1.7 trillion to US\$3.8 trillion based on climate targets that are aligned with the Paris Agreement on climate change.^d This force for preservation is further exacerbated by the large share of government ownership of natural gas reserves—approximately 80 percent. As a result, governments may be reluctant to abandon these assets due to windfall profits and rents.

Sources: ESMAP et al. 2023; Hansen 2022.

- a. An electrolyzer is a device that uses electricity to split water or other components into their constituent elements. It is a critical technology for producing low-emission hydrogen from renewable electricity.
- b. ESMAP et al. (2023).
- c. Melekh, Grubb, and Dixon (2024).
- d. Hansen (2022).

Notes

1. Stern (2023). Pursuit of net zero is important for stabilizing global temperatures and keeping global surface temperature increases below 2 degrees Celsius.
2. See For a Livable Climate: Net-Zero Commitments Must Be Backed by Credible Action (dashboard), United Nations, New York, <https://www.un.org/en/climatechange/net-zero-coalition>.
3. Dasgupta (2018).
4. Glennerster and Jayachandran (2023).
5. Introduced by Hausmann et al. (2014), “economic complexity” refers to a measure of a society’s productive knowledge. Prosperous societies have the knowledge to make a larger variety of more complex products. Hausmann et al. (2014) attempt to measure the amount of productive knowledge countries hold and how they can move to accumulate more of it by making more complex products.
6. Helveston, He, and Davidson (2022).
7. Green (2019).
8. Way et al. (2022).
9. Mealy and Teytelboym (2022).
10. Bloom et al. (2023).
11. Bettarelli et al. (2023).
12. Mealy and Teytelboym (2022).
13. Barattieri, Mattoo, and Taglioni (2024). Any attempt to measure industrial policies is fraught with challenges, and this database reflects only one measure of industrial policies, which may overrepresent countries that issue a relatively large quantity of legislative documents or those with greater regulatory transparency.
14. Jain et al. (2024).
15. As research conducted by Rozenberg and Fay (2019) suggests.
16. Lall et al. (2023).
17. Glennerster and Jayachandran (2023).
18. Foster et al. (2023).
19. Gardner and Henry 2023; World Bank (2015).
20. Lall and Vagliasindi (2024).
21. Schmidt, Cancellata, and Pereira (2016).
22. The social rate of return refers to the extrafinancial value of an investment (such as the value of environmental or social outcomes).
23. See PPI (Private Participation in Infrastructure Database), World Bank, Washington, DC, <http://ppi.worldbank.org/>.
24. Using parameters from Lowe, Papageorgiou, and Pérez-Sebastián (2019).
25. Egli (2020); Mazzucato and Semieniuk (2018); Steffen and Waidelich (2022).
26. Polzin et al. (2019); Salm (2018).
27. Steffen et al. (2020).
28. Egli 2020; Mazzucato and Semieniuk (2018).
29. Egli, Steffen, and Schmidt (2018); Kirkpatrick and Bennear (2014).
30. Waissbein et al. (2013); WEF (2014).
31. Egli, Steffen, and Schmidt 2018; Estache and Steichen 2015; Lüthi and Wüstenhagen (2012).
32. IRENA (2023).
33. Estimates of the cost of capital are based on the cost of debt and the cost of equity. The cost of debt is the cost to finance a loan for a renewable energy asset. The cost of equity is the return on equity required by the project developer (IRENA 2023).
34. Iyer et al. (2015); Schmidt, Cancellata, and Pereira (2016).
35. Zhou et al. (2023).
36. Noothout et al. (2016).
37. Kahn and Lall (2022). This surge in demand reflects a combination of relatively high-income elasticities and modest price elasticities—see the meta-analysis in Labandeira, Labeaga, and López-Otero (2017). This combination implies that energy demand is likely to continue growing, particularly for middle-income countries, notwithstanding efforts to enhance energy efficiency.
38. Pindyck (2021).
39. IEA (2021).
40. Deichmann et al. (2019).
41. See Scenarios Portal, Network for Greening the Financial System, Paris, <https://www.ngfs.net/ngfs-scenarios-portal/>.
42. The LEED certification is based on a scored rating mechanism that evaluates the environmental performance of buildings, including location, sustainable sites, water efficiency, energy efficiency and atmosphere, material selection and resources used, indoor air quality, and integrative process.
43. Qiu and Kahn (2019).
44. Cirera, Lee, and Ding (2024).
45. Albornoz et al. (2009).
46. Holladay (2016); Richter and Schiersch (2017).
47. Eskeland and Harrison (2003).
48. Bryan and Williams (2021).
49. Bashmakov (2007); Bashmakov et al. (2023).
50. A feed-in tariff is a policy tool that encourages the use of renewable energy technologies by guaranteeing customers a set price for the electricity they generate.
51. Carbon capture, utilization, and storage (CCUS) is an advanced iteration of the traditional carbon capture and storage (CCS) technology. CCS focuses mainly on the capture and sequestration of carbon dioxide to mitigate emissions, whereas CCUS takes a step further by finding practical applications for the captured carbon. DACCS is direct air capture with carbon storage. BECCS is bioenergy with carbon capture and storage.
52. World Bank and ESMAP (2024).
53. IEA (2023b).

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