Climate Change and Development Series

DIVERSIFICATION AND COOPERATION IN A DECARBONIZING WORLD

Climate Strategies for Fossil Fuel–Dependent Countries

Grzegorz Peszko
Dominique van der Mensbrugghe
Alexander Golub
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Climate Change and Development

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Contents

Boxes

Figures

Tables

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Executive Summary

Introduction

Fossil fuel–dependent countries (FFDCs) face the conundrum of being both highly vulnerable to climate change and exposed to the global efforts to mitigate it. FFDCs that rely on oil, gas, and coal are at greatest risk of upheaval from a low-carbon transition (LCT). Stakeholders in these countries know that an LCT will cause a global decline in fossil fuel industries and related value chains on which their economies depend and find themselves at a crossroads due to the uncertainty about whether and when tipping points will come.

Stakeholders in FFDCs—especially those in emerging market economies facing the development challenges of poverty and lack of opportunity—are deeply concerned about the costs of suddenly shifting away from foundational infrastructure and systems built up over decades on the back of fossil fuels and related industries.

This book provides a road map and proactive strategies that the global community and FFDCs can use to create the right incentives and enabling environments to encourage FFDC participation in the LCT, while acknowledging the constraints that they face. Achieving the objectives of the Paris Agreement requires a realistic assessment of these challenges and resolute action to tackle them.

A Low-Carbon Transition Brings New Structural Challenges to FFDCs

For FFDCs, the transition to a low-carbon future means welcoming mitigation of climate change risks while recognizing that those same response measures entail an eventual shift away from the fossil fuels that power their economies and societies. Although unique in many ways, these countries as a whole represent almost one-third of the global population, 20 percent of direct global greenhouse gas (GHG) emissions, and more than 80 percent of emissions embodied in known oil and gas reserves.

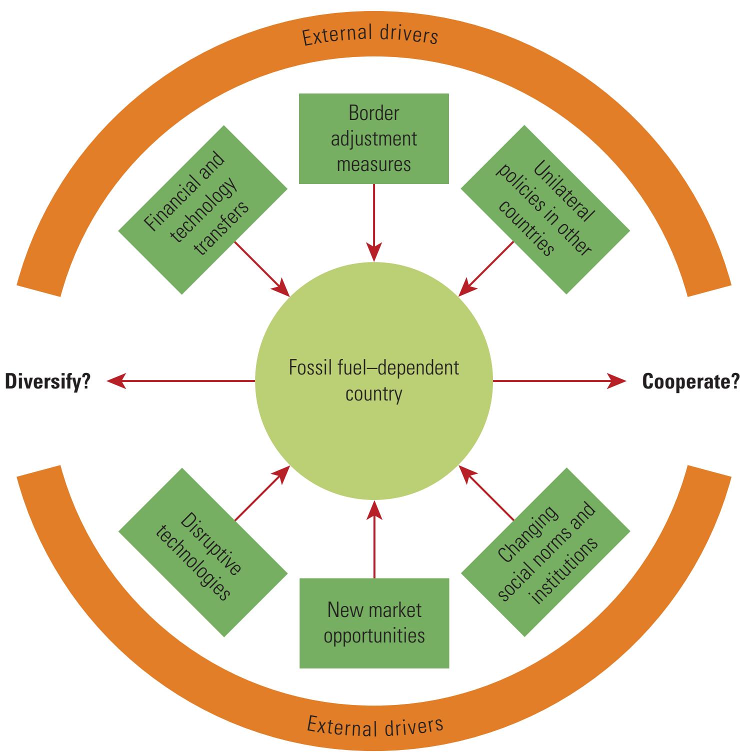
Some stakeholders in FFDCs regard the LCT as an opportunity to deepen diversification, but most consider it a risk to their narrow revenue and employment base in carbon-intensive activities, such as oil, gas, and coal extraction; downstream processing; and fossil fuel–intensive manufacturing including refineries, petrochemicals, steel, cement, and thermal power.

Pursuing their own economic imperatives, FFDCs have universally articulated aspirations to diversify away from a dependence on fossil fuel income and contributed to the objectives of the Paris Agreement by submitting their nationally determined contributions (NDCs). However, it is likely that their existing national strategies do not sufficiently prepare their economies for the many possible impacts of a global LCT.

In addition, the uncertainty of the pace and scope of the LCT hinders the ability of governments, businesses, and other stakeholders to make timely, effective decisions. The uncertainty is particularly deep with respect to policy developments by the largest economies, consumption choices of the growing middle class in developing countries, and structural disruptions in transport, energy, land use, and carbon capture and sequestration.

Uncertainty is not, however, a good excuse for inaction. Successful decisions under deep uncertainty require consideration of multiple plausible futures and being prepared for best-case and worst-case scenarios. This book suggests a framework for action for FFDCs and their partners based on an analysis of two broad strategies—one concerning economic diversification, and the other concerning cooperating on global efforts to stabilize the climate (figure ES.1).

FIGURE ES.1 **How a Low-Carbon Transition Could Unfold and How FFDCs Could Prepare for It**



Source: World Bank.

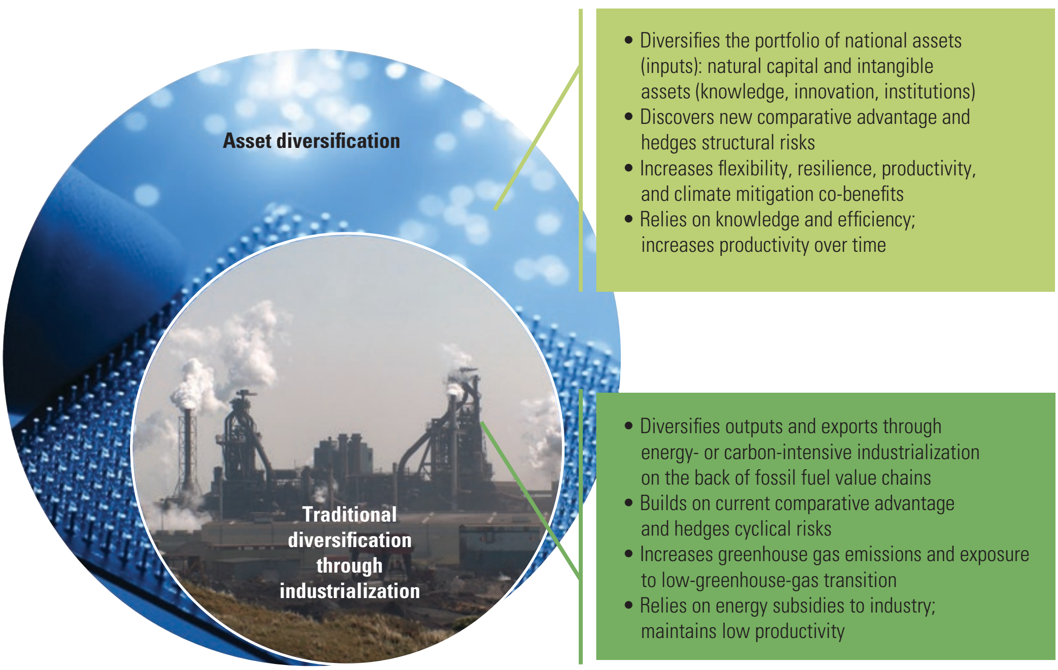
Economic Diversification during a Low-Carbon Transition

Broader approaches to diversification are better fitted to manage the impacts of a global LCT. FFDCs have long grappled with commodity price volatility using macro-fiscal policies that counterbalance the impacts of commodity price cycles and traditional diversification through vertical, energy-intensive industrialization that branches out from fossil fuel extraction to add value in domestic fuel processing and fuel-intensive manufacturing. Although such diversification strategies help to hedge against cyclical risks in commodity markets, they also increase exposure to the structural impacts of an LCT by deepening economic dependence on traditional emissions-intensive industries.

Rather than focusing on diversifying tradable products in the traditional fossil fuel product space, the diversification strategy today may need to focus more on diversifying the underlying wealth—the portfolio of assets used by an economy, including human capital and renewable natural capital, along with underground assets and produced capital. Such asset diversification (figure ES.2) leads to more productive and competitive economies that are also more flexible and resilient to external shocks, especially if supported by strong institutions and good governance.

Macroeconomic simulations carried out for this book show that asset diversification is the best long-term economic strategy for FFDCs. By reducing knowledge and

FIGURE ES.2 Two Broad Diversification Strategies



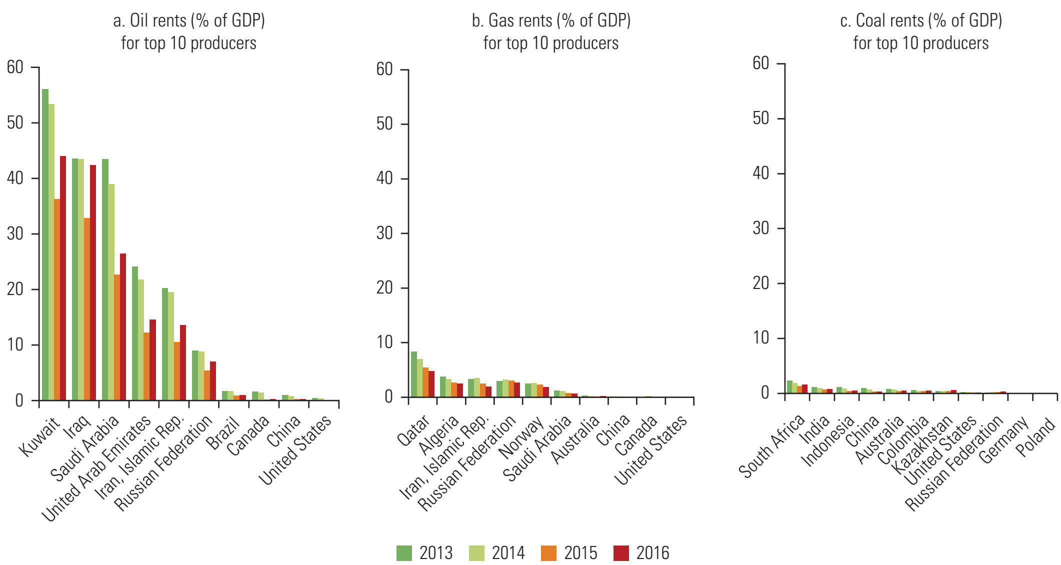
Source: World Bank.

productivity gaps with the most advanced countries, it is the only growth model that can push consumption and growth above business as usual in the long term.

Asset diversification falls victim to a "tragedy of the horizon," however. Changing the comparative advantage held by traditional fossil fuel industries unsettles current sources of revenue and requires building new skills, capabilities, and innovation systems from scratch. It carries economic and policy risks because of the need for large upfront investments with delayed returns that appear uncertain and elusive in a time frame that is relevant for current policy makers and business leaders. The upfront investments can also be challenging to justify socially because they compete with short-term consumption aspirations.

Mobilizing investments in asset diversification requires long-term revenue visibility. FFDCs are concerned that an LCT will drain current fossil fuel–related revenues before a critical mass of new capital and capabilities can generate new sources of sustainable income. This book suggests that fuel-related revenues in FFDCs can be lower than expected, but the impact will differ by fuel. Many oil and gas exporters can expect significant revenue flows in the next two to three decades. At the same time, any LCT will quickly erode coal revenues, but the associated systemic risk is negligible because coal is a small part of even the most coal-dominated economies (figure ES.3). Locally stranded labor and regional economic impacts are more challenging for coal countries to deal with than stranded assets on a national level.

FIGURE ES.3 Fossil Fuel Rents as a Share of GDP for 10 Top Fuel Producers, 2013–17



Source: World Bank World Development Indicators.

Note: GDP = gross domestic product.

The impacts of an LCT will vary from country to country. Competition between all fuel producers will increase as demand shrinks and disruptive clean technologies capture more markets. Producers with low extraction costs, lower upfront capital needs, better access to investors and developers, higher accumulated financial strength, lower leverage, and more highly developed export infrastructure will be in a privileged position for maintaining their revenues.

Although low fuel prices can mean limited resources and financial and social challenges for asset diversification, high fuel prices can unleash countervailing economic forces. Interestingly, high extractive export revenues can make asset diversification more, not less, difficult. Windfall profits from exports of oil and gas inflate exchange rates and feed a Dutch disease and a resource curse that crowd out non–fuel related economic activities, deteriorate governance, and increase the power of incumbents to resist change. An LCT could reverse the resource curse and make diversification easier because lower commodity prices and revenues would depreciate local currencies and make manufacturing exports cheaper and imports

FIGURE ES.4 **Countries' Preparedness for a Low-Carbon Transition**

Source: Based on several databases.

Note: Some likely poorly prepared countries are not in the figure because the full data sets were not available to the authors. Examples include Turkmenistan and Papua New Guinea.

more expensive, triggering increased localization of production of non–fuel related activities in FFDCs.

The countries best prepared for an LCT are those least exposed to its impacts and most resilient to them, able to swiftly adapt to changing external conditions and harness emerging opportunities (figure ES.4). The index of preparedness developed in this study suggests that the least prepared countries, including Iraq and Libya, are exceptionally vulnerable to external shocks from the LCT, given that long-term conflicts have destroyed almost all non-oil tradable industries and tarnished already weak institutions. Equatorial Guinea, Nigeria, and República Bolivariana de Venezuela are among the countries that are both the most exposed and the least resilient, given their poor governance records. Cambodia is vulnerable mainly because of the large share of young coal power plants in the generation mix, as is Guyana because of its recently discovered large oil reserves. Azerbaijan, Botswana, and Kazakhstan share high exposure and relatively weak resilience. Some Gulf Cooperation Council countries can be considered borderline cases–although significantly exposed, they also enjoy relatively high resilience. On the other hand, Norway is more exposed than some less-prepared countries, such as Angola, but nonetheless is well prepared for an LCT thanks to its resilience, in particular its economic flexibility, diversification, and high quality of human capital and institutions.

The Paris Agreement Opens Room to Align Incentives and Ignite Broad Coalitions for Climate Action

Asset diversification alone may not be enough to stabilize GHG emissions in many FFDCs, because their comparative advantage in emission-intensive industries is strong. Simulations realized for this book suggest that even ambitious asset diversification policies may not be able to trigger the major structural shift toward a low-emissions economy. Paradoxically, ambitious unilateral climate policies in the rest of the world can further entrench fuel-intensive economic structures in FFDCs. Rapid unilateral decarbonization in other countries would increase the costs for their energy-intensive industries while depressing global fuel prices and reducing the opportunity cost of using fossil fuels in FFDCs. As a result, industries in FFDCs could expand market share in the globally declining emissions-intensive products, partly offsetting climate mitigation co-benefits of asset diversification. Cooperative domestic climate policies need to complement asset diversification to engage FFDCs in global climate action.

FFDCs have some self-interest in domestic cooperative climate policies. A comparable level of effort of climate policy—for example, in setting carbon prices—can help diversify away from products linked to fossil fuels and prevent possible trade sanctions from being implemented by other countries, enhancing the long-term upside of asset diversification. However, domestic climate policies remain costly for FFDCs over the short term, unless there is a credible threat that other countries may impose trade sanctions on noncooperative countries. Otherwise, FFDCs have short-term incentives to postpone policies that increase domestic energy costs and to continue prioritizing traditional, pollution-intensive industries, because it is their familiar product space and skill set, even if it exposes them to possible future external LCT impacts and a long-term middle-income trap.

In contrast, net fuel importers and those countries that use relatively less fuel have a fundamental advantage over FFDCs in harnessing opportunities from an LCT. Many have already accumulated skills and capabilities in diversified, clean, and knowledge-intensive economic activities and have an established competitive edge in those market segments that gives them stronger incentives to lead on climate action. FFDCs could be negatively affected by climate policies in these countries. In particular, carbon prices applied by fuel importers—cooperative or not—extract a portion of resource rents from FFDCs, leaving them with less revenues available for risky long-term investments in asset diversification. But these effects do not create an incentive for FFDCs to cooperate on climate action, unless it helps slow down the transition away from fossil fuels (especially oil, which is highly dependent on demand from the transport sector and has more limited domestic uses than coal and gas).

Incentives to implement cooperative climate policies in FFDCs can be strengthened by the international community. The Paris Agreement acknowledged the primacy of domestic self-interest in climate policy and achieved universal participation (at least initially), but at the cost of not allocating any mitigation commitments to individual countries. The architecture of the Paris Agreement (Article 6.1) offers a conducive space for willing parties to form bottom-up clubs to unilaterally ignite ambitious climate action. For such clubs to be effective and comprehensive, their founders would need to complement their individual NDCs with collectively determined contributions, and apply an enforcement mechanism based on reciprocity ("I will if you will") to build trust, prevent existing club members from defecting, and induce the cooperation of reluctant parties.

New, unconventional international incentives can help overcome weak short-term incentives and capabilities to cooperate on climate action. Among positive incentives, strategic, conditional financial and technology transfers could be an effective alternative to the current retail, project-by-project climate finance that involves large transaction costs and weak incentive effects. Other promising cooperative instruments are bilateral or multilateral technology and policy cooperation agreements between fuel exporters and importers, such as harmonized carbon prices with revenue-sharing agreements implemented through multilateral wellhead carbon tax agreements. Wellhead tax agreements, if designed to prevent negative outcomes on low-income countries, would align international incentives to cooperate, reduce global emissions, and provide FFDCs with the resources necessary for diversification while addressing the social and political impacts of an LCT.

Among the negative incentives are different possible forms of border tax adjustments. Traditional border tax adjustments based on the carbon content of imports from FFDCs may not be enough to encourage cooperative climate policies in many FFDCs. The credible threat of “incentive-based” trade sanctions, such as those proposed by Nobel Prize winner William Nordhaus, could prompt FFDCs to seek cooperative deals, but this is a risky path for all.

Resource-rich, lower-income, and conflict-affected countries (many of them in Africa and the Middle East) pose development and ethical dilemmas. They have not yet converted resource rents into alternative assets and may find it relatively more difficult to attract investors. Other challenging cases include middle-income coal exporters that may also lack the financial and political capital to address local social challenges of the LCT because of sticky, stranded labor.

Simulations suggest that the incentives needed for the most vulnerable FFDCs to participate in a global LCT would cost only one-eighth of the savings that their participation would generate in other countries. The required transfers would still reach a total of $663 billion between 2015 and 2050, and would meet significant practical and political challenges.

A Road Map to the Low-Carbon Transition for FFDCs

Successful economic strategies in FFDCs will need to strike a balance between (1) managing traditional carbon-intensive assets and their revenue volatility and (2) managing the transition to knowledge-intensive growth models relying on much broader portfolios of assets. Ultimately, sustainable and resilient development implies an economy that is less exposed and more adaptable to external shocks.

Traditional, emissions-intensive diversification may be a necessary, but temporary enabler of an LCT. It hedges against the volatility of commodity prices and builds on existing strengths and capabilities to allow FFDCs to maintain adequate levels of current revenue and to enable long-term and high-risk investments in innovation systems outside of current comfort zones. Predictable revenue flows help FFDCs establish a new place in the global economic geography and alleviate political economy and social challenges associated with the transition to new asset classes.

But traditional diversification carries a risk of locking FFDCs in a vicious cycle of low productivity, poor governance, and high emissions, thereby increasing vulnerability to impacts of an LCT. Changing the established national comparative advantage requires bold and consistent policy efforts, high-quality institutions, a skilled and motivated workforce, external incentives, and predictable access to finance.

This book makes a case for international recognition that the contributions of FFDCs to the goals of the Paris Agreement can and should be different from the contributions of net fuel importers. Efforts to pursue asset diversification with mitigation co-benefits could form a core of their NDCs.

However, because the comparative advantage of FFDCs in energy and emissions-intensive products is so entrenched, additional domestic policy efforts would be needed to break away from their dependence on the fossil fuel–intensive value chain. Such policies would include removing resource price distortions and implementing environmental fiscal reforms, mission-oriented research and development (R&D), and innovation systems, as well as regulatory frameworks and a business environment that encourages new, low-carbon private entrants to challenge the entrenched positions of emissions-intensive incumbents, especially those that are state owned.

The international community may need to find ways to encourage and enable structural policy reforms as FFDC contributions to the goals of the Paris Agreement. This book identifies no silver bullet but provides new insights about effective pathways of global cooperation toward the goals of the Paris Agreement, in line with fair and sustainable development for all.

One of the key conclusions of this study is that asset diversification represents a fundamental shift toward a dematerialized long-term growth model, in which fewer material inputs generate higher economic output and welfare. Therefore, the risk of stranded assets is not a helpful focus for dialogue on climate action in the fossil fuel–dependent economies. Changes in the value of underground and produced assets are less relevant indicators of economic performance during an LCT than changes in asset structure, and in income and welfare flows. A low-carbon transition triggers a transition from a traditional capital-intensive growth model to a more labor- and knowledge-intensive growth model, in which human and renewable natural capital, as well as intangibles, increasingly substitute for produced and natural (exhaustible) assets in driving prosperity.

Abbreviations

AOSIS	Alliance of Small Island States
BAT	border adjustment tax
BAU	business as usual
BCA	border carbon adjustment
BCAT	border carbon adjustment tax
BOF	basic oxygen furnace
BP	British Petroleum
C	Celsius
CGE	computable general equilibrium
CO_2	carbon dioxide
COP	Conference of the Parties
CPI	Climate Policy Initiative
CPLC	Carbon Pricing Leadership Coalition
EAF	electric arc furnace
EBRD	European Bank for Reconstruction and Development
ECI	Economic Complexity Index
ESRB	European Systemic Risk Board
EU	European Union
FFDC	fossil fuel–dependent country
GCC	Gulf Cooperation Council
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule
GNI	gross national income
GTAP	Global Trade Analysis Project
$GtCO_2$	(metric) gigatons of carbon dioxide
HHI	Herfindahl–Hirschman index
HT	high growth rate of low-carbon technologies
IDDRI	Institute for Sustainable Development and International Relations
IEA	International Energy Agency
IIGCC	International Investors Group on Climate Change
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change

IRENA	International Renewable Energy Agency
LCT	low-carbon transition
LNG	liquefied natural gas
LSE	London School of Economics
NDC	nationally determined contribution
NEA	Nuclear Energy Agency
NES	new energy solutions
NPV	net present value
OECD	Organisation for Economic Co-operation and Development
OGCI	oil and gas climate investments
OPEC	Organization of the Petroleum Exporting Countries
PCA	principal component analysis
PIK	Potsdam Institut für Klimafolgenforschung
PV	photovoltaic
R&D	research and development
SI	International System of Units
SOE	state-owned enterprise
TCFD	Task Force on Climate-Related Financial Disclosures
tCO_2e	tonne of carbon dioxide equivalent
UCISL	University of Cambridge Institute for Sustainability Leadership
UNFCCC	United Nations Framework Convention on Climate Change
WSA	World Steel Association

All dollar amounts are US dollars unless otherwise indicated.

1. Introduction

This book provides a stocktaking of what the global low-carbon transition (LCT) may mean for fossil fuel–dependent countries (FFDCs) and how they can manage it. FFDCs are most exposed to the impacts of a global LCT and, at the same time, are often least prepared to manage it. Their economies depend on the export of oil, gas, or coal, on the use of carbon-intensive infrastructure (for example, refineries, petrochemicals, coal power plants), or both. These countries face at least two climate-related risks. The first-order risk arises from weather-related events induced by climate change. The second-order risk is financial, fiscal, and macrostructural. It arises from the potentially accelerated transition of the global economy away from carbon-intensive fuels (Carney 2015). This book focuses on managing this transition risk and harnessing its related opportunities.

Although FFDCs significantly differ from one another in many respects, they jointly account for almost 30 percent of the world's population, 15 percent of gross domestic product (GDP), and 20 percent of global direct greenhouse gas (GHG) emissions. On average, their direct emissions per capita are lower than those of the rest of the world, but the emissions intensity of their GDP is higher than the world's average. They hold the key to the globe's remaining fossil fuel reserves: their share in the global value of underground proven reserves of oil and gas amounts to 82 and 85 percent respectively.[1] In 2016 they produced 67 percent of the world's oil and 55 percent of the world's gas (BP 2018).

The primary audience for this study is decision-makers in FFDCs. By focusing on FFDCs, this book complements previous World Bank Group reports (CPLC 2017; Fay et al. 2015; Kossoy et al. 2015; World Bank, Ecofys, and Vivid Economics 2016, 2017). However, decision-makers in the rest of the world may also find this book useful in managing the transition of their own fuel-extractive and carbon-intensive sectors as well as in developing their climate policies to encourage global efforts toward climate goals.

This book analyzes the strategies available to FFDCs for managing the risks and tapping into the opportunities of an LCT. For these countries, the risk associated with being an early LCT mover is arguably higher than it is for countries that are more diversified and have a comparative advantage in knowledge-intensive economic activities. Many stakeholders in FFDCs understandably find it risky to abandon the growth drivers that have served them well so far. But they also realize that holding on to the same growth drivers in the face of significant global change is itself a source of risk. This book provides guidance on how to navigate this dual challenge. It identifies welfare-enhancing pathways for FFDCs to deepen diversification, hedge risks, and potentially discover new sources of comparative advantage. It also explores new instruments that the international community can apply to encourage comprehensive cooperation toward the mitigation goal included in the Paris Agreement, while acknowledging the special circumstances of the countries that are less prepared to decarbonize.

Many FFDCs have long been concerned with the negative impacts of policy measures of other countries responding to climate change. Their special circumstances were recognized in the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 (UNFCCC 2018), the Kyoto Protocol (Barnetta and Dessaib 2002), and the Paris Agreement (box 1.1). The UNFCCC documents call on all parties to take full consideration of the specific needs and concerns of developing-country parties arising from the impact of the implementation of response measures when addressing climate change (UNFCCC 2018). This book provides guidance on how to operationalize the Paris Agreement, while directly addressing the concerns and dilemmas of the countries that are less prepared to decarbonize. In addition, this analysis helps identify new design elements and incentives that can be built into future

BOX 1.1 Climate Response Measures in the UNFCCC Documents

- Article 4.8 of the Convention and Articles 2.3 and 3.14 of the Kyoto Protocol provide a basis for addressing the impact of the implementation of response measures.
- Article 4.8(h) in the Climate Convention commits the parties to consider the specific needs and concerns of developing-country parties arising from the impact of the implementation of response measures, including on "Countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products" (UNFCCC 1992).
- When addressing climate change concerns, the Kyoto Protocol commits parties to strive to minimize adverse economic, social, and environmental impacts on other parties, especially developing-country parties, and in particular, those identified in Articles 4.8 and 4.9 of the Convention, taking into account Article 3 of the Convention.
- The Paris Agreement states that parties shall take into consideration in the implementation of the agreement the concern of parties with economies most affected by the impacts of response measures, particularly developing-country parties.
- Response measures are being further addressed in the context of the Bali Road Map process, the Cancun Agreements, and the Durban Outcome.

Source: https://unfccc.int/topics/mitigation/workstreams/response-measures.

strategies of coalitions and clubs involved in the implementation of the Paris Agreement, potentially reducing roadblocks to a mutually beneficial cooperative outcome.

FFDCs developed a comparative economic advantage in fossil fuel–intensive sectors in the period when climate change was not yet recognized as a global risk. These sectors—whether extractive, energy related, or manufacturing—are engines of growth and welfare. They often employ a significant share of a country's capital and labor and generate the bulk of export revenues. In cases in which extraction of resources was accompanied by sound macro-fiscal frameworks and good governance, FFDCs accumulated physical and financial capital as well as skills and capabilities in running businesses and institutions. Accordingly, millions of people were pulled out of poverty and leapfrogged to a middle- or high-income level within a single generation. Several low-income FFDCs in Africa, Latin America, and South Asia that have discovered, though not yet tapped, large underground fossil fuel reserves hope it will drive similar prosperity for their economies.

FFDCs were already grappling with the downsides of dependency on narrow sources of income well before the impacts of climate change were widely understood. Prices in fossil fuel markets can be volatile; fossil fuel exports can lead to an appreciation of their currency, which may undermine the competitiveness of the rest of the economy; and the riches on offer can lead to rent-seeking and corruption rather than dynamism and entrepreneurship (Ross 2013). FFDCs have adopted a variety of responses—including countercyclical macro-fiscal policies, forced savings in stabilization and sovereign wealth funds, and exchange rate flexibility (IMF 2012; Ossowski and Halland 2016). This book explores whether the same policy responses can hedge the potential impacts of an LCT.

Several countries and regions have already revealed an-interest in pursuing some aspects of an LCT independently of efforts to achieve the goals of the Paris Agreement. Most European Union member states, California and a few other US states, British Columbia and Quebec in Canada, Chile, China, India, the Republic of Korea, New Zealand, and, more recently, Morocco have invested in exploiting their first-mover advantage in low-carbon, knowledge-intensive technologies and products. What all these countries and regions have in common is that they are net importers of fossil fuels and usually have already accumulated capital, skills, and capabilities in knowledge-intensive rather than energy-intensive economic activities. Literature on carbon pricing is still dominated by the perspective of net importers of fossil fuels, where win-win opportunities are relatively easy to identify.

To date, surprisingly little consideration has been given to the implications of an LCT for FFDCs, especially the developing countries among them (Manley, Cust, and Cecchinato 2017). Yet as early as 2012, Cramton and Stoft observed that any global climate agreement would probably make countries that export a significant amount of fossil fuels worse off, at least over the short term, and hence unwilling to voluntarily cooperate in the absence of additional incentives. The more popular literature has predominantly focused on how large, listed international oil and gas companies may or may not be affected (Carbon Tracker 2015, 2017), while central banks in Europe have begun research on the implications for financial sector stability in Organisation for Economic Co-operation and Development (OECD) countries and large emerging market economies (Bank of England 2015; Carbon Tracker 2017; Carney 2015; Cleveland, Schuwerk, and Weber 2015; FSB 2017; Regelink et al. 2017; Weyzig et al. 2014). The authors who recognized that a global LCT poses a challenge to sovereigns (Caldecott et al. 2016; CPI 2016; Lange, Wodon, and Cust and Manley in Carey 2018) paved the way for this book.

The perspective of fossil fuel exporters on climate policy is not a new issue in the economic literature, and although underresearched, its influence on the policy debate, and hence its impact on climate cooperation, has been limited. As early as 1982, Bergstrom showed that if the main oil-consuming nations cooperated with each other they could extract significant rents from oil-producing nations through national excise taxes, counterbalancing Organization of the Petroleum Exporting Countries (OPEC) cartel goals. Dong and Whalley (2009); Johansson et al. (2009); and Liski and Tahvonen (2004) confirm that OECD countries' traditional demand-side climate policies would capture OPEC oil rents. Bauer et al. (2016) apply the REMIND model[2] to show that carbon prices introduced by importers of fossil fuels capture a portion of resource rents from fuel exporters, while Strand (2008, 2013) and Karp, Siddiqui, and Strand (2015) find through the use of a theoretical model that a carbon tax extracts higher rents from exporters than does a cap-and-trade scheme. Franks, Edenhofer, and Lessmann (2015) and Edenhofer and Ockenfels (2015) move the debate further by demonstrating that, for fuel importers, carbon taxes are superior to capital taxes because they capture part of the resource rent that is held initially by the owners and exporters of fossil fuels. They show that this result holds regardless of whether fuel importers cooperate, and that fuel exporters are worse off even if they can strategically influence prices with an export tax. Elliott et al. (2010); Erickson et al. (2015); and Seto et al. (2016) all explore further why carbon lock-in makes fossil fuel producers reluctant to undertake climate action. Stiglitz (2015) notes that fossil fuel exporters may not have the incentive to implement traditional demand-side domestic carbon pricing under the pressure of moral suasion alone.

Wirl (1995) finds that the best strategy for oil exporters is to preempt importers' carbon taxes at the wellhead. Dullieux, Ragot, and Schubert (2011) suggest that in anticipation of a consumers' carbon tax, OPEC could respond by increasing producer prices to postpone extraction and reduce consumption, and thereby diminish the impact of the carbon tax. In this way, they argue that OPEC can reap a part of the "climate rent." Similarly, Böhringer, Rosendahl, and Schneider (2018) argue that OPEC may want to retain resource rents by increasing the oil price as a response to European Union climate policy, thereby reversing leakage, although the coalition or cartel size critically affects the scope for rent-seeking and leakage reduction. A particular stream of the literature proposes supply-side climate policies for major fossil fuel producers (mainly coal) as a way to solve the "green paradox" challenge (Sinn 2008, 2012). The examples include Asheim (2012); Collier and Venables (2014); Day and Day (2017); Eichner and Pethig (2017); Fæhn et al. (2017); Gerarden, Reeder, and Stock (2016); Harstad (2012); Lazarus, Erickson, and Tempest (2015); Muttitt et al. (2016); Piggot et al. (2018); and Richter, Mendelevitch, and Jotzo (2018).

This book proposes framing the LCT as a risk-management and development challenge to FFDCs; it analyzes the risks and opportunities a global LCT presents to FFDCs. It identifies ways these could be managed and tapped. It identifies welfare-enhancing pathways for FFDCs to deepen diversification, enhance future growth, and cooperate in international initiatives to stabilize the Earth's climate consistent with the mitigation goal adopted in the Paris Agreement. It also explores new instruments that the international community can apply to turn the contributions of individual countries into cooperative actions on the ground.

This book acknowledges that the predicament of an LCT is its deep uncertainty. The timing and forms of tipping points are unknowable because they depend on multiple sovereign decisions not yet made by key players or accepted by stakeholders because of conflicting visions of a preferred future. The LCT could take place as a smooth and regular transition or as a brutal shift in incentives and policies later on. Different scenarios are more or less disruptive, including for FFDCs. So far, climate policies have brought about marginal rather than disruptive changes. Yet the future is not a linear extension of the past. It took 150 years for coal in Europe to displace biomass as the primary energy source, but only about 30 years for coal to give way to oil and gas. No one knows for sure what the dynamics of a future energy transition will look like and whether the global transition to zero-carbon fuels will happen faster than previous transformations.

> There's an abundance of hydrocarbons in the world (…) more hydrocarbons than the world needs, possibly… I don't know how those [factors shaping the future of energy] are going to play out...Nobody does. But I think it would be very unwise to ignore them.
>
> Bernard Looney, BP's head of exploration and production
> (*Financial Times* 2017)

This book relies on qualitative analysis underpinned by quantitative modeling. The World Bank and the Purdue University teams have developed a new version of a global, dynamic, recursive general equilibrium model (GTAP-ENVISAGE), which has been integrated with extractive models for the oil and gas sectors (from Rystad UCube) and coal mining (from Wood Mackenzie). The model simulates an array of exploratory scenarios designed through combinations of uncertain but plausible external impacts over which FFDCs have little control (Peszko, van der Mensbrugghe, and Golub 2020). They can, however, make strategic choices to manage uncertainty and the possible impacts of an LCT.

The main objectives of this book are to help decision-makers in fossil fuel–dependent countries do the following:

- Better understand their exposure and vulnerability to the uncertain impacts of a possible LCT
- Better manage their national wealth, including fossil fuel reserves and carbon-intensive infrastructure
- Identify policy and asset allocation strategies that are robust; can serve as new engines of growth and wealth creation under uncertain future economic, technology, social, and policy trends; and contribute to the global objective of decarbonizing the world economy.

The book is structured as follows: Chapter 2 discusses the challenges, risks, and opportunities an LCT could pose for FFDCs. Chapter 3 reviews the varying impacts such a transition could have on different sectors and countries. Chapter 4 introduces a conceptual framework for the strategic options FFDCs have to hedge against transition risks. Chapter 5 focuses on benchmarking the preparedness of various countries to an LCT, and chapter 6 outlines practical diversification and climate negotiation strategies that can be used to increase resilience to transition impacts and harness associated opportunities.

Notes

1. Calculated as expected resource rents.
2. REMIND is a hybrid model that links an optimal economic growth model with a detailed energy system model. It is developed and used by Potsdam Institut für Klimafolgenforschung (PIK). Unlike the computable general equilibrium model used in this study, REMIND has a relatively aggregated structure of the economy and performs intertemporal optimization with perfect foresight.

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2. Challenges, Risks, and Opportunities of a Low-Carbon Transition

Existing Challenges for FFDCs

Fossil fuel–dependent countries (FFDCs), especially those that rely heavily on fossil fuel exports, face many challenges, even before considering the prospect of a low-carbon transition (LCT). A significant body of research addresses the question of whether resource-rich economies are "cursed" or "blessed" by their endowments (Auty 2001; Badeeb, Lean, and Clark 2017; Gelb 1988, 2010; Ross 2013; van der Ploeg 2011). Studies using measures of resource dependence generally find a negative relationship between economic growth and resource endowments (Auty 2001; Gylfason, Herbertsson, and Zoega 1999). Similarly, Hidalgo et al. (2007) and Hausmann et al. (2013) show that economic complexity and diverse capabilities pave the way to prosperity. Lederman and Maloney (2007) find that annual gross domestic product (GDP) growth per capita of net exporters of natural resources was only 0.6 percent, on average, in the period 1980–2005, while the figure for net importers was 2.2 percent. They also argue, however, that the resource curse can be avoided, because how goods are produced is more important than what goods are produced.

Three major channels have been identified for the adverse effects of resource endowments:

- Dependence on natural resource exports exposes countries to volatile commodity markets that generate macroeconomic instability. Volatile resource prices can, without careful planning, significantly lower the government's resource-based revenues. In Nigeria, for instance, the difference between $50 and $150 per barrel of oil represented 50 percent of GDP (Gelb 2010). The pressures this creates became evident in the wake of the oil price declines earlier this decade but also have historical precedents. For example, Mexico and República Bolivariana de Venezuela experienced sharp declines in government revenues in the 1980s following oil price volatility, with associated slumps in economic activity and a significant drop in government spending. Going back further, in the late nineteenth and early twentieth century, Chile's specialization in exports of primary goods was beneficial in the period of global economic expansion, but led to severe domestic economic problems when World War I and the subsequent Great Depression triggered a significant drop in prices. Citing these cases, Willebald, Badia-Miró, and Pinilla (2015) identify a so-called staple trap, in which export dependence creates lock-in effects that block structural change and impede long-term growth. Even before extracting resource rents, some emerging FFDCs fell victim to a presource curse (Cust and Mihalyi 2017) in which, following discoveries of resources, usually oil, the inflated expectations of immediate richness led to unaffordable consumption, unsustainable borrowing, and growth disappointments, as recently experienced by Ghana (Bawumia and Halland 2017), Mozambique (IMF 2018), Sierra Leone, and Mongolia (Cust and Mihalyi 2017).

- The capital inflows typically associated with fossil fuel extraction raise the real exchange rate and reduce the competitiveness of the rest of the economy. Significant increases in fossil fuel extraction will result in higher exports, but often require foreign direct investment. If these flows are large enough, they will lead to an appreciation of the nominal exchange rate, making the domestic production of other tradables less competitive. This is precisely what happened in the wake of the discovery of natural gas fields in the Netherlands in 1959, and the subsequent gas boom hence is often known as the Dutch disease. This term became widely used in economics (*Economist* 1977) to describe the paradoxical situation in which seemingly good news, such as the discovery of large oil reserves, turns out to have a negative impact on a country's broader economy as a result of the sharp appreciation of the country's currency (Corden and Neary 1982; Gelb 1988). Conversely, one could expect that a decline in the price and value of fossil fuel exports (like we have seen since 2014) will heal Dutch disease automatically and improve the competitiveness of other tradables, although this is not always the case (box 2.1).
- The concentration of large resource rents[1] in one sector of the economy can result in poor governance, which undermines longer-term growth. Van der Ploeg (2011) finds that the resource curse is not inevitable for resource-rich countries and depends critically on the quality of institutions. Often, the significant rents derived from fossil fuel exports benefit elites rather than financially supporting pro-growth policies (Haber and Menaldo 2011). Rents can end up being allocated politically via patronage, such as highly paid public sector jobs, rather than through markets. Resource rents are often either quickly spent by the elite on imported consumer goods or invested inefficiently in "white elephant" projects (Robinson and Torvik 2005). Governments in resource-rich countries are less accountable for public expenditure, which leads to inefficient spending. This results in dominance of "extractive" over "inclusive" institutions, as Acemoglu and Robinson (2012) put it. Extractive institutions also distort the economy, reducing the efficiency of investment, hindering structural change, and hence lowering GDP growth (Auty 2012). Devarajan (2018) concludes that "oil-rich countries systematically misallocate public expenditures relative to non-oil countries—by favoring consumption over capital, and

BOX 2.1 The Oil Price Collapse and the "Reverse Resource Curse"

The oil price collapse of 2013–15 was a mixed blessing for noncommodity sectors in oil-exporting countries.

The IMF (2016) concludes that, while noncommodity tradable sectors suffer during commodity booms, busts generally do not lead to a rapid reversal process. The IMF's cross-country analysis finds that in commodity-exporting countries, manufactured exports respond less quickly to a real depreciation during periods of falling commodity prices than to a real depreciation in periods of stable commodity prices. This may be because a deterioration in the terms of trade leads to the perception that the external economic environment is volatile or because it is typically associated with a downturn in global demand.

The Russian Federation shows these dynamics at work. The noncommodity sectors' response to the near 30 percent depreciation during 2014–16 was weak and unevenly distributed across sectors. Diversification of exports toward non-energy tradable sectors was hampered by structural factors, including rigid product and labor markets, the lack of a financial system that could rapidly shift credit to new sectors, burdensome customs procedures, and restricted access to markets beyond neighboring countries (through trade agreements) (IMF 2017b).

Norway is something of an exception, given that the real depreciation that occurred in the period 2013–15, coupled with relatively low wage growth, boosted domestic tourism and helped traditional manufacturing exports recover somewhat. However, this was a relatively modest, short-lived rebound. Over a longer time frame, structural issues such as stagnant productivity and wage inflation may hold back the further expansion of non-oil sectors (IMF 2017a).

> within consumption, inefficient subsidies and public-sector wages over targeted transfers. Furthermore, for given levels of expenditure, value-for-money is considerably less in oil-rich countries." This challenge has been keenly felt in, for example, República Bolivariana de Venezuela and Gulf Cooperation Council[2] countries, where the private sector is often unable to attract talent because its pay is uncompetitive compared with readily available, well-paid government positions financed by resource rents (IMF 2016). Empirical analysis of the Arab world by Hoda and Zaki (2014) confirms that the curse is largely institutional and can be rectified by reforms of political and economic institutions.

Fortunately, successful risk management strategies are feasible even for countries with significant resource endowments. Experience has shown that primary specialization need not block structural change or hamper economic growth in FFDCs. Countries as diverse as Malaysia and Norway would have experienced relative economic decline if they had failed to restructure their economies and diversify their assets. In fact, in Malaysia, the important increases in GDP per capita occurred only after the country had diversified. As Willebald, Badia-Miró, and Pinilla (2015, 18) note,

> History teaches us that "curses" and "blessings" are constructions—they are the result of the socioeconomic system… Thus, successful experiences of economic development in countries like Australia and Canada highlight the fact that institutions promoting interaction between enabling and receiving sectors are

fundamental to science-based and innovation-driven growth in resource-based economies. It is crucial, therefore, to develop institutional structures to support knowledge capabilities in the growth of natural resource–based industries.

New Risks for FFDCs

FFDCs face two different climate-related risks. First, along with all countries, they face the risk of the physical impacts of climate change associated with weather-related events. Second, they face the macrostructural risk of a transition to a global low-carbon economy. This distinction between different climate-related risks was popularized in 2015 by the Governor of the Bank of England in his speech to Lloyd's, the leading United Kingdom insurance company (box 2.2).

This book only addresses the transition risk. The physical risk associated with weather-related events is broadly covered in the literature, including several World Bank publications (for example, World Bank 2012; Hallegatte et al. 2017; Rigaud et al. 2018). This study uses a broad approach to transition risk—it covers not only financial risks, but also fiscal, economic, and social risks. Liability risk is not covered here because it is largely a specific legal issue, although it may become systemic if the concept of "loss and damage" introduced into United Nations Framework Convention on Climate Change (UNFCCC) negotiations becomes an enforceable economic reality.

The systemic nature of LCT transition risk is well recognized by financial system regulators. For example, several central banks in the European Union (in particular, those in France, the Netherlands, and the United Kingdom) have identified the LCT risk as one of the potential systemic risks to the financial sector and are conducting extensive research to establish how the exposed financial institutions are prepared to manage this risk

BOX 2.2 Climate-Related Risks to Financial and Economic Stability

- *Physical risks*: the first-order risks that arise from weather-related events, such as floods and storms. They comprise impacts directly resulting from such events, such as damage to property, and also those that may arise indirectly through subsequent events, such as disruption of global supply chains or resource scarcity.
- *Transition risks*: the financial risks that could arise from the transition to a low-carbon economy. This risk factor is mainly about the potential repricing of carbon-intensive financial assets, and the speed at which any such repricing may occur.
- *Liability risks:* the risks that could arise from parties who have suffered loss and damage from climate change, and then seek to recover losses from others who they believe may have been responsible.

Source: Carney 2015.

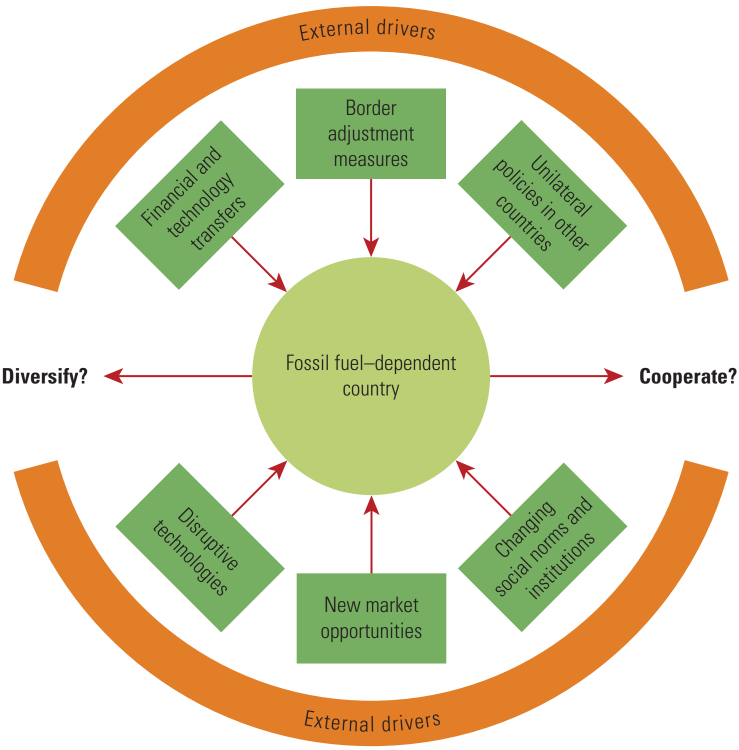
(Bank of England 2015, 2018; French Treasury, Banque de France, and Autorité de Contrôle Prudentiel et de Résolution 2016; Regelink et al. 2017; Schotten et al. 2016). The Bank of Canada has also recognized the issue (Lane 2017). The European Systemic Risk Board found that a transition to a low-carbon economy that occurs late and abruptly could affect systemic risk via three main channels: (1) the macroeconomic impact of sudden changes in energy use, (2) the revaluation of carbon-intensive assets, and (3) a rise in the incidence of natural catastrophes (ESRB 2016). However, most central banks are still cautious about supporting sustainable finance by lowering capital requirements for green lending and penalizing fuel-dependent assets at this stage. They are focused on researching the risks and exploring the macroprudential policy responses.

Anticipating a formal move by financial sector regulators, several commercial banks and insurance companies have begun conducting systematic assessments of their asset portfolios' exposure to an LCT (Redmond and Wilkins 2013; TCFD 2016). Many international and national companies that rely heavily on fossil fuels or carbon-related activities are also assessing future business plans in light of possible developments under a transition (for example, BP, E.ON, RWE, Shell, and Vattenfall), often prompted by concerned institutional investors.

The LCT can take different forms and can affect FFDCs through several intertwined channels (figure 2.1). Some of these impacts are perceived by FFDCs as external shocks or threats, others as external opportunities. Rarely can FFDCs influence the drivers or the pathways of these impacts. The first channel is the emergence of disruptive technologies—partly driven by market forces, and partly facilitated by supportive policies and infrastructure investments in other countries. The second channel involves the deliberate efforts of climate leaders to pursue greenhouse gas emissions reduction through domestic policies, through, for example, administrative measures, price-based policies (removal of fossil fuel subsidies, cap-and-trade systems, carbon and energy taxes), and sectoral policies (especially in energy, transport, industry, and agriculture). Furthermore, the pioneers of climate action can use trade policies to prevent leakage of heavy industry and emissions to "pollution havens" and to make climate action a more comprehensive global endeavor. Eventually the growth of new institutions, sudden shifts in investors' preferences, and changes in social norms may lead to tipping points that fundamentally alter the competitiveness of carbon-intensive activities. An LCT also brings new opportunities. New opportunities for value creation are opening outside of the fossil fuel value chain. The growth of influential new business lobbies can make the transition self-perpetuating (Arbib and Seba 2017; *Financial Times* 2017). Finally, international climate policies may involve financial, technology, and knowledge transfers.

FFDCs can manage LCT risks and tap into emerging opportunities with two broad strategic choices: (1) whether and how to diversify their economies and (2) whether and how to cooperate on global efforts to stabilize the climate (figure 2.1).

FIGURE 2.1 How a Low-Carbon Transition Could Unfold and How FFDCs Could Prepare for It



Source: World Bank.

An LCT: Smooth Sailing or Tipping Points?

The external impact of an LCT would be very different in scale and nature from the historically familiar cyclical volatility of commodity markets. An LCT would lead to a structural decline in fossil fuel–based industries and linked value chains, with associated systemic risks to the countries and communities that depend on them. It would entail a permanent decline in the value of FFDCs' underground and produced assets, and hence their ability to maintain income to finance diversification and meet the needs of their populations. The impact of an LCT could be protracted, especially if coalitions of countries representing FFDCs' major export markets introduce incentive trade restrictions on countries that do not take climate action, as previously studied by Lessman, Marschinski, and Edenhofer (2009) and Nordhaus (2015) in the context of international climate agreements. In recent years, many low-carbon-technology costs have fallen rapidly (Kittner, Lill, and Kammen 2017; Louw 2018), policy ambition has (on the whole) increased (World Bank, Ecofys, and Vivid Economics 2017; IRENA 2017), new low-carbon industrial lobbies and institutions have emerged, and, as shown by pressure on institutional investors to divest their fossil fuel holdings (IIGCC

2017), the social acceptability of emissions-intensive activity is declining (KPMG 2017). These trends are discussed in this section.

Managing the LCT is made more difficult by the uncertainty over the pathways and lead time of structural shifts. The predicament of an LCT is that associated uncertainties are deep. The speed and form of such a fundamental economic and societal change are unknowable because they depend on multiple sovereign decisions not yet made by key players with conflicting visions of the preferred future. Therefore, planning is based on diverging beliefs and wishes involving an LCT, rather than converging probabilities, especially with respect to structural disruptions in transport, energy, land use, and carbon capture and sequestration, as well as future generations' lifestyle choices. Convergence exists in integrated assessment models about what should be done to achieve 1.5-degree and 2-degree Celsius (C) climate goals (Clarke et al. 2014), in which researchers assume similar binding global carbon budget constraints on their models and use backcasting (Robinson 1988) or backward induction (von Neumann and Morgenstern 1953) to identify various pathways to meet these common constraints. Decision-makers, however, must rely on forward induction in their planning, that is, rationalizing the past behavior of other players and pursuing individually preferred futures (Stalnaker 1998). Multiple possible impacts complicate decisions about how to plan for an LCT amid doubt about whether tipping points will materialize within a relevant time frame.

On one side of the spectrum of expected futures, the combination of sunk investments, old networks, entrenched institutions and policies, and opposition from vested interests can put a drag on the pace of transition. Many commentators contrast the bold aspirational objectives of the Paris Agreement with the current trajectory of global emissions and the aspirations of an emerging middle class in developing countries (BP 2017; IEA 2018). They note the limited level of ambition in the first round of submitted nationally determined contributions (NDCs) (UNFCCC 2016) and point to the dependence of many countries on high-carbon infrastructure and the challenges inherent in decarbonizing sectors as diverse as cement, steel, maritime transport, and aviation (Dale and Fattouh 2017; ExxonMobil 2018; IEA 2016). Electrification of transport faces constraints because of charging infrastructure and congestion (KPMG 2017). IEA (2018) forecasts continuous growth of oil demand through the entire forecasting period until 2023, despite market penetration of electric vehicles. Nontransport use of oil is seen by industry as the key demand driver going forward. For example, the 2018 BP Energy Outlook suggests that the noncombusted use of fuels, such as feedstocks for petrochemicals, lubricants, and bitumen, will become an increasingly important component of overall industrial demand by 2040, although the forecasted volumes are a small fraction of the oil used in transport.

Canada, Saudi Arabia, and other countries invest significant research and development (R&D) sums on carbon capture, storage, and use in enhanced oil recovery and in materials, hoping to achieve breakthroughs in technology-driven solutions to climate change. If commercially scalable, these technologies could decouple the growth of demand for fossil fuels from the growth of emissions. On the policy side, OECD et al. (2015) point at the misalignment between existing policy frameworks and climate objectives, which hinders low-carbon investment and consumption choices. Some climate policy reversals and stalls—such as those of Australia in 2013; Poland in 2016; the United States in 2017; Ontario, Canada in 2018; and France in 2018—have added to the confusion about where the world is heading.

Different factors can slow the diffusion of low-carbon technologies. Acemoglu et al. (2012) provide empirical evidence for geographical knowledge spillovers (a firm's choice about whether to innovate clean or dirty is influenced by the practice of the countries where its researchers and inventors are located) and for path dependence (firms tend to direct innovation toward what they are already good at). It is intuitive that innovation activity tends to focus on the dominant technologies, for which returns on incremental improvements are easily observed and understood. Hausmann and Hidalgo (2010) identify a strong quiescence trap in the world, that is, countries with few capabilities have negligible or no return on the accumulation of more capabilities, while at the same time countries with many capabilities will experience large returns—that is, increased diversification—to the accumulation of additional capabilities. This suggests that relatively less diversified FFDCs will find it more challenging to start diversifying their economies than already more diversified countries.

On the other end of the spectrum of expectations, an LCT could gather momentum exponentially, catching FFDCs off guard. The future is unlikely to be a linear extension of the past. Key sectors can reach a tipping point abruptly, creating potentially systemic risk via a macroeconomic "hard landing" and the unexpected revaluation of carbon-intensive assets (ESRB 2016). Tang et al. (2018) and many others argue that China's structural reforms shifting from a labor- and energy-intensive growth model to one that is capital and technology intensive will permanently and structurally reduce coal consumption in the future. As the largest coal, oil, and gas consumer in the world, China is driving the fluctuations in the global market for fossil fuels. Therefore, the effects of a transition are likely to spill across borders because decarbonization policies in other countries are bound to affect global markets (Acemoglu et al. 2012; Cherif, Hasanov, and Pande 2017), especially if other countries apply "carrots and sticks" to encourage a large coalition toward climate action.

There are precedents from the deep structural transformations of the past. Examples from history show how change can happen quickly (Wilson 2012), from the reduced acceptability of smoking in many countries to the rapid emergence of mobile telephony, which has largely displaced (or leapfrogged, in the case of many developing countries) fixed-line telephony. The formative phases of new technologies in the energy sector usually took two to three decades (Wilson 2012), but can be accelerated by policies that break dependency on historical paths and create new market opportunities (Geels 2005; Pearson and Foxon 2012).

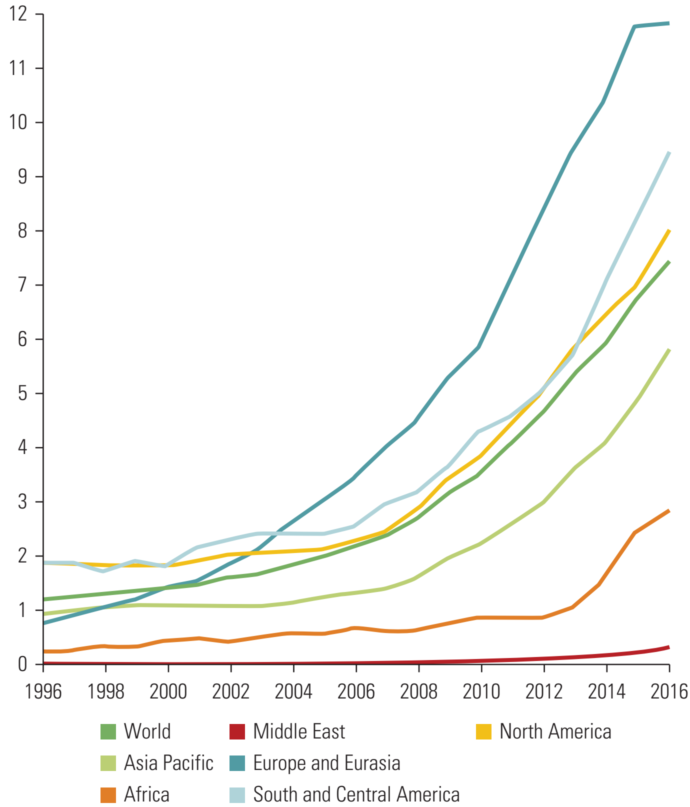
The emergence of tipping points can be ignited by feedback loops that interact across the economy, accelerating institutional and behavioral change. The role of tipping points is crucial in this context (Heal and Kunreuther 2012).[3] The trigger of a tipping point could be a specific climate or energy policy, or a breakthrough technology (such as cheap and effective energy storage); the point is that policies, institutions, and technologies reinforce each other in a positive feedback loop. Indeed, each of these events makes the others more likely to happen, driving expectations and reinforcing the dynamics of transition, potentially leading to rapid and permanent structural market shifts. However, this means that if a tipping point is reached, innovation activity can quickly be redirected elsewhere. Investments in enabling infrastructure (Grübler, Nakićenović, and Victor 1999) can further spur technology tipping points through positive network externalities and increasing returns for the deployment of new disruptive technologies. This can be intertwined with sudden shifts in investor and consumer preferences that accelerate new technology penetration rates. The development of new skills and integrated technologies as well as supportive institutions and consumer behaviors could further facilitate technology cost reductions and policies across the economy (Dechezleprêtre, Neumayer, and Perkins 2015). As more players start to move, expectations of new opportunities can become self-fulfilling.

This book argues that falling costs of new technologies, accelerating policy action, the emergence of new institutions, and changing social norms and investors' preferences are the key drivers of possible tipping points. These and their interlinkages are elaborated in the next subsections.

Falling Costs of New Technologies

The falling cost of key low-carbon technologies has proved to be game-changing by driving the exponential growth of their application (figure 2.2). The unit costs of low-carbon technologies have huge potential to continue to fall as these new technologies are developed and deployed and engineers learn how to cheaply connect and service them. This potential is far higher for new technologies than it is for long-established, high-carbon incumbents.[4] Falling costs have already allowed solar photovoltaic (PV) and onshore wind technologies to become competitive with gas and coal for power generation in a number of locations, even without a high carbon price. The cost of solar PV modules fell by 60 percent in the two years to the first half of 2017 and by a factor of five in the five years after 2008 (Louw 2018). Energy storage prices are falling even faster than solar PV and wind technologies: a recent study finds that R&D investments for energy storage projects have lowered lithium ion battery costs from $10,000/kWh in the early 1990s to an estimated $100/kWh in 2018 (Kittner, Lill, and Kammen 2017). Lower prices and accumulated skills will allow new combinations of solar, wind, and energy storage to outcompete coal and gas on cost in several locations. Policy options identified by Massachusetts Institute of Technology (Hart, Bonvillian, and Austin 2018) could further bolster innovation and grid penetration.

FIGURE 2.2 Nonhydro Renewables Share of Power Generation by Region
percent



Source: BP 2017, © BP p.l.c. 2017. Reproduced with permission from BP; further permission required for reuse.

At a certain threshold of the penetration of nonhydro renewables in electricity generation, the cost of integrating their variable supply into the grid rises steeply, possibly slowing their further expansion. The share of variable renewable energy sources in power generation is still very small—less than 8 percent on average in the world, and much less in developing countries where the grids and institutions that manage them are weaker. For example, grid integration of variable renewables includes costs of grid connection, expansion, and upgrading, plus system operation costs, such as the balancing costs and the costs incurred from reduced utilization rates of existing conventional plants. In less flexible power systems, these costs could reach up to $30/MWh with variable sources' penetration rates of 30 to 40 percent (IRENA 2015). Although these costs should not be entirely attributed to variable renewables, especially when the system is not flexible enough to deal with normal variability (in the short term), nonetheless, they pose an additional challenge for system operation when the penetration rates of variable renewables exceed 10 to 20 percent of total power generation. Rapidly falling costs of electricity storage and progress with smart grid technologies can be a game changer, but the entrenched behavior of consumers and system operators can be more difficult to change, especially in countries with vertically integrated state-owned power utilities where thermal generation and system operation are managed by the same entity.

The success of new technologies depends not only on their costs but also on networks and infrastructure that can lock them in or push them out to the technology "valley of death" (a term used to describe the phase in which a proven technology gets stuck between prototypes and commercialization). Public policies and investments in networks and infrastructure steer the initial course of penetration of future technologies. But once established, successful networks and infrastructure rapidly spread with private investment and creativity. Once publicly funded (Mazzucato 2013), Internet-based networks are already disrupting traditional business models in energy, transport, and tourism, dramatically reducing the transaction costs associated with the market penetration of new low-carbon technologies and behaviors—from roof-top solar panels through energy-intelligent buildings, energy storage to car sharing. The spread of the "Internet of Things" and the near-zero marginal cost of production and distribution technologies (Ashton 2009) can revolutionize manufacturing, boost resource efficiency, and digitalize much of transport and trade (Aguzzi et al. 2014). A 2017 KPMG survey of executives in the automotive industry notes that "the auto industry is lost in transition between evolutionary, revolutionary, and disruptive trends that all need to be managed at the same time" (KPMG 2017, 2).

The energy sector is not the only sector to benefit from productivity improvements associated with an LCT. Data suggest that potential spillovers from low-carbon innovation to other sectors may be higher than for higher-carbon sectors. Using data on 1 million patents and 3 million citations, Dechezleprêtre, Neumayer, and Perkins (2015) suggest that spillovers from low-carbon innovation are more than 40 percent greater than from conventional technologies (in the energy production and transportation sectors). Acemoglu et al. (2012) also make a powerful theoretical case to suggest that once the "clean innovation machine" has been "switched on and is running," it can be more innovative and productive than the conventional alternative. In this scenario, carbon prices may only need to be temporary (necessary for several decades) because the energy and economic system will, over time, become locked into a low-carbon product technology base.

Policy Action Gathers Momentum

Although the UNFCCC negotiations are often seen as moving slowly, explicit or implicit climate policies are being continuously enacted. In 2017 about 67 national and subnational jurisdictions implemented or were scheduled to implement 47 carbon pricing initiatives (World Bank, Ecofys, and Vivid Economics 2017). Yet explicit carbon pricing still covers only 15 percent of global greenhouse gas emissions. The observed carbon prices are low, ranging from less than $1 up to $140 per tonne of carbon dioxide equivalent (tCO_2e), with about three-quarters of emissions covered by carbon pricing priced at less than $10/$tCO_2e$. This is substantially lower than the price levels that are consistent with achieving the temperature goal of the Paris Agreement, in the range of $40–$80/tCO_2e in 2020 (CPLC 2017). Furthermore, Edenhofer (2015) argues that because of widespread subsidies to fossil fuels around the world, the average net global carbon price was negative (even as low as minus $150/$tCO_2$). According to the International Energy Agency (IEA), in 2016 fossil fuel subsidies were equal to $40 per barrel of oil, which is equivalent to an emissions subsidy of $93/$tCO_2e$ (IEA 2017, 84). The estimated value of global fossil fuel consumption subsidies decreased by 18 percent to $260 billion in 2016, due in part to lower prices for main fuels but also to continued efforts at reform (IEA 2017).

Nonpricing climate policy instruments are more widespread than carbon pricing. According to the latest Global Climate Legislation Study, which covers 99 jurisdictions that collectively account for 93 percent of global emissions, the number of climate laws (pricing and nonpricing) has approximately doubled every four to five years: there were 50 laws at the time of the Kyoto Agreement in 1997, about 100 in 2002, about 200 in 2005, 400 at the time of the Copenhagen Accord in 2009, and 850 laws in 2016 (LSE 2016).

The policy-led nature of climate action and its role in driving climate innovation makes the emergence of tipping points more likely. Policy decisions build on each other, and on their consequences. The anticipated payoff to a business or political leader considering investments in renewables and resource efficiency depends on what they expect others to do. If a critical mass of businesses (for example, GM, Tesla, or Volvo), countries (for example, China, or the members of Organisation for Economic Co-operation and Development), or regions (for example, US states and Canadian provinces) are expected to move at scale, the cost of the underlying technologies would be expected to fall faster, niche finance would become mainstream, and new global markets would be expected to expand rapidly.

Many of the policy drivers reflect domestic incentives to mitigate emissions. For example, moving away from burning coal near populated areas and making dense cities more livable through investments in extensive public transport reduce the impact of pollution on health and productivity. The European Environment Agency (2015) estimates that premature deaths resulting from just one particulate pollutant, PM2.5, were about 428,000 in 2014 in Europe alone, with an additional 78,000 people dying each year from exposure to NO_2 (nitrogen dioxide) air pollution. Another study by the Global Commission on the Economy and Climate, led by the World Resources Institute, suggests that the health impacts of PM2.5 exposure (including premature deaths) are between 10 and 13 percent of annual GDP in China (Global Commission on the Economy and Climate 2015). Urban planning can also help relieve traffic congestion, which can lead to significant losses of time and output. Recognizing these opportunities is important in driving change because having domestic incentives to mitigate emissions fosters international cooperation.

At the same time policy reversals can slow down the LCT. Many observers believe that the repeal of the Clean Power Plan in the United States may not be able to turn the clean technology tide in the US energy sector; however, like the repeal of the emissions trading system in Australia, while it did not stop renewable energy penetration, it slowed the transition. A series of regulatory changes implemented by Poland in 2016 were able to effectively freeze the previously buoyant development of wind energy and pushed several existing wind farms to bankruptcy, with negative spillovers to the financial sector, where at least one exposed bank had to make large write-offs to cover losses on wind loans that became stranded assets (wnp.pl 2017). The social unrest of the "yellow vests" in France in 2018–19 over the environmentally motivated fuel price increases casts doubt on the social acceptance of an LCT even among climate policy leaders. These events underscore the importance of smart design and implementation of reforms. In several developing countries, in particular in Asia and Africa, capacity payments and long-term power purchase agreements are locking in large fleets of new thermal, often coal, power plants for decades. Take-or-pay clauses in these contracts already inhibit new renewable energy entrants and lead to the curtailment of existing renewable plants even if their electricity is cheaper to generate than that generated by thermal incumbents. System reforms to enhance flexibility and efficiency and open the generation market to new entrants are often blocked by state-owned, vertically integrated utilities supported by vocal coal mining interest groups.

Emergence of New Institutions

Increased development and deployment of clean technologies can give rise to new industrial lobbies and constituencies, which can help drive green policies and the formation of new regulatory institutions (Lockwood 2013). For example, city mayors promising more bicycle lanes, congestion charging, and pedestrianization garner more public support in dense, resource-efficient cities than in sprawling, car-based ones, whose citizens may instead prefer highways to be expanded and the lowering of fuel costs, which further lock in carbon-intensive infrastructure (Rode, Stern, and Zenghelis 2012). On the other hand, as discussed later, current lobbies' resistance to change can decelerate the transition to a low-carbon economy.

Institutional change can help overcome infrastructural lock-in. As long as one particular technology remains dominant, innovation efforts will focus on products and services linked to the use of that technology, and fewer efforts will be directed at development of an alternative technology and its associated network. However, if institutional change results in a new technology becoming dominant by allowing technology-related tipping points to be reached, innovation activity can shift quickly. A good example is the challenge of developing electric vehicle infrastructure (Eberle and von Helmolt 2010). If electric vehicle infrastructure becomes established, the incentives to conduct R&D on electric cars will increase substantially relative to fuel cell or combustion engine vehicles. There are some signs this may happen—Volvo announced it would stop designing combustion engine–only cars in 2019 and start focusing its R&D on electric vehicles; others have followed suit with their own announcements. Several countries have even announced plans to ban the sale of thermal vehicles (for example, Norway starting in 2025, the United Kingdom in 2035, France and Canada in 2040, and Costa Rica in 2050). Since the Industrial Revolution, firms have been routinely exploiting this path dependence in technology adoption and the network effects to diffuse their innovations and create new markets (Bessen 2014). For instance, realizing that fossil fuel–driven networks are hard to dislodge, in June 2014 Tesla Motors announced it would "not initiate patent lawsuits against" parties who use its technology "in good faith." Some companies have already begun to use Tesla's patented technology. At the same time, Tesla is slow to share its charging infrastructure with other brands and the clause "in good faith" regarding its patents entails following a patent pledge.[5] Toyota also announced royalty-free use of 5,680 fuel cell–related patents.

Changing Social Norms

Changes in social norms can interact with institutional, policy, and technological changes. Social norms can be defined as the predominant behavior within a society, supported by a shared understanding of acceptable actions and sustained through social interactions (Ostrom 2000). Social feedback helps make norms self-reinforcing and therefore stable. However, because people prefer to behave like others, social feedback also makes people vulnerable to abrupt changes resulting from policy changes or elsewhere. For example, regulations on smoking in public places, bans on asbestos, various taxes and subsidies to support R&D in green technologies, and investments in cycling infrastructure and public transport have accelerated the process of shifting norms. Thus, policies can play a significant role by giving people reasons to change their expectations (Young 2015).

Emitting carbon with full knowledge of the damage it causes is increasingly seen in a negative light (Green 2018). This applies in particular to fossil fuels (especially coal and unconventional oil and gas) and particular activities in fossil fuel supply chains (for example, investment, production, and large-scale consumption in coal-fired power stations). The wave of popular lawsuits against US oil companies for health damages caused by climate change has triggered threats of legal action against European oil majors. The concept of "unburnable carbon" (Carbon Tracker Initiative 2011; Griffin et al. 2015) has become widely acknowledged, and civil society actions have started targeting the exploration and development of new fossil fuel deposits. Anti–fossil fuel norms are already concentrating moral pressure on the largest emitters (Collier and Venables 2014). A total of 34 member states of the Organisation for Economic

Co-operation and Development have agreed to end state subsidies that finance the export of technologies to build coal-fired power plants. In 2016, the Chinese central government also imposed a three-year moratorium on the construction of new coal mines and coal-fired power stations, although the government and development banks actively support expansion of Chinese-built coal power plants abroad. Although individual leaders may reverse the policies of their predecessors, the global trend toward greater action is clear. Three-fourths of auto executives surveyed by KPMG (2017) believe that traditional internal combustion engines will remain technologically relevant, but socially unacceptable in five to ten years.

Shifting social norms play a role in increasing the traction of calls for fossil fuel divestment aimed at major institutional investors (Ansar, Caldecott, and Tilbury 2013). Norway's sovereign wealth fund has recently declared its intention to entirely divest from coal, while divestment of US coal has also gathered pace.[6] A number of long-term institutional investors (for example, university pension funds) are under pressure to divest fossil fuel assets. Share prices of sectors that rely heavily on fossil fuels have lagged the S&P 500 average (see "stranded assets total return swap" in Roston [2017]). On the other hand, climate skeptics also step up efforts to influence public opinion. Brulle (2013) finds that donations to organizations that deny global warming are financed by fossil fuel or conservative interest groups and often funneled through third-party pass-through organizations that conceal the original funder.

The Paris Agreement and Global Cooperation to Decarbonize the World Economy

The Paris Agreement is the first fully inclusive international climate agreement. It established a global goal to keep the world's temperature rise this century below 2 degrees C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees C. Each country can determine its own national contribution to that global temperature stabilization objective, recognizing individual circumstances and capabilities. This was different than its predecessor—the Kyoto Protocol—which established a target on greenhouse gas emissions, and broke down the total emissions cap to individual, legally binding commitments, albeit only on a subset of countries deemed developed at that time.

The freedom to choose one's own level of ambition and the nonbinding nature of individual commitments under the Paris Agreement helped achieve universal participation (at least initially). It successfully drew all countries into submitting their nationally determined contributions (NDCs). Several studies showed, however, that the initially submitted NDCs together do not add up to the global effort needed to achieve the global 2-degree C objective (OECD 2018). However, the Paris Agreement is a multistage strategic game. In the following stages a pledge-and-review process is expected to prompt countries to renew their commitments in five-year cycles. Each country's decision to increase its level of ambition is voluntary and no benchmarks for how much to increase the ambition are defined, to say nothing of sanctions. In the absence of enforcement mechanisms, countries are often expected to be willing to increase their level of ambition of climate mitigation action because of "naming and shaming" (Falkner 2016) and moral pressure (Figueres 2016) supported by financial and technology transfers through climate finance and carbon markets from developed to developing countries (Cramton and Stoft 2012; Gollier and Tirole 2015; Jakob, Steckel, and Edenhofer 2014).

Despite its nonbinding nature, the open, bottom-up, flexible architecture of the Paris Agreement provides new opportunities to foster climate cooperation. In contrast to the Kyoto Protocol, where any cooperative climate action had to be negotiated between all parties and agreed upon by consensus, the Paris Agreement opens up room for collaborative, bottom-up, and unilateral initiatives of clubs of countries to launch ambitious climate mitigation actions. The flexibility granted in Article 6 could create an enabling environment to break the impasse in the efforts to establish comprehensive and stable cooperation toward the mitigation goal. Article 6.1 explicitly acknowledges that a group of parties can form a club of the parties to pursue voluntary cooperation to allow for higher ambition in their mitigation and adaptation actions, and Articles 6.2, 6.4, and 6.8 identify market and nonmarket approaches that could operationalize international climate cooperation. Like-minded countries can jointly pursue their own sustainable development objectives—through energy, technology, and climate policies that reduce the use of fossil fuels and push down the costs of low-carbon technologies and infrastructure. They are constrained only by other acts of international law, such as the World Trade Organization, in their choices of the application of "carrots and sticks," including trade sanctions targeted at nonparticipating parties.

Economists argue that in the absence of a global government with coercive powers, any effective and stable international environmental agreement needs to be bound by aligning the self-interests of the participants, hence rendering it self-enforcing (Barrett 1994, 2003; Diamantoudi and Sartzetakis 2006; Hoel 1992; Hoel and Schneider 1997). For a climate action club to be stable, its members should enjoy exclusive benefits and privileges that prevent them from defecting or free-riding on the efforts of other members. Nobel Prize-winning economist Elinor Ostrom, after studying how communities make decisions about their common goods, concluded that two conditions are essential to maintaining cooperation (Ostrom 2000, 2009). One is trust based on a common commitment, and another—enforcement—is based on the principle of reciprocity ("I will if you will").

The Paris Agreement explicitly acknowledges the primacy of domestic self-interest in climate policy by allowing the countries to determine their own NDCs (Cramton et al. 2017; Gollier and Tirole 2015; MacKay et al. 2015). MacKay et al. (2015) argue that individual commitments cannot be meaningfully enforced with reciprocal actions. The pledge and review process built into the Paris Agreement provides some transparency, but not the incentives to ratchet up the level of ambition toward the mitigation objective. Additional incentives may emerge from bottom-up club initiatives outside the legal UNFCCC instruments. Stiglitz (2015, 33) argues that the Paris Agreement cannot rely on public pressure alone to implement existing NDCs because "there is simply insufficient 'solidarity' at the global level."

Once integrated by a common commitment and reciprocity, a club of climate action leaders could start playing a multistage strategic game to entice more reluctant nonmembers to join the club. The menu of incentives a club can apply include financial and technology transfers, carbon markets, and border adjustment taxes (Böhringer, Rosendahl, and Schneider 2018; Cosbey et al. 2012; Kortum and Weisbach 2016; Nordhaus 2015), or other sanctions (Dannenberg 2016). Several authors (Falkner 2016; Keohane, Petsonk, and Hanafi 2017; Victor and Jones 2018) explore various ways to increase the size of the climate action coalition, usually through different forms of pricing and transfer mechanisms (Hovi et al. 2016, 2; Victor 2011). Steckel et al. (2017) propose that climate finance be redesigned as strategic incentives to establish national climate policies, rather than a merely project-by-project incremental financing mechanism. Many other economic and political issues can also be linked to cooperative behavior in international climate games (Barrett and Dannenberg 2016; Carraro 2016; Carraro and Marchiori 2004).

The literature on incentives for climate cooperation is dominated by the old developed-developing countries divide and the assumption that the level of ambition of mitigation action is inversely related to income. Recently, however, several low-income countries that are vulnerable to climate change (such as the Alliance of Small Island States [AOSIS] group) have become global leaders of climate mitigation without waiting for massive foreign financial transfers, although their ability to act is constrained by their lack of resources. This engagement proves that the willingness to cooperate on climate action is no longer determined primarily by income level.

Countries most reluctant to cooperate include those that depend on fossil fuel revenues and energy-intensive power and manufacturing sectors. Many FFDCs—whether low or high income—have been reluctant to implement domestic climate mitigation actions amid concerns that doing so would disrupt their (often narrow) revenue sources and established comparative advantage. Without addressing these concerns, an international coalition may not be comprehensive and stable enough to achieve the mitigation goal of the Paris Agreement. But the architecture of the agreement makes it more difficult for FFDCs to delay or derail proactive action by climate pioneers.

So far, few efforts have been made toward establishing clubs of climate action under the Paris Agreement. The European Union, with its climate-energy policy package, is one example. Other efforts include technology-focused initiatives, such as the Renewable Energy Club established by Germany and nine other countries in 2013, the REDD+ mechanism for forestry, and the Powering Past Coal Alliance launched by Canada, the United Kingdom, and several other countries and stakeholders at COP 23 (Conference of the Parties) in Bonn/Fiji in 2017. The Carbon Pricing Leadership Coalition is another attempt to initiate dialogue between parties that may have aligned interests to harmonize prices of carbon across jurisdictions. The narrow focus, limited participation, and modus operandi of these clubs have not yet achieved a critical mass of market and political power to increase the global level of ambition. The pursuit of scaling up climate finance encounters persistent difficulties (OECD et al. 2015; Westphal et al. 2015). The project-by-project architecture of climate finance generates low flows, high transaction costs, and weak strategic incentives to cooperate (Steckel et al. 2017). Carbon markets are stalled by the prolonged absence of buyers.

In today's interconnected world, tipping point dynamics in any large market or set of large markets will affect the activities of other markets. While those involved in producing and exporting low-carbon goods and services stand to profit, those producing and exporting carbon-intensive goods and services could see their markets shrink and the prices of their outputs fall. Policy actions taken by one country affect other countries as well. The impacts of policies can be propagated through trade, cross-border investment flows, and increasingly also knowledge and information flows—the latter often being truly global: available anywhere, anytime.

Notes

1. *Resource rent* is the difference between the price at which an output from a resource is sold and its extraction and production costs, including normal return. Resource rents are shared in different proportions between the host government and the extractive industry. These proportions depend on the fiscal "take" by the government—through royalties and tax or profit-sharing instruments.
2. The Gulf Cooperation Council countries are Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates.
3. A *tipping set* is a set of agents that, by changing their strategies, can tip the rest of the agents from one equilibrium point to another. If there is a small tipping set, not everyone has to agree to change their behavior: agreement by a small subset will suffice (Heal and Kunreuther 2012).
4. Although the so-called sailing ship effect—whereby the introduction of steamships induced a leap forward in efficiency and design of sailing ships—suggests that incumbent industries can "brush up their act" through competitive innovation when faced with existential competition. The effective development and deployment of fracking technologies illustrates this effect.
5. Tesla's patent pledge can be found at https://www.tesla.com/about/legal#patent-pledge.
6. See "Inside the War on Coal" at the Politico website: http://www.politico.com/agenda/story/2015/05/inside-war-on-coal-000002?utm_term=0_876aab4fd7-d7a965efd7-303449629&utm_content=bufferbaeab&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer.

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3. Potential Impacts on Different Sectors and Countries

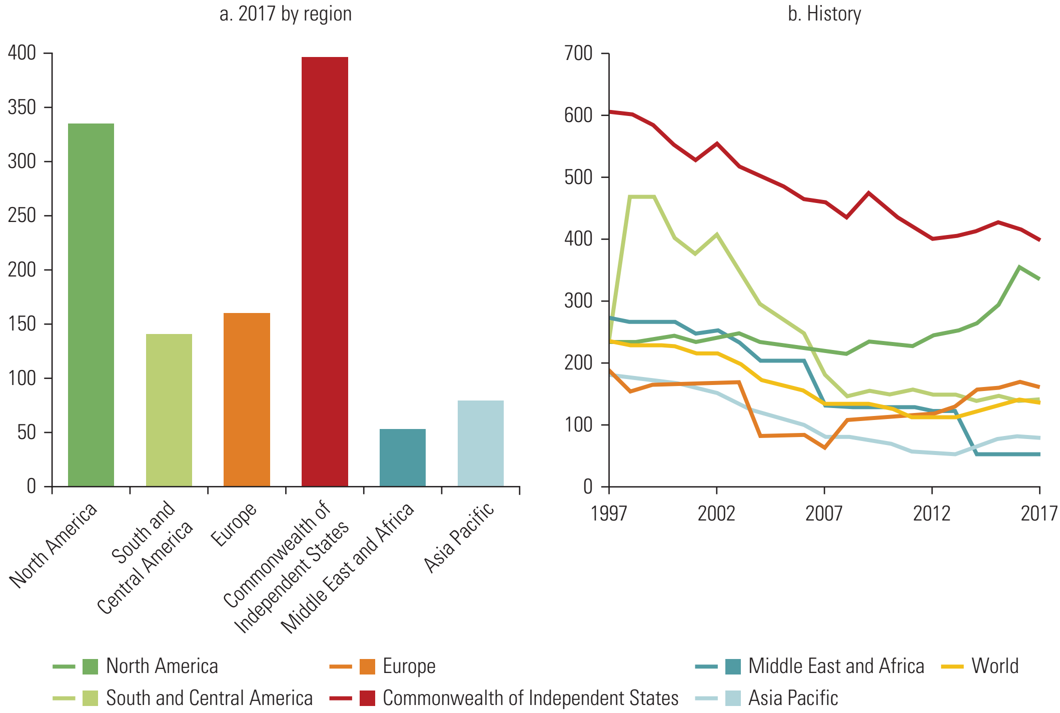
As chapter 2 discusses, a low-carbon transition (LCT) can occur through several intertwined channels, such as disruptive clean technologies, networks that lock in these technologies, shifts in consumer and investor preferences, changes in policies and institutions, and the growth of influential new business lobbies. The combination of these pressures is likely to manifest in different ways across different carbon-intensive activities. Market dynamics and background technological and demand conditions vary significantly across different fossil fuels and carbon-intensive activities. This means that the same underlying drivers can have very different impacts on different activities and hence, on different fossil fuel–dependent countries (FFDCs).

Coal Sector

Coal is the most abundant fossil fuel and arguably the most vulnerable to the impacts of a transition. Known coal reserves are vast; they would suffice for more than 160 years at the current production rate (figure 3.1). In fact, the International Energy Agency (IEA) noted that global coal reserves are far larger than the amounts required even under very long-term business-as-usual scenarios. The notion that reserves will be left in the ground is, therefore, uncontroversial for the coal industry, regardless of climate policies (IEA 2015d, 275). The largest reserves are located in North America, Europe, and Eurasia (figure 3.1).

Coal is also the most carbon intensive of the fossil fuels and all scenarios consistent with a 2-degree Celsius (C) goal show a rapid exit from coal-generated electricity. In addition, coal produces high levels of local air pollution, and it requires large amounts of water when used as a fuel for power generation. Partly as a result of these challenges, confidence in the future of the global coal industry has dropped in recent years. In particular, in relatively wealthy regions of the United States and the European Union (EU), increasing extraction costs and social and regulatory pressure to control local environmental impacts will mean that most of the coal reserves will remain unmined, even without the impact of climate policies. Many of the world's coal assets in the United States and the EU are held by companies already in financial distress: Alpha Natural Resources, a leading US coal producer, filed for bankruptcy in 2015. Peabody Energy, once the largest private sector coal company, went bankrupt in April 2016.

FIGURE 3.1 **Coal Reserves-to-Production Ratios**
years



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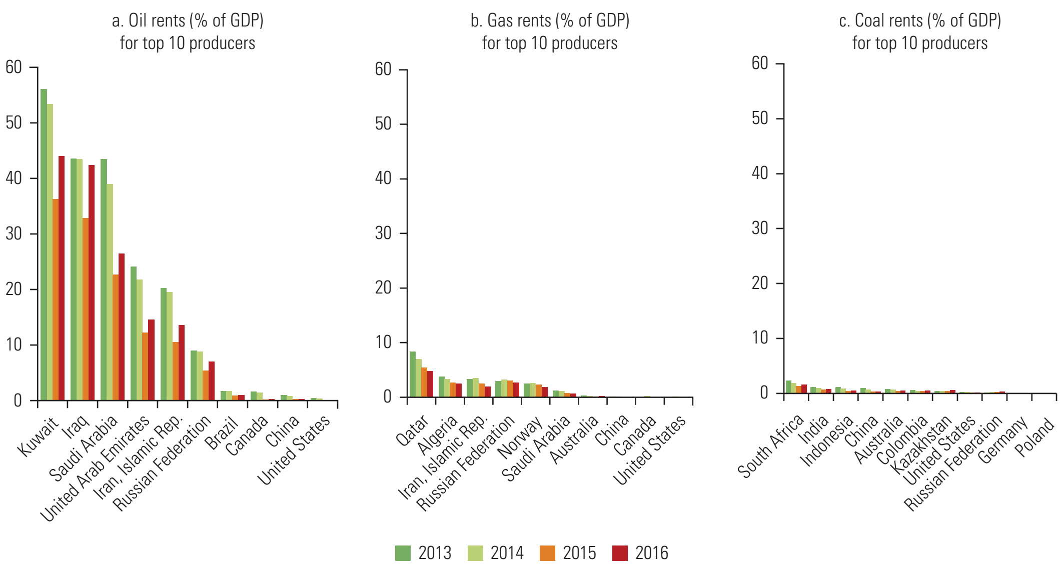
China and the EU, together comprising seven-tenths of the global market for coal, are already signaling shifts away from coal in the power sector, while the largest growing market, India, is seeking domestic self-sufficiency (IEA 2015b).

Market conditions in the coal industry raise the possibility of a "disorderly exit" in the face of decarbonization challenges. Both thermal and metallurgical coal have relatively flat supply curves, in contrast, for example, to oil. This means that a large amount of coal is offered at a similar price level; in other words, if demand declines, no clear merit order suggests which producers will reduce output. Instead they may compete on their short-term operating costs, which is not financially viable in the long term and may impose fiscal and debt burdens on host countries, especially if mines are state owned. Large swaths of the industry could simply close. Mines in North America and Europe may be particularly exposed—not only do they face increasing costs but they are also located far from the growing markets of Southeast Asia and Africa. The transportation costs per unit of energy content of coal are higher than for oil and gas, and lignite is de facto nontradable, although the cheapest coal (for example, that from Columbia and South Africa) can still be competitive in distant markets.

The pressures created by a decline in demand for coal are geographically concentrated and may be severe—especially when local upstream and downstream links are considered—although localized in relatively few places. But coal mining contraction is not likely to cause systemic economic disruption in any country because, unlike the case of oil and gas, even the largest coal exporters do not generate large tax revenues from coal, and rents are generally small (figure 3.2). But locally it can have a major impact. In Poland, for example, coal exports account for an insignificant proportion of total exports. However, the coal-dependent power sector is likely to face serious challenges, especially as new coal power plants are being added with government support, despite the clear decarbonization objectives of the EU energy and climate policy. Sometimes it is not only the coal mining but also coal-dependent transport infrastructure that may be affected by an LCT. For example, Mozambique is contemplating the construction of major new infrastructure to allow the export of its coal reserves. If new railways and ports are designed with a single function in mind, they may generate lower-than-expected income if export markets accelerate the phasing out of coal in their power sectors (box 3.1).

The largest challenge in the coal industry relates to the risk of stranded miners (IEA 2015c). Coal mining is labor intensive compared with oil and gas extraction, with an estimated global workforce of between 7 million and 9.5 million (depending on estimates), 5.3 million of whom are in China (Sartor 2018). Revenue per employee tends

FIGURE 3.2 Fossil Fuel Rents as a Share of GDP for 10 Top Fuel Producers, 2013–17



Source: World Bank World Development Indicators.

Note: GDP = gross domestic product.

BOX 3.1 Coal Transport Infrastructure: Risk of Stranded Assets in Mozambique

Mozambique intends to develop its remote reserves of coal and build a major railway to bring coal to domestic markets. Its coal reserves are located in sparsely populated rural areas, far from transport routes that could bring coal to the international market. For several years the government has been trying to raise funds for the construction of a railway route that would connect mines with ports, but so far without success.

Mozambique continues to have a hard time finding lenders willing to finance the planned railway. The country has insufficient fiscal space for such a large loan. Additionally, the drop in international demand for coal and the resulting drop in its price have made it harder to attract direct investors. Two Indian companies have bought extraction and operation licenses in two large mines but have frozen their capital expenditures, and not a single investor has expressed interest in coal *exploration*.

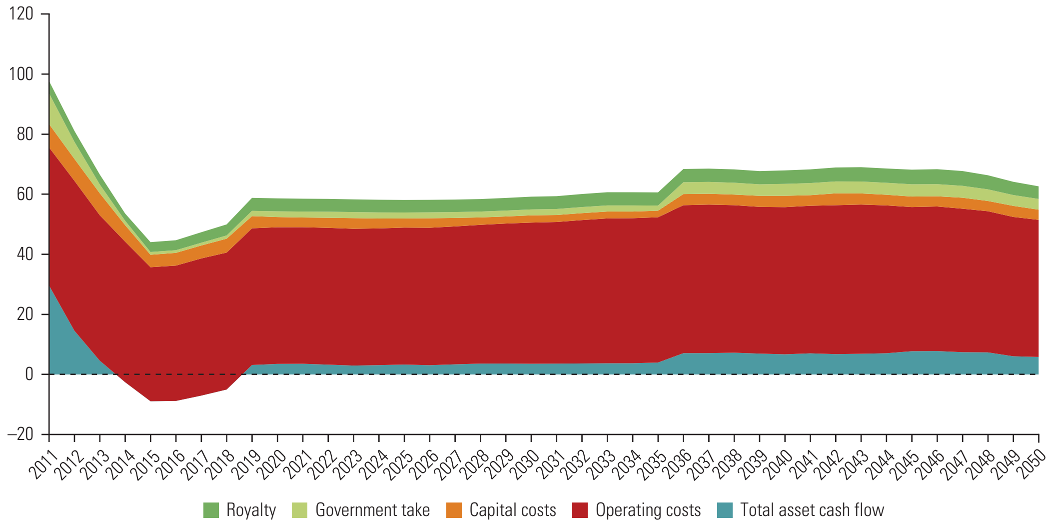
Even if short-term market dynamics were to reverse, significant uncertainties surround coal demand that may lead to these transport assets becoming stranded in the long term if constructed. In the medium to long term, global demand for coal may either rebound or continue contracting because of the low-carbon transition in other countries. Thus, under some of the future scenarios (marked by high uncertainty), today's investments in this sector—both in exploration and in upstream infrastructure—may yield lower returns than expected, or may even entail the decommissioning of certain facilities before they reach the end of their economic lifetime. The railway infrastructure, in particular, could be exposed to the risk of capacity underutilization if built for the freight transport of coal. Instead, a more expensive, multifunctional railway system could be built to stimulate regional development and the export of agricultural products from currently isolated communities.

to be about 70 percent lower than in the oil and gas industry, with a much higher proportion of revenues accounting for operating costs, predominately labor (figure 3.3). Because labor is the least mobile factor of coal production (given the geographic and skill constraints of a coal workforce), the coal industry's decline puts greater social and political pressure on affected mining regions than the decline of other sectors potentially affected by an LCT, as discussed in several papers produced under the Climate Strategies and IDDRI (Institute for Sustainable Development and International Relations) Coal Transition Initiative (Sartor 2018).

Oil and Gas Sectors

Currently, the oil and gas sectors are experiencing less immediate pressure from an LCT than coal, but future stakes are more significant in economic terms. Both oil and gas are still expected to play major roles in future energy even as the world is moving toward an LCT, providing between 45 and 50 percent of global primary energy in 2040 in the IEA Sustainable Development Scenario (IEA 2017). This reflects the expected continued role for hydrocarbons as a transport fuel and in many industrial applications, and the flexibility of gas as a fuel for electricity generation. Global oil reserves are sufficient

FIGURE 3.3 **Breakdown of Coal Sector Cash Flow, 2011–50**
US$/tonne

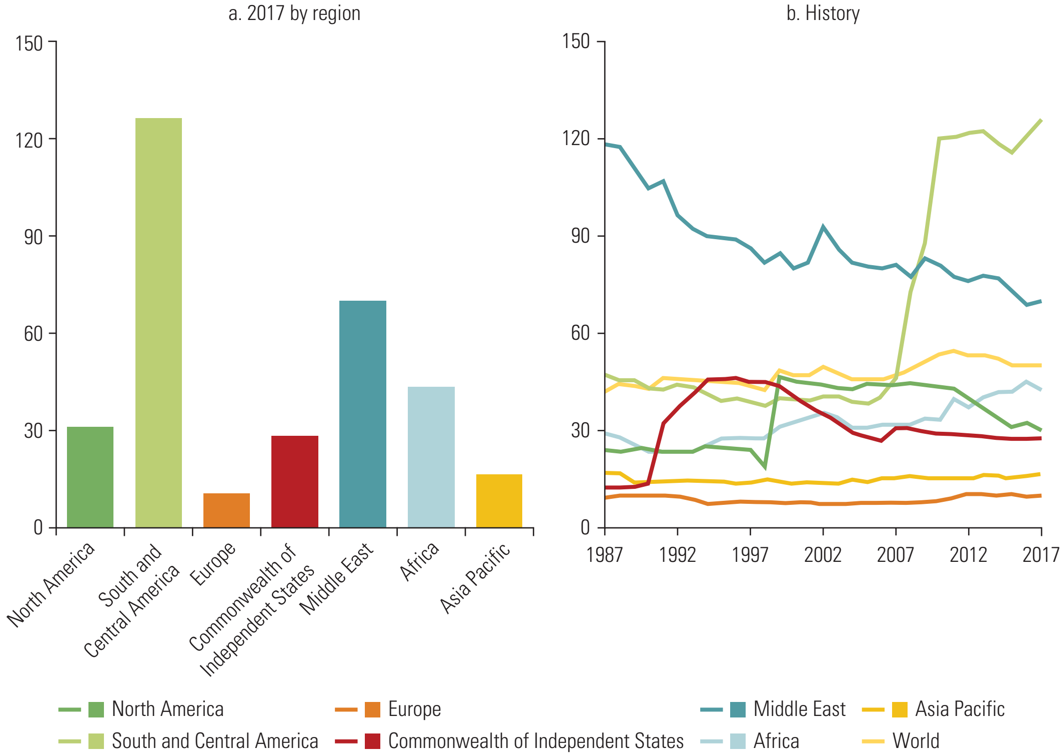


Source: Analysis based on Wood Mackenzie (accessed May 31, 2016), https://www.woodmac.com/research/products/upstream/global-economic-model/.

for about 50 years with current consumption rates and are higher than 30 years ago (figure 3.4). The reserves-to-production ratio has been relatively flat or increasing during the past 30 years because of the exploration for and discovery of new reserves and improvements in extraction efficiency. In effect, the world is not running out of oil soon, and without exogenous policy or market forces to reduce demand, an LCT will not be driven by supply constraints. The growth of reserves was mainly driven by new discoveries in South and Central America, where the largest global reserves are located, followed by discoveries in the Middle East.

At the same time, the competitive dynamics of the sectors have changed drastically as the result of a technological revolution. The combination of horizontal drilling and hydraulic fracking techniques have enabled oil and gas to be extracted in vast quantities from shale reserves in the United States at a cost as low as $60 per barrel of oil, with costs continuing to fall and significant efforts being made to extract oil and gas from shale in other countries. Shale production introduces competitive pressure into the sector because extraction is less capital intensive and has shorter lead times than other marginal sources of supply (Wang et al. 2014; Kilian 2016). The fall in oil prices since mid-2014 was due in large part to conventional producers, particularly Saudi Arabia, responding to this pressure (Behar and Ritz 2017). On the demand side, the tightening of vehicle fuel efficiency standards, new battery technologies, and infrastructure supporting electric vehicles create uncertainty about the peak demand for oil, while the switch to renewable energy in power systems and demand-side energy management make future demand for gas uncertain.

FIGURE 3.4 Oil Reserves-to-Production Ratios
years



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The competitive pressures from shale may also feed into global gas markets via liquefied natural gas (LNG) exports. LNG provided 60 percent of interregional gas trade in 2014, and the IEA expects LNG volumes to increase by 50 percent by 2020 (IEA 2015a). This boom has been driven by high gas prices outside the United States, but the start of LNG exports linked to US gas prices in 2016 exposes international markets to the competitive pressures of US shale gas. Even when US gas prices are not used as a benchmark for global LNG trade, the growth in LNG means that regional gas markets are likely to become more competitive in the future because LNG can connect them all. Moreover, cost reduction and higher flexibility thanks to floating offshore gas terminals could further disrupt the energy sector. Nonetheless, with the current production-to-consumption ratio, the current known gas reserves are vast—enough for more than 60 years. The largest gas reserves are located in the Middle East, followed by the Commonwealth of Independent States and Africa (figure 3.5). The global reserves-to-production ratio has been relatively stable for the past 30 years, suggesting that, as with oil, gas scarcity is not imminent.

Shale oil is expected to provide most of the new oil supply in the coming decades. Figure 3.6 shows the expected sources of oil supply to 2050, based on an analysis of Rystad's Ucube database. Current sources will continue providing 60 percent of total supply in 2025, whereas conventional sources currently under development will supply only 10 percent. Shale oil production in the United States has already surpassed that in Saudi Arabia or the Russian Federation, and new developments, largely from shale, may provide 30 percent of oil supply in 2025.

Uncertain demand and competitive supply pressures are likely to make investors much more selective when developing new resources with large capital needs, long lead times, and high break-even prices. The resilience of US shale oil producers to the oil price shock of 2014 proved that supply-side efficiency through technology progress and management changes can be very responsive to prices, even in a relatively short time. Several analysts agree that the oil reserves that are probably most exposed to competitive pressure are oil fields in the Arctic, tar sands in Canada, and some not-yet-developed deepwater and ultra-deepwater reserves (figure 3.7). In 2017, for example, Shell decided to divest its Canadian oil sand interests, which is one of the highest-cost sources of crude oil.

FIGURE 3.5 Gas Reserves-to-Production Ratios
years

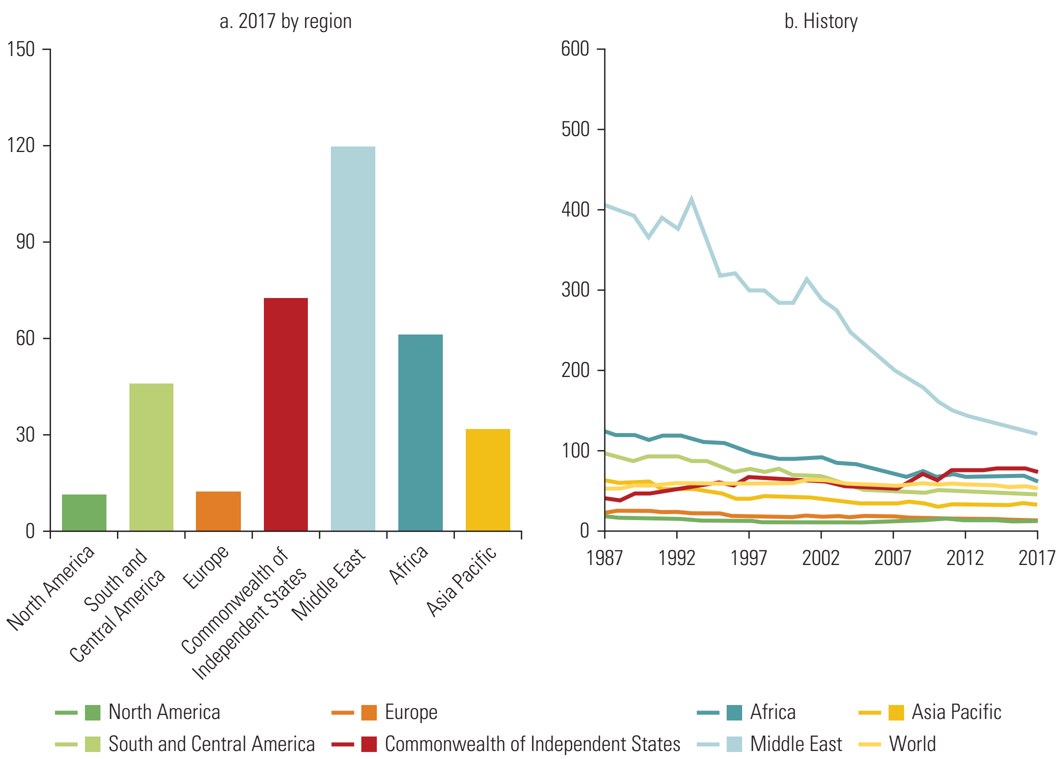

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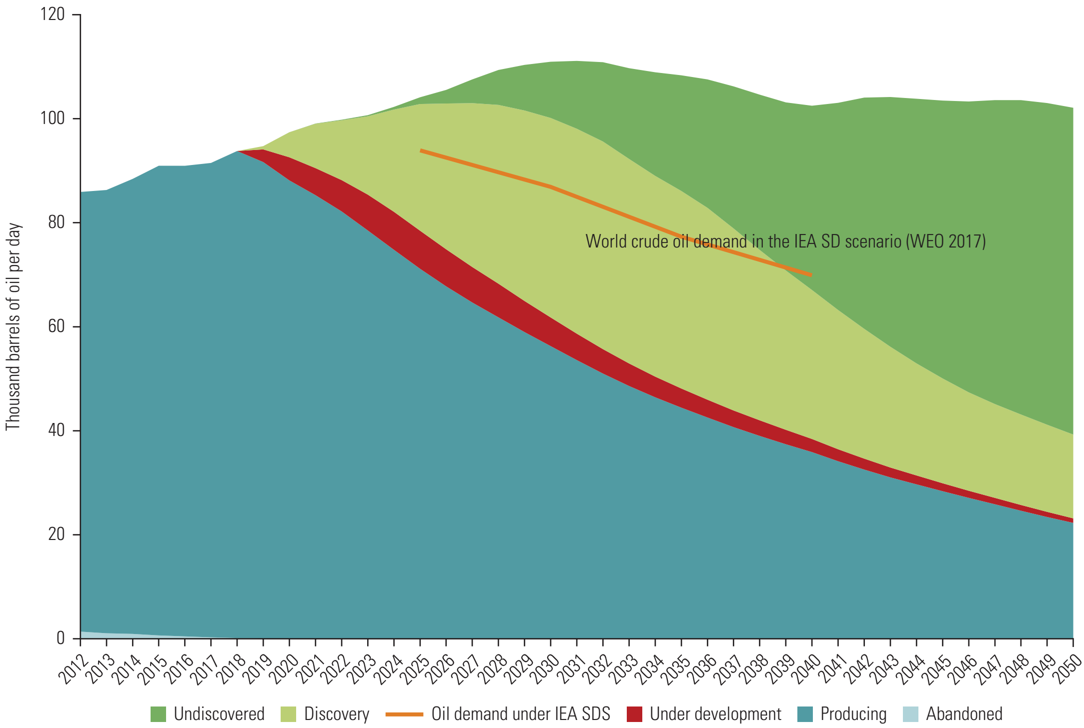
FIGURE 3.6 **Room for New Oil and Gas Field Development in 2-Degree Celsius IEA Scenarios**



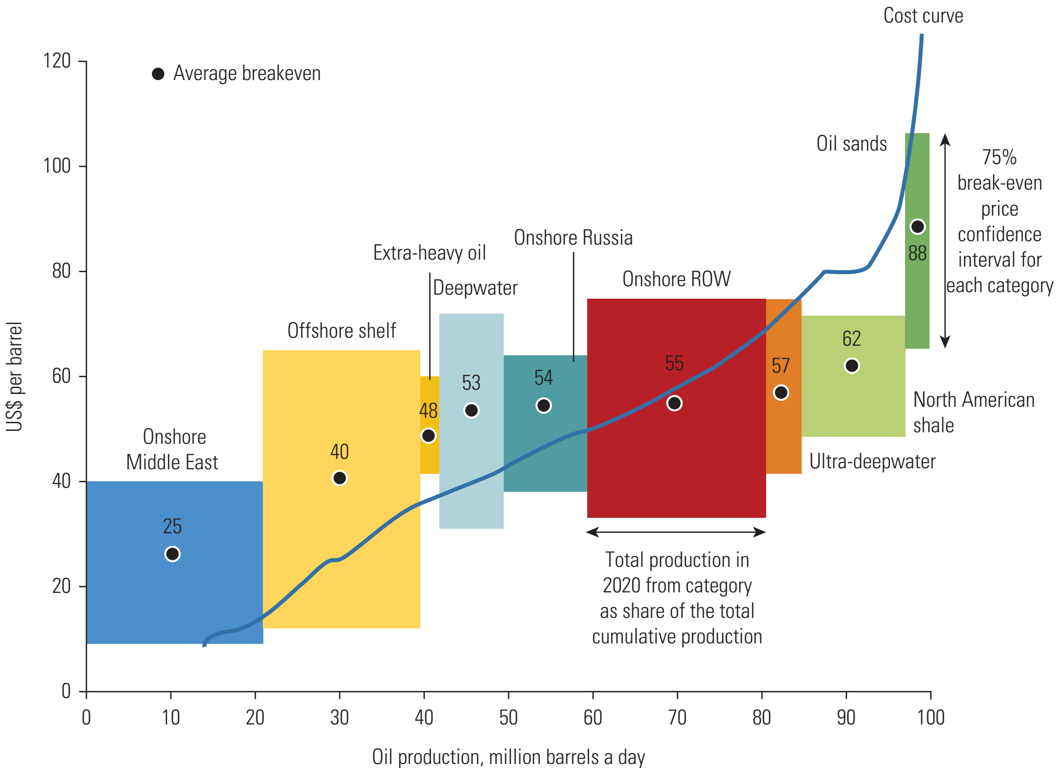
Sources: Based on Rystad Ucube, March 2019; IEA WEO 2017 Sustainable Development Scenario.

Note: IEA = International Energy Agency; SD = sustainable development; SDS = sustainable development scenario; WEO = World Energy Outlook. Figure shows global liquids supply to 2050 split by life cycle category. Crude oil, condensate, and natural gas liquids are included.

These technological changes mean that "peak oil" is much more likely to be driven by demand-side pressures—in other words, decarbonization—than supply-side constraints. Historically, there has been huge concern about global oil production becoming constrained by limited availability. These demand-side decarbonization pressures will play out in increasingly competitive and fragmented oil and gas markets, most likely dominated by low-cost existing producers and a competitive fringe of shale producers. By contrast, the development of high-cost, conventional reserves may become increasingly uncompetitive, especially given their high capital needs and long lead times.

For instance, Brandt (2007) analyzed 139 potentially overlapping oil-producing regions throughout the world and argued that production in 123 regions could be reasonably modeled as single-peaked and that production in 74 of these regions had, in fact, already peaked. The potential political, social, and economic repercussions of peak oil resulting from supply-side constraints were a major focus of other studies (Hirsch, Bezdek, and Wendling 2005; Heinburg 2005). By contrast, the shale revolution means that most industry observers now consider demand-side constraints far more likely to lead to peak consumption, with some studies supported by oil majors

FIGURE 3.7 Global Oil Supply Cost Curve and Break-Even Prices



Sources: Rystad Energy research and analysis; IMF staff calculations (Arezki and Matsumoto 2017).

Note: The break-even price is the Brent oil price at which the net present value equals zero, considering all future cash flows, using a real discount rate of 7.5 percent. Oil refers to crude oil, condensate, and natural gas liquids. ROW = rest of world.

suggesting this peak consumption could be reached in the 2020s or 2030s (*Financial Times* 2017). Similarly, Helm (2017) argues that technology innovation and the global move toward the Internet of Things will inexorably reduce the demand for oil, gas, and renewables—and prove more effective than current efforts to avert climate change. He argues that both oil companies and fossil fuel–exporting nations will need to adjust to the permanence of low demand for, and low prices of, oil.

Oil is responsible for most of the economic dependence on fossil fuel rents and exports. The importance of oil rents and export revenue for the total output of the economy (for the period 2013–17) dwarfs that of gas and coal for major exporters of each fuel (figure 3.2).

Depending on assumptions made about future technologies and policies to generate negative emissions after 2050 (that is, to remove carbon from the atmosphere and sequester it in the ground or in a forest), there may still be room for limited new exploration and new oil and gas field development in the face of an LCT that is consistent with the 2-degree C goal, although supply competition would be tighter, as discussed earlier in this chapter. The decline in production of the fields currently in operation—estimated at 6 percent per year (Statoil 2017)—is higher than the decline in global demand for oil and gas in the scenarios consistent with the 2-degree C goal. This is illustrated in figure 3.6, in which the global oil supply split by life-cycle category from Rystad is overlaid with world primary energy demand from the IEA Sustainable Development Scenario (IEA 2017), which is compatible with the 2-degree C target. Other analysts confirm this observation, for example, Statoil (2017). Even Carbon Tracker (2017) argues that only one-third of new oil development projects are "not needed" in a 2-degree C constrained future.[1] However, this fraction is dependent on many uncertain factors, including the sensitivity of the climate system and the ability to remove carbon from the atmosphere after 2050. In many scenarios, though, FFDCs have access to increasing revenues from oil and gas sales to finance diversification, although an LCT will increase competition and cause revenues to grow more slowly than many in the industry currently expect (Peszko, van der Mensbrugghe, and Golub 2020).

Refineries

Refineries are likely to face the same pressures as oil, but amplified. Refineries take crude oil as an input and transform it into refined products, such as gasoline and diesel and jet fuel. They therefore would face declines in demand as refined products are taxed, biofuels displace refined products, and consumers switch to electric vehicles and more efficient modes of transportation. This is the same pressure that oil production faces, but refineries tend to have thinner margins because they are more competitive than crude extraction given their relatively similar cost structures.

Refineries differ in their complexity, with more complex refineries typically enjoying higher margins. Complexity describes a refinery's capability to convert lower-quality crude oil into higher-value refined products. Complex refineries have historically been more competitive on an operating basis because lower-quality crudes—those that are heavier (with longer hydrocarbons) and sour (with a higher sulphur content)—have been more abundant and therefore cheaper. This has generally led to a higher margin on an operating cost basis (the net cash margin). This higher net cash margin has tended to compensate for the higher capital costs of more complex refineries.[2]

The availability of higher-quality crude from shale may erode the competitive advantage of complex refineries. Crude oil from shale tends to be lighter and sweeter than conventional crude oil. The large amount of shale oil that has become available in recent years has lowered the cost of light, sweet crude, and in parallel reduced the cost advantage that more complex refineries used to enjoy thanks to their use of heavy, sour crudes.

Moreover, the relatively complex refineries tend to be more energy intensive, which will most likely lead to a disadvantage in a low-carbon world. The 41 lowest-complexity refineries use, on average, 1.75 gigajoules (GJ) of energy per ton of crude processed, while the 40 highest-complexity refineries (with an index of greater than 10.5) use, on average, 4.64 GJ of energy per ton of crude. Han et al. (2015) find a similar result across 61 refineries in the United States and the EU. Because an LCT is expected to increase energy costs, the margins of the more complex, and thus more energy intensive, refineries will come under pressure.

The extent to which complexity will improve refineries' resilience or represent a liability for them in a low-carbon world remains unclear. The outcome depends on the extent to which energy costs increase, the extent to which shale oil reduces the relative competitiveness of complex refineries, and the pace at which new refineries are opened in non-OECD countries, as well as their level of trade with OECD countries. Refineries often seek protection from competitive pressure through vertical integration with fuel suppliers. This structure may prompt parent oil companies with deep pockets to inject liquidity in bad times for refineries. In the long run, however, constraints in competitive sourcing of crude supplies may also be a source of risk for refineries.

Carbon-Intensive Manufacturing: Steel and Cement

The importance of steel is likely to remain unchallenged as economies develop, with production expected to increase from 1.6 million tonnes[3] in 2015 to 2.8–3.6 million tonnes by 2050. Concerns in the industry seem less focused on the impact of an LCT than on the unequal levels of climate policy ambition across countries, which could jeopardize fair competition in the sector (WSA 2019). Steel can be produced in two ways: through the more emissions-intensive, basic oxygen furnace (BOF) process, which uses iron ore and coking coal; or the less emissions-intensive electric arc furnace (EAF) process, which primarily uses scrap steel and electricity. The share of BOF in global steel production in 2014 was 74 percent, while the share of EAF was only 26 percent. Estimates of current steel-related emissions range from about 2.5 billion tonnes (WSA 2019) to up to 2.9 billion tonnes (McKinsey & Company 2018), not counting mining and transportation, with BOF accounting for 90 percent of these emissions. Coal is difficult to substitute for in the BOF process, while the EAF process is constrained by the availability of scrap metal, particularly in developing countries with limited scrapping and recycling (given their relatively new infrastructure).

Cement is less internationally traded (except over relatively short cross-border distances), and very carbon intensive. Production is concentrated in countries with the highest level of construction activity, particularly China, which accounts for more than half of the world's cement (*Reuters* 2018). Cement accounts for 34 percent of industrial direct emissions (IEA 2015b) and for 5 percent of total global emissions. Nearly two-thirds of cement emissions come directly from the production process, with the remaining third from energy use. With China's change in its growth model, global demand for cement is already stabilizing and may peak soon in other countries (figure 3.8).

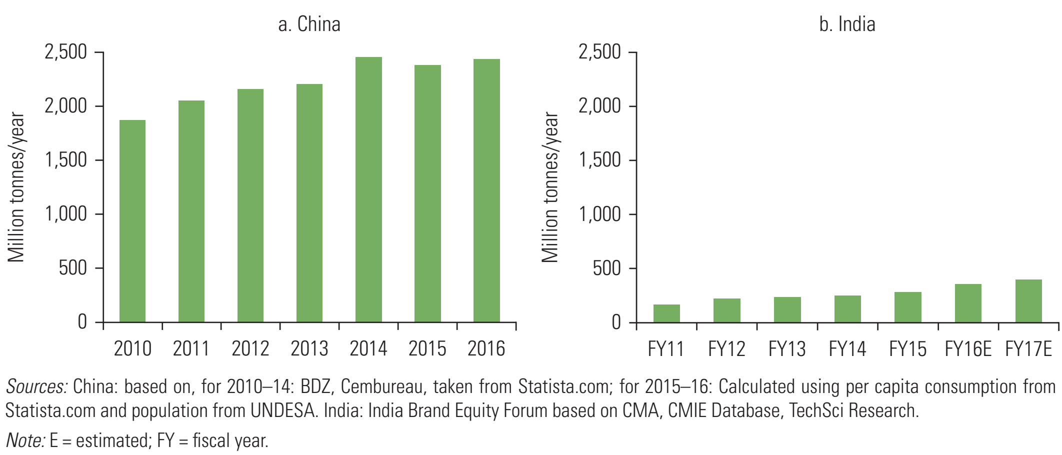
Overall, the emergence of fundamentally different technologies and materials is difficult to foresee in the short to medium term; the largest pressures will probably be concentrated in specific regions as a result of asymmetric carbon intensities. No other materials currently provide sufficient strength and flexibility at the cost of steel, while there are significant interdependencies between the use of cement as a bonding agent and other building materials in the construction sector.

An LCT would mean that the most carbon-efficient producers would stand to gain market share. Competitive positions can still be disrupted in the transition to a low-carbon world if faced with global cooperative action or border carbon adjustment measures, particularly for steel and cement manufacturers with significantly higher carbon intensities than others. In the steel sector, plants exhibit major differences in energy intensity, while in the cement sector, there are differences in energy efficiency, fuels used, and levels of clinker use. In both sectors, carbon capture, use, and storage could become a crucially important technology.

Why Focus on Sovereigns and State-Owned Enterprises?

Much attention has been given to the impact of an LCT on international extractive companies.[4] Less attention has been paid to the impact on FFDCs and state-owned enterprises (SOEs)—to what extent they may be affected, and what economic growth

FIGURE 3.8 Domestic Consumption of Cement in China and India



Sources: China: based on, for 2010–14: BDZ, Cembureau, taken from Statista.com; for 2015–16: Calculated using per capita consumption from Statista.com and population from UNDESA. India: India Brand Equity Forum based on CMA, CMIE Database, TechSci Research.

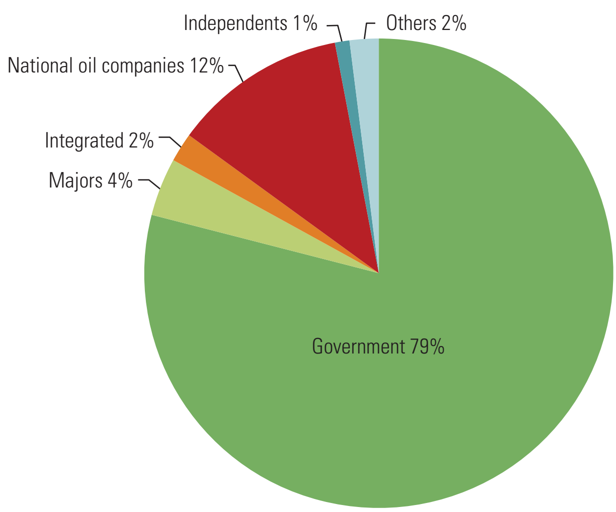
Note: E = estimated; FY = fiscal year.

and development strategies they should adopt in anticipation (CPI 2016; Helm 2017). Previous analysis (Nelson et al. 2014) suggests that governments rather than corporations bear the brunt of transition risks. And this book's analysis suggests that governments can expect to receive almost 80 percent of the net present value of future oil and gas revenue, with a further 12 percent of future revenue flowing to national oil companies (figure 3.9). Although these figures are more extreme than for gas and coal extraction (figure 3.10) or carbon-intensive industries, they demonstrate that there may be acute direct exposure and impact to governments themselves.

Historically, several countries relied heavily on fossil fuels to generate export revenues (figure 3.10). Most of this export dependency affects oil-rich countries and, rarely, gas exporters (for example, Qatar). An abundance of coal, as discussed earlier, does not lead to the Dutch disease.

The Climate Policy Initiative (CPI 2016) designed a methodology to assess the impact of climate-related policies on national budgets over the medium and long term, including the fiscal implications of falling natural resource–based revenues. It recommends that governments model different demand scenarios for their resources over the next 20 to 30 years to assess the impacts of changes in demand, costs, and prices on their key assets and cash flows—taking care to separate the impact on the public sector from that on the private sector.

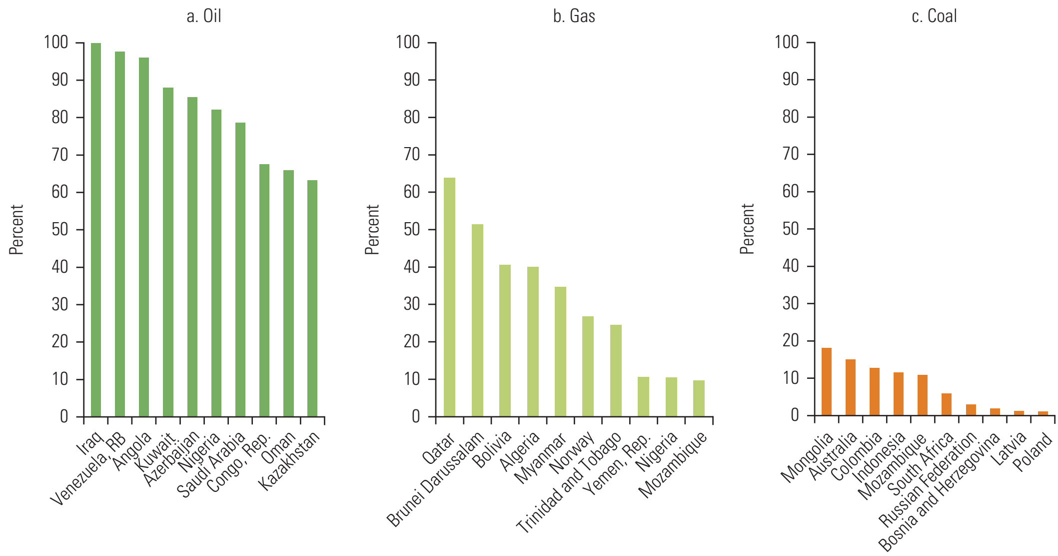
FIGURE 3.9 Shares in Expected Revenue from Oil and Gas between 2013 and 2050



Source: Analysis based on Rystad UCube database.

Note: Majors = international companies. Net present value calculated using a 6 percent discount rate. Coal revenues are not included because they are negligible.

FIGURE 3.10 Export Revenues from Fossil Fuels as a Share of Total Export Revenues for the Top 10 Most Dependent Countries (2013–17)



Source: Based on World Development Indicators database.

Moreover, SOEs face institutional constraints that make it harder for them to respond to transition risks. SOEs often have other important mandates aside from those related to their core business—providing employment and investing in infrastructure, for instance. These additional, noncommercial mandates may limit their flexibility to respond to risks. In addition, because SOEs' financial capital is often concentrated in their home markets and their access to international sources of capital is limited, they are also less flexible than private companies with regard to sources of capital. Human capital likewise tends to be concentrated in the SOE's home country and often lacks the technical know-how required for the use of state-of-the-art fracking and deep-sea exploration technologies. Finally, SOEs often vehemently defend their vested interests, successfully preserving the status quo and thus frustrating government efforts to prepare for a transition (see the section "Traditional Diversification" in chapter 4).

The resource rents of many FFDCs finance a range of essential expenditures. The development plans of middle- and low-income countries—such as Angola, Cameroon, Kazakhstan, Mozambique, Myanmar, Tanzania, and Uganda—often rely on realizing direct rents from carbon-intensive activities to invest in the health, education, and infrastructure needed for continued development and to lift the remainder of their populations out of poverty. The indirect tax revenues derived from the multiplied impact on wages, salaries, and profits distributed through, and spent in, the rest of the economy will also affect public finances through a lower tax take. Countries with histories of conflict, such as Iraq and Libya, have few alternatives to fossil fuel revenues to finance the reconstruction of their economies and restore prosperity.

An emerging qualitative literature studies the risk of stranded assets in countries that depend on fossil fuel resources. For example, Caldecott et al. (2016) discuss the challenges and opportunities facing lower-income and emerging market economies in Latin America and the Caribbean if their fossil fuel resources become "unburnable" given carbon budget constraints. In a similar vein, Manley, Cust, and Cecchinato (2017) qualitatively discuss the challenges to stranded nations under constraints of "unburnable carbon." They conclude that these fossil fuel–rich countries are exposed to the risk of permanent loss of value of their underground wealth, and that they may be pursuing policies that increase their exposure and result in them being less able to manage the related risks. Cust and Manley in Lange, Wodon, and Carey (2018) use the wealth accounting framework to estimate and discuss the carbon wealth of nations—the value of fossil fuel reserves—and the risks that advances in technology and climate policies may pose to the value of this wealth.

Formal models are beginning to be applied to support analytical work on stranded assets. Makarov, Chen, and Paltsev (2017) applied the Massachusetts Institute of Technology (MIT) Economic Projection and Policy Analysis model to assess the impacts of the Paris Agreement on the Russian economy. The study simulates the impacts of alternative global emissions constraints, some based on the Paris Agreement nationally determined contribution pledges and others in which mitigation efforts are increased after 2030 to be on a 2-degree C trajectory. Interestingly, the study also simulates three simple diversification scenarios with which Russia can prepare for these impacts. The authors find that Russia could best mitigate the adverse impact of climate policies by diversification of the economy, moving to low-carbon energy sources, and investing in human capital development. Climate Policy Initiative (Nelson et al. 2014) explores the impact an LCT would have on the value of investor portfolios when fossil fuel assets lose value because they are left in the ground or produce lower returns from declining demand and price. They apply regional and global economic single sector models for coal, oil, natural gas, and power to examine how the decline in value would be spread between governments and investors and among various countries, and how both the level of stranded assets and their distribution would depend on policy. They conclude that governments, rather than private investors and corporations, face the majority of stranding risk.

Notes

1. The Paris Agreement has another aspirational goal of 1.5 degrees C, in which case additional new oil development projects "would not be needed."
2. World Bank analysis of Wood Mackenzie data, 2014.

3. The *tonne*, commonly referred to as the *metric ton* in the United States, is a non-SI (International System of Units) metric unit of mass equal to 1,000 kilograms. For practical reasons, this book uses the term tonne rather than metric ton.
4. See, for example, the work of the Carbon Tracker Initiative (www.carbontracker.org) and the Task Force on Climate-Related Financial Disclosures (www.fsb-tcfd.org).

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4. Strategic Framework for Dealing with the Potential Impacts of a Low-Carbon Transition

Although we have established that deep uncertainty is a predicament of a low-carbon transition (LCT), this book argues that this uncertainty is not a good excuse for inaction. Pasteur's (1854) observation that "fortune favors the prepared mind" is more relevant than ever for an LCT because surprise impacts can be systemically disruptive. Financial institutions, insurance companies, and financial system regulators are already taking measures to manage this risk. Successful decisions under deep uncertainty require the consideration of many possible futures and being prepared for plausible best-case and worst-case scenarios.

This chapter analyzes different strategic options that FFDCs could use to adequately prepare for, and respond to, a global LCT, whether the transition is driven by technology or policy. This study focuses on two key sets of strategic choices to manage its impacts:

1. Diversification strategies can take one or both of the following forms:
   - Downstream industrialization within the fossil-fuel product space through traditional diversification of outputs and exports, for example, through supporting domestic use of fossil fuels
   - Diversification of the broader economic asset base, including investment in renewable natural capital and intangible assets, such as institutions and human capital, that can drive a transition toward a productivity-driven, knowledge-based economy.
2. International cooperation strategies involve the following:
   - Commitments to domestic climate policy instruments that are aligned with a club of countries committed to emissions-mitigation actions, with benefits linked to climate club–exclusive privileges (for example, in the domains of trade or financial and technology transfers)
   - Abstention from such internationally coordinated policy actions (free-riding).

These two strategic choices are unpacked in the remainder of this chapter.

Diversification Options for FFDCs

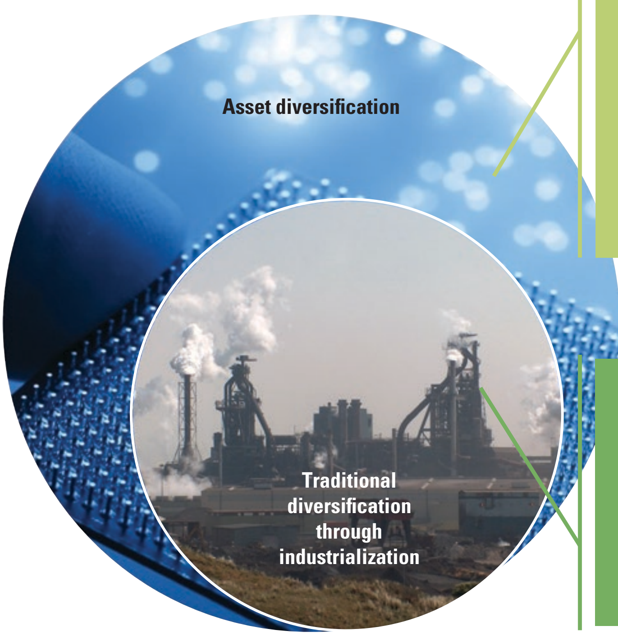
The broad diversification strategies analyzed here are not alternatives, and can be pursued jointly, depending on a country's existing strengths, market position, and accumulated skills and capabilities. Asset diversification can be seen as an extension of traditional export diversification (figure 4.1). The balancing act involves resource allocation decisions that harmonize short-term cash-flow requirements with long-term sustainable development needs.

Traditional Diversification

Fossil fuels and their related industrial value chains have become FFDCs' natural comparative advantage, providing energy security and a source of revenues. The prevailing growth model in many FFDCs (for example, the Gulf Cooperation Council [GCC] countries), consisting of extracting oil and gas and producing related products and nontradables while importing most of the tradable consumption goods, have also constrained their economic performance (Cherif and Hasanov 2014).

Many FFDCs have already expressed their aspirations to achieve more diversified economies in their development plans. For instance, Saudi Arabia's Vision 2030 states that "diversifying our economy is vital for its sustainability. Although oil and gas are essential pillars of our economy, we have begun expanding our investments into additional sectors."[1] Qatar is making progress toward its diversification goals contained in its Vision 2030 (Alagos 2017). In the Russian Federation, the "Concept of Long-Term Socio-Economic Development of Russia until 2020" calls for modernization and innovation as

FIGURE 4.1 Two Broad Diversification Strategies



- Diversifies the portfolio of national assets (inputs): natural capital and intangible assets (knowledge, innovation, institutions)
- Discovers new comparative advantage and hedges structural risks
- Increases flexibility, resilience, productivity, and climate mitigation co-benefits
- Relies on knowledge and efficiency; increases productivity over time

- Diversifies outputs and exports through energy- or carbon-intensive industrialization on the back of fossil fuel value chains
- Builds on current comparative advantage and hedges cyclical risks
- Increases greenhouse gas emissions and exposure to low-greenhouse-gas transition
- Relies on energy subsidies to industry; maintains low productivity

Source: World Bank.

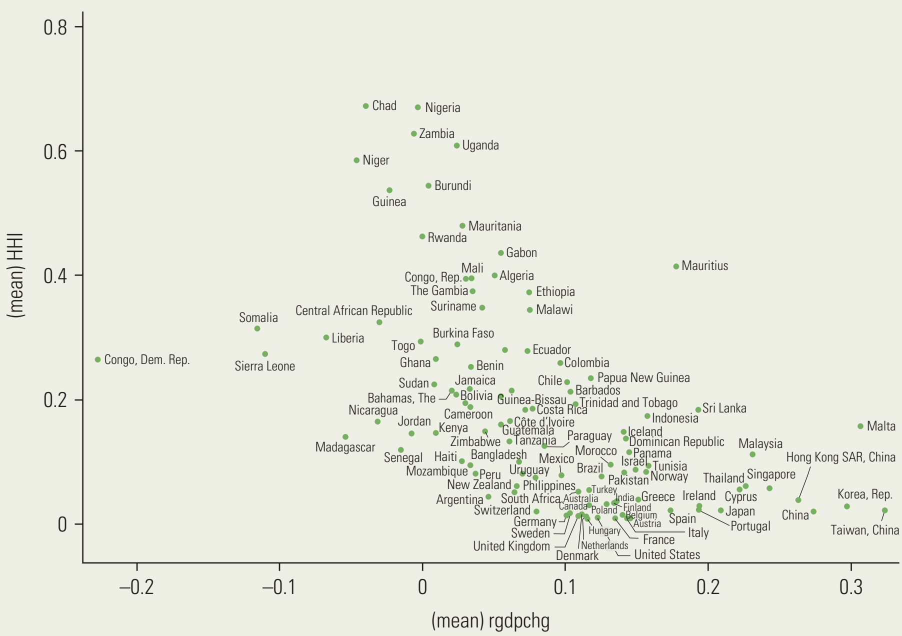
an important goal to secure the development of its economy.[2] Additionally, the May Decree 2018 of the President lays the groundwork for national priority projects.[3]

Traditionally, FFDCs have put diversification efforts into products and exports closely related to hydrocarbons (box 4.1). This strategy is typically associated with identifying sectors that are closely linked to areas in which the economy has an existing comparative advantage and that offer additional opportunities for value creation. In FFDCs, this approach often implies keeping domestic fuel prices low and pursuing

BOX 4.1 Empirical Evidence for Export Diversification

Some studies find a positive relationship between export diversification and welfare. For instance, Hesse (2008) reviews the literature on the benefits of export diversification and finds strong evidence of a negative correlation between export concentration (measured by a Herfindahl index) and cumulative gross domestic product (GDP) per capita growth over five-year intervals in the period 1961–2000. The Herfindahl index (also known as the Herfindahl–Hirschman index, HHI, or sometimes HHI-score) is a measure of the size of firms in relation to the industry and is an indicator of the degree of competition among them. The results are presented in figure B4.1.1. Many of the successful East Asian countries are located in the lower right corner of the figure, with relatively low levels of export concentration. Poor growth in Sub-Saharan African economies is correlated with a very strong concentration in exports.

FIGURE B4.1.1 Relationship between Export Concentration and GDP per Capita Growth (1961–2000)



Source: Hesse 2008.

Note: HHI = Herfindahl index; rgdpchg = real GDP per capita growth rate (chain-weighted index).

(*Box continues on the following page.*)

BOX 4.1 Empirical Evidence for Export Diversification (continued)

Yet these results are controversial. Gill et al. (2014) question the utility of metrics such as export and production diversification. Exports can be concentrated for many reasons, among others, underdevelopment or the size of the economy. Furthermore, production and export concentration metrics are highly sensitive to the level of sectoral aggregation, and the authors show that using different levels of aggregation in an analysis can yield opposing outcomes.

More fundamentally, whether export diversification is either necessary or sufficient to achieve economic development is unclear. The World Bank (2014a) suggests that the optimal level of diversification is context specific, and that export diversification alone is not sufficient to deliver strong growth. For instance, while diversification away from fossil fuel exports helped create flourishing economies in the United Kingdom and the United States, in countries such as Australia, Canada, Norway, and the United Arab Emirates, heavy reliance on fossil fuel exports occurred alongside strong economic growth. On the other hand, both Argentina and Brazil sought to diversify their export base but have arguably not succeeded in achieving their development goals.

vertical industrial policies that strengthen downstream, carbon-intensive capabilities. A classic example would be to move from oil, gas, and coal extraction to refining the oil and producing petrochemicals, steel, cement, and fertilizers, or fueling airlines and thermal power plants. In GCC countries, recent diversification into manufacturing has been highly concentrated in the chemicals sector, which is largely oil related (Callen et al. 2014), although steel and aluminum attracted significant government-led investments in Saudi Arabia and Qatar. Similarly, in Kazakhstan, carbon-intensive industries such as metallurgy and chemicals have long been central to diversification efforts (Felipe and Hidalgo 2015).

Traditional export diversification has borne fruit when successfully accomplished. As highlighted in box 4.1, traditional diversification has often been associated with higher levels and stronger resilience of GDP growth. This success is due to a wider range of higher-value-added products that provide a hedge against resource price volatility, as well as the development of sectors that have greater technological spillovers. A more diversified economy also becomes less susceptible to rent-seeking by providing a wider range of opportunities and less concentrated power in society.

Yet as evidenced by many stalled attempts, and despite some notable successes, even traditional diversification can be challenging for commodity exporters. The International Monetary Fund (IMF) concluded that a key challenge for GCC countries is to find ways to develop non-oil tradable sectors that support sustainable private sector employment (Cherif, Hasanov, and Zhu 2016). Some analysts (for example, Cherif and Hasanov 2014) argue that GCC countries' inability to diversify away from oil stems mainly from market failures associated with Dutch disease. They suggest that government policies should target high-value-added sectors with large spillovers and productivity gains. Few countries have succeeded in overcoming the dominance of natural resources and primary commodities (in particular oil). Policy makers' focus on short-term rents from resources and their allocation of these rents to ensure political survival has tended to undermine institution building and distracted from policies and investments necessary to sustain growth in the long term (World Bank 2017).

Furthermore, vested domestic interests must often be overcome for economic transformation to happen. State-owned enterprises lobby forcefully against diversification that could undermine their position and influence. Moe (2007) explores the role of governments in influencing long-run economic growth since the Industrial Revolution by looking at France, Germany, Japan, the United Kingdom, and the United States. Combining the Schumpeterian (Schumpeter 1943) process of creative destruction with Olson's (1982) theory of vested interests, he argues that the most successful economies were those in which the governments did not excessively prioritize the demands of powerful incumbent interest groups. He concludes that, "What matters is the state['s]… ability and willingness to pursue policies of structural change. And hence, what matters is whether or not the state is in possession of sufficient political consensus and social cohesion for political elites to be able to go against powerful vested interests resisting change" (Moe 2007, 268).

Although traditional diversification has helped to hedge against cyclical risks, this study poses a question as to its effectiveness in managing a possible structural decline in fossil fuel–dependent markets. Heavy industrialization usually increases domestic emissions of greenhouse gases and local pollutants. Diversifying away from oil and gas by investing downstream in production of higher-value-added products that use hydrocarbons as feedstock will only get riskier if the importers and domestic consumers are increasingly concerned about the carbon content of final goods. Such diversification can increase exposure to LCT risks, especially if other countries adopt border carbon adjustment (BCA) measures. Policies and trade measures can translate these concerns into higher prices for final consumers, lower producer prices, and structurally declining export demand.

Asset Diversification

LCT risks underscore the urgency of broader approaches to diversification, not so much focused on what a country makes at home and sells abroad, but on how it goes about making those goods and services (Gill et al. 2014). That is, rather than being focused on diversifying outputs, the focus is on diversifying inputs—the assets being utilized by an economy (hence the term asset diversification).[4] These assets are human (people and their skills [Lange, Wodon, and Carey 2018]), naturally delivered ecosystem services (Helm 2015), produced (for example, factories and infrastructure) and, of crucial importance, intangible assets, including human and knowledge capital as well as institutions that organize societies (Lange, Wodon, and Carey 2018; Hamilton and

Hepburn 2014, 2017). (See box 4.2.) They contribute to creating a more productive economy, with intangible assets also particularly important in building competitive knowledge economies that are more flexible, adaptable, and resilient to a wide range of external shocks. This type of diversification can coexist with traditional (vertical) industrial policies, building on existing comparative advantage and investing in new capabilities. Both types of diversification contribute to economic complexity.

Rapid progress has been made in the development of methodologies that account for the value of natural and intangible assets in the economic performance of nations (Hamilton and Hepburn 2014; Helm 2015; Lange et al. 2011; Lange, Wodon, and Carey 2018). However, renewable natural and intangible assets have not yet become integrated into mainstream economic models and macro-fiscal policy frameworks. Hence, they are often overlooked, underpriced, and mismanaged by decision-makers, even if they make a vital contribution to the sustainability of economic growth. But sustainability is less visible to policy makers focused on year-to-year output growth. The understanding of the role of intangible and ecosystem assets to an economy is increasing.

BOX 4.2 Classification of Assets and Capital

Gill et al. (2014) decompose an economy's assets into three broad categories: natural, produced, and intangible, defined as follows:

- Natural assets include resources like subsoil assets, forests, wetlands, rivers, oceans, and farmland.
- Produced assets are physical investments, like machinery and infrastructure.
- Intangible assets represent the contribution of labor, human capital, social capital, institutions, knowledge capital, and the rule of law.

Hamilton and Hepburn (2014) break down the wealth of a nation into various forms of capital, the most important of which are the following:

- Physical or produced capital, which includes physical infrastructure, buildings, machinery, and the like
- Human capital, which incorporates the education and stock of knowledge embodied in people
- Natural capital, which includes underground assets, commercial land, fish stocks, and natural land, including the ecosystem services that it provides
- Intellectual property, which includes the value of contracts, leases, patents, software, databases, and other intangible property
- Social and institutional capital, which incorporates intangible factors such as the quality of institutions, the rule of law, and various forms of social capital that enable goods and services to be produced
- Net financial assets, which is the measure of the net holdings of financial assets across national borders; within national borders, financial assets and liabilities cancel each other out

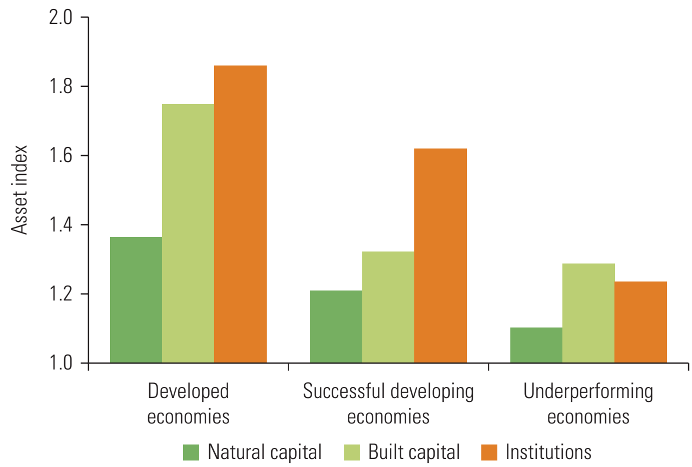
In FFDCs, asset diversification typically implies renewed efforts to bolster economic flexibility by investing in renewable natural and intangible assets such as human capital, institutions, and innovation (EBRD 2014; Gill et al. 2014; IMF 2016; McKinsey & Company 2015). Australia, Canada, Chile, and Norway provide examples of this form of broad asset diversification, financed by the continued proceeds of resource extraction (Grunfeld and Moxnes 2003). Whether these investments are made often makes the difference between the emergence of productive or stagnating economies, fully participatory societies or societies that exclude many of their citizens, and countries with stable or fragile governments (Gill et al. 2014).

Asset diversification has already built competitive and resilient knowledge economies. Some of the most successful western economies today—including the Netherlands, the United Kingdom, and the United States—have achieved advanced diversification in both products and assets, starting from initial reliance on primary products, and become leading knowledge-based economies. Countries such as Australia, Canada, Chile, Malaysia, Norway, and to a lesser extent Indonesia, are examples of economies that are still relatively concentrated on output diversification metrics but have successfully diversified their portfolio of national assets, developing more knowledge-intensive manufacturing and services (Gelb 2010; Tijaja and Faisal 2014; World Bank 2014b; Zen 2012).

Asset diversification and associated structural transformation have been strong drivers of the reduction of the energy and emissions intensity of former industrial economies. Asset diversification can have important climate mitigation co-benefits.

Many FFDCs and other resource-rich emerging market economies have performed particularly poorly in investment in intangible assets. Figure 4.2 presents a comparison of asset endowments across different groups of resource-rich countries. It makes a striking case for the development of strong institutions. Poor institutions can impede growth in various ways. For example, Gelb (2010) reports that Algeria’s failure to diversify away from oil exports was the result of a poor business climate and poor enforcement of the “rules of the game” for markets—in other words, a result of its institutions. By contrast, Botswana’s annual growth rate has averaged nearly 8 percent since the 1970s, and is often at least partly attributed to its meritocratic government and strong governance of the savings of rents from diamond extraction (World Bank 2014a; Pegg 2010), although a lack of strong institutions in the areas of tax administration, state-owned enterprises, and the labor market have held back private sector development and economic diversification (Harvey 2015; IMF 2017). Further lessons can be drawn from the experiences of Chile and Mexico, both of which pursued export diversification strategies in the 1980s. Chile’s diversification strategy was accompanied by investment in strong economic institutions and human capital, leading to sustained growth and a robust business climate. In contrast, Mexico struggled to implement institutional reforms and missed out on potential growth, with real wages remaining stagnant between 1994 and 2012 (Weisbrot, Lefebvre, and Sammut 2014).

FIGURE 4.2 Importance of Public Institutions for the Asset Index



Source: Gill et al. 2014.
Note: The asset index ranges from 1 to 2. The higher the index value, the better the result.

Knowledge and human capital also play a crucial role in supporting development. Knowledge capital refers to nonphysical (intangible) assets such as skills; intellectual property such as patents, designs, and trademarks; and economic competencies including organizational know-how. Lange, Wodon, and Carey (2018) measure human capital as the discounted value of earnings over a person's lifetime, which should reflect the value of skills, experience, and effort by the working population over their lifetimes disaggregated by gender and employment status (employed, self-employed). The amount of productive knowledge contained in an economy can also be approximated by indexes of years of schooling or quality of education (see the section "Produced and Intangible Assets").

Recent work in so-called latent diversification has a broadly similar implication. Latent diversification looks at a country's capacity to change the mix of products it exports as circumstances change over time, rather than focusing on its export share in a single year. Lederman, Pienknagura, and Rojas (2015) find that the capacity to shift production factors to other sets of export lines is important for weathering economic shocks. This implies that having a flexible set of assets, such as robust institutions, may result in better performance over time than having inflexible inputs such as a single natural resource.

Institutional development is central to growth (Acemoglu, Johnson, and Robinson 2005; Easterly and Levine 2003). Some economic historians, such as Mokyr (1990), North (1990), and Rosenberg and Birdzell (1985), have concluded that differences in governance and institutions are key to explaining economic success. Some even argue that factors such as a codified rule of law explain why the Industrial Revolution took place in the western world rather than elsewhere, and why certain countries are more innovative than others. A growing number of studies also emphasize that the structure of incentives facing agents in an economy is a crucial determinant of that economy's performance.[5] Rodrik (2004), for example, emphasizes five institutions important for growth and innovation—those that protect property rights, provide regulatory oversight, promote more economic stability, and provide social insurance, and those that manage conflicts. These studies corroborate the central importance of a country's institutions and economic policies in explaining why some developing countries (especially in Southeast Asia) have broken out of the middle-income trap and grown faster than rich countries. At the same time, a growing body of institutional economic literature recognizes the importance of the active role of the well-governed state not only in creating general framework conditions for markets and entrepreneurship, but also in actively driving innovation through targeted investments in research and development (R&D) and commercialization of disruptive technologies (Mazzucato 2013).

Changing the established national comparative advantage takes time and requires large, continuous, and risky investments. Cherif and Hasanov (2014) note that several decades of preparatory work are required to develop a non-oil tradable sector. It is easier to temporarily leapfrog several income levels by consuming resource rents than permanently shifting the core productive strengths of an economy. Experience with innovation policies in Southeast Asia and Latin America suggests that accumulating new skills and capabilities to innovate outside of the natural comparative advantage requires a specific set of favorable conditions and opportunities, as well as a large and sustainable flow of funds (Edquist 1997). To enter the global innovation race, FFDCs will need to build entire sectoral and national innovation systems (Malerba 2004). Malerba (2004) lists the three main pillars of successful innovations systems: knowledge and technologies, actors and networks, and institutions. These pillars often need to be built from scratch with associated skills and capabilities of firms, as well as with basic capacity in science. Sophisticated leapfrogging policies are available—but not always to those who would be able to implement them on the ground (Lee 2013).

Some FFDCs, such as Russia and GCC countries, have accumulated a critical mass of capabilities to generate new technologies, but many others still need to build capabilities to absorb technologies generated by others. Several FFDCs are concerned that this lag may lead to a new pattern of economic dependency and could replace one source of economic vulnerability with another.

Innovation also requires a steady flow of funding for upstream R&D by firms, universities, and governments, and for commercialization of new technologies (by venture capitalists, banks, and governments). In the more advanced and diversified resource-rich economies (Australia, Canada, Norway), the public sector played a large role in financing R&D (although it entailed a set of agency and transaction costs), while innovations in the most successful sectors in India; Malaysia; Taiwan, China; and Thailand were mainly privately funded (Malerba 2004). Mazzucato (2013) provides evidence that most of the large tech firms in Silicon Valley in the United States were developed on the basis of technologies and networks funded by government institutions that took risks that venture capitalists were not willing to bear. Thus, the architecture of cooperative climate agreements would need to recognize the special circumstances of FFDCs and enable them to access a predictable flow of funding for innovation and asset diversification with strong mitigation co-benefits.

Different ways to diversify are not mutually exclusive. This study shows that traditional export diversification within the fossil fuel product space may become a riskier and less sustainable proposition amid the possible structural impacts of an LCT. But asset diversification alone—investing in human capital, better regulations, and infrastructure—may not be sufficient to ignite a new sustainable tradable production growth engine, especially among major oil and gas exporters. Cherif and Hasanov (2014) argue that successful diversification strategies have relied on a policy mix of promoting vertical diversification in comparative advantage sectors such as oil and gas and petrochemicals and endeavors into horizontal diversification beyond these sectors with an emphasis on technological upgrade and competition in international markets. Therefore, a dynamic, comprehensive "hedging portfolio" of policies and investments, combining ingredients of traditional and asset diversification, will be needed to prepare for the challenges of an LCT. A flexible mix of diversification approaches will have to be customized to the country context and be flexible enough to adjust to evolving external conditions and internal capabilities.

Simulations performed in Peszko, van der Mensbrugghe, and Golub (2020) suggest that the short-term costs and risks of moving away from areas of historic comparative advantage, toward asset diversification, are high. By building on accumulated capital, capabilities, skills, and abundant domestic resources, traditional diversification provides initially higher and more certain revenue, output, and consumption compared with asset diversification.

Asset diversification requires upfront investments that do not immediately bear fruit— productivity improvements in new sectors need time to materialize and discovering new sources of global comparative advantage requires risky efforts and long-term investment in national and sectoral innovation systems. It is therefore not surprising that many stakeholders in FFDCs feel safer holding on to their current strengths in the fossil fuel product space (discussed also by Hidalgo et al. [2007]) even if this strategy exposes them to higher long-term risks. Pursuing a shift away from core strengths pushes incumbent economic agents out of their comfort zone and into the comfort zone of their current foreign competitors.

Options for Climate Action and Cooperation

Willingness to Abate and Cooperate

The next question is how different approaches to diversification interact with the climate change agenda and international cooperation. As chapter 2 argues, the Paris Agreement created new opportunities for cooperative bottom-up climate action clubs, but not the incentives to establish them. Pursuing their own economic imperatives, FFDCs have universally submitted their nationally defined contributions (NDCs), but many have been reluctant to implement ambitious domestic climate mitigation policies amid concerns about the "adverse impact of climate response measures" (UNFCCC 2018).

The weak incentives for FFDCs to be leaders of climate action should be no surprise. Just like climate change, climate policies also have transboundary spillover effects and relocate wealth across countries. Franks, Edenhofer, and Lessmann (2015) show that carbon prices introduced by importers of fossil fuels capture a portion of resource rents, transferring it from exporters (FFDCs) to importers. Similarly, Edenhofer and Ockenfels (2015) observe that prices on carbon emissions drive a wedge between the revenues generated by countries supplying fossil fuels and the revenues generated by those consuming the fuels. Such rent capture by fossil fuels importers leaves FFDCs with less revenue available for risky long-term investment in asset diversification. Therefore, Stiglitz (2015) writes that net exporters of fossil fuels may not have the incentives to implement cooperative domestic carbon pricing without additional incentives needed to go beyond moral persuasion.[6]

Without FFDC participation, other countries may also be less willing to ratchet up their own levels of effort to stabilize global climate change. Fragmented, unilateral climate policies of selected countries may lead to relocation of polluting economic activities to other countries that would free-ride on their efforts by enjoying the benefits of climate change mitigation without contributing to its costs. In fact, concerns about free-riding were a key factor that disintegrated the Kyoto Protocol before it even formally entered into force in 2005. The United States refused to ratify it in 2001, arguing that many large emerging market economies, including China and India, would free-ride without emissions caps. Several other large emitters—with greenhouse gas emissions caps, including Canada and Japan—rescinded their commitments in 2012. Each country had specific interests for revising their level of ambition, but the common narrative was that other large emitters that do less would benefit from unilateral mitigation action.

Facing asymmetric climate policies across the world, climate action leaders may mitigate the negative competitiveness impacts on their industries and emissions leakage by offering exemptions and export rebates for exposed, trade-intensive sectors or by implementing border carbon adjustments (Kossoy et al. 2015). Most literature and policy initiatives focus on traditional border carbon adjustment taxes (BCATs) on carbon content in imports (see reviews by Cosbey and Fischer [2014] and Mehling

TABLE 4.1 Choices of Possible Instruments of Climate Cooperation Strategies

Free-ride on climate action of the rest of the world	Cooperate in global climate action
• Avoid domestic carbon prices • Face risk of border adjustment taxes (BATs) ○ *Traditional border carbon adjustment tax (BCAT)* in which a tax is imposed on the carbon content of imported goods and services ○ *Nordhaus-type BAT*, a flat ad valorem trade sanction on all imports from noncooperating countries	• Avoid surprise policy actions abroad and BATs • Implement domestic climate policies through ○ *Traditional consumption- or emissions-based carbon taxes* ○ *Wellhead or extraction-based carbon taxes*

Source: Peszko, van der Mensbrugghe, and Golub 2020.

et al. [2017]). Mattoo et al. (2009) distinguish between border taxes on the carbon content of imports and the carbon content in domestic production, but Nordhaus (2015) is the first to discuss a punitive tariff on the import of all goods from noncooperative countries. Table 4.1 illustrates possible choices of policy instruments of cooperation strategies, as used in Peszko, van der Mensbrugghe, and Golub (2020).

Price-Based Cooperative Instruments

The Paris Agreement is the first fully inclusive international climate agreement under which all countries have expressed individual commitments by submitting their NDCs. The freedom to choose one's own level of ambition and the nonbinding nature of NDCs successfully drew countries into the Paris Agreement: 163 out of 197 parties to the convention had submitted NDCs by November 2017.[7] But this is just the first phase of a multistage "climate game." The Paris Agreement provides a regular pledge-and-review process through which countries are expected to ratchet up their ambition in five-year cycles. Countries' decisions to increase the level of ambition must be voluntary by the nature of the global political architecture, based on the self-interest of sovereign nation states (Barret 1994; Hoel 1992). This means that individual countries must have an incentive to increase their level of ambition over time. The pathways to establishing a credible, self-enforcing mechanism that encourages international cooperation toward the 2-degree (or 1.5-degree) Celsius (C) target have been discussed for several years (for example, Diamantoudi and Sartzetakis 2006; Hoel and Schneider 1997), but have yet to materialize.

The bottom-up, flexible nature of the Paris Agreement provides a new opportunity to foster climate cooperation. In contrast to the Kyoto Protocol, where any cooperative climate action had to be negotiated between all parties and agreed to by consensus, the Paris Agreement offers ample room for collaborative, bottom-up, and unilateral initiatives of clubs of countries to launch ambitious climate mitigation actions. Like-minded countries can jointly pursue their own sustainable development objectives—through energy, technology, and climate policies that reduce the use of fossil fuels and push down the costs of low-carbon technologies and infrastructure (for example, in transport and electricity). They are constrained only by the World Trade Organization in their choices of whether to apply carrots or sticks, including trade sanctions targeted at nonparticipating parties. FFDCs may therefore be caught by surprise (Hovi et al. 2016), because, compared with the Kyoto Protocol, under which they could exercise veto power, they now have less control over decisions made by clubs of other countries.

But opportunities to cooperate are not the same as incentives to cooperate. As discussed in the section "Emergence of New Institutions" in chapter 2, effective incentives can be established under Article 6 by a club of countries pursuing ambitious actions toward the mitigation goal on the basis of joint commitment and reciprocity, with credible "carrots and sticks" offered to nonparticipants.

From the inception of the United Nations Framework Convention on Climate Change (UNFCCC), the important imperative of the cooperative climate architecture was to achieve global goals at the least cost to the global economy. The price-based instruments, at least in theory, offered the flexibility needed to achieve cost-effective global solutions. Market-based mechanisms of the Kyoto Protocol (Articles 6, 12, and 17) were the prominent examples of an economic approach to climate policy, whereas the Paris Agreement allows parties to experiment with a greater variety of price-based instruments to facilitate international cooperation. The menu includes market-based approaches under Articles 6.2 and 6.4 of the Paris Agreement, and nonmarket approaches, such as carbon taxes, under Article 6.8 (box 4.3). The market-based approaches suffer from the fundamental problem of an absence of buyers willing to pay for carbon assets to justify the costs of a higher level of climate policy ambition. The absence of enforceable emissions targets allocated to individual countries under the Paris Agreement casts doubt about whether and when international carbon markets can reemerge.

Internationally harmonized emissions-based carbon prices are commonly expected to be combined with climate finance. Once developed countries collect carbon price revenues from their emissions, it becomes possible to share them through financial transfers with developing countries to facilitate their participation and address equity concerns (CPLC 2017; Cramton et al. 2017; Cramton and Stoft 2012; Dion and Laurent 2015; Edenhofer and Ockenfels 2015; Gollier and Tirole 2015).

It may be in the interest of the rest of the world to provide financial transfers to FFDCs to support their LCT. According to simulations presented in Peszko, van der Mensbrugghe, and Golub (2020), cooperation by FFDCs to keep climate change below 2 degree C would reduce by $5.5 trillion the losses experienced by other high-income countries. These countries would need to use only about one-eighth of these savings, or $663 billion until 2050 (approximately $22 billion per year), to provide the necessary incentives for the most vulnerable FFDCs to participate, generating massive benefits for themselves if it led to universal participation. Notwithstanding their importance in motivating cooperative behavior (World Bank, Ecofys, and Vivid Economics 2016, 2017), efforts to scale up climate finance and carbon markets encounter persistent difficulties (Westphal et al. 2015). As discussed earlier, climate finance tends to be fragmented, with high transaction costs and weak incentives for increasing the level of ambition. This study reinforces those voices that call for financial transfers to be

BOX 4.3 **Traditional View on Price-Based Cooperative Policy Instruments under the Paris Agreement**

Linked carbon markets (Article 6.2 of the Paris Agreement). The Kyoto Protocol was a precursor to international carbon markets, including three flexible mechanisms: (1) International Emissions Trading (Article 17), under which Annex I countries that adopted binding emissions caps could exchange emissions allowances to reduce the overall costs of compliance; (2) Joint Implementation (Article 6), a project-based baseline-and-credit mechanism available also to Annex I countries; and (3) Clean Development Mechanism (Article 12), a pure offset baseline-and-credit mechanism that linked uncapped developing countries' potential supply of emissions credits with Annex I countries' potential demand. After the United States declined to ratify the Kyoto Protocol in 2001, the largest source of demand (and the main rationale for flexible mechanisms) disappeared and the carbon markets gradually crumbled. The Paris Agreement, through Article 6.2, introduces flexibility for bilateral or multilateral arrangements between parties that can rely on mitigation outcomes that could be generated and transferred under a variety of mechanisms, procedures, and protocols.

The project-based carbon-crediting mechanism (Article 6.4 of the Paris Agreement) is expected to be similar to the Clean Development Mechanism under the Kyoto Protocol and governed by parties under a United Nations Framework Convention on Climate Change (UNFCCC) process. It will most likely leave the least flexibility for bottom-up innovation by the climate clubs.

Internationally harmonized emissions-based and consumption-based carbon taxes (Article 6.8). Emissions-based carbon taxes are imposed on the carbon content of fossil fuels consumed within a country. Such taxes can be collected anywhere in the value chain—from the upstream point of entry into the economy, to the downstream point of final combustion. International harmonization of emissions-based carbon taxes can take the form of internationally agreed upon minimum tax rates (Weitzman 2014). Consumption-based carbon taxes are one specific design of emissions taxes. They are paid by final consumers of products, irrespective of the origin of the product or process (Neuhoff et al. 2015). Hence, they extend coverage to the emissions that occur outside of a country's borders. It has been argued that if implemented as nondiscriminatory measures, consumption-based carbon taxes would be World Trade Organization–compliant, although others claim they will fall under Article XX of the General Agreement on Tariffs and Trade. As a downstream tax, they require an understanding of the carbon intensity of upstream processes associated with the product, including that which occurs in other jurisdictions from which a product or its components were imported. This adds to the complexity of the scheme, though its proponents suggest that the charge could be simply calculated using an assumption of global best practice carbon efficiency at all stages of production.

strategically designed as conditional incentives for results-based cooperative policy efforts rather than project-by-project financing (Steckel et al. 2017).

This book also introduces an alternative design of internationally harmonized carbon taxes, collected from producers rather than consumers of fossil fuels (box 4.4). Unlike the traditional harmonized carbon pricing discussed above, such production-based carbon taxes are not levied on emissions or the carbon embedded in final products (whether produced domestically or imported), but on the carbon content of fossil fuels at the point where they are first extracted from the ground (wellhead or mine mouth, hence wellhead taxes hereafter). Unlike emissions-based carbon taxes, they are

BOX 4.4 **Wellhead Carbon Tax**

A wellhead carbon *tax* is defined for the purposes of this study as a uniform tax on carbon embedded in fossil fuels. In the extreme version, the tax is collected only at the point of extraction and collected from fossil fuel producers, regardless of whether the fuels are consumed domestically or exported. In this version, importers agree to not impose an emissions-based carbon tax on the emissions embedded in the fuel because taxes have already been applied by exporters. In a more realistic scenario, various revenue-sharing ratios can be bilaterally or multilaterally negotiated between fossil fuel exporters and importers through agreements on the harmonized tax rates. This may be more feasible and easier to negotiate than internationally harmonized emissions-based or consumption-based taxes, which require agreement not only on tax rates but also on explicit financial transfers between countries.

Wellhead carbon taxes are a variation of internationally coordinated carbon pricing and were briefly discussed in the early years of the United Nations Framework Convention on Climate Change (UNFCCC) after the Rio summit (Wirl 1995). They can be designed as joint and contingent commitments needed to operationalize the incentive structure under the Paris Agreement as argued by Weitzman (2014), Nordhaus (2015), MacKay et al. (2015), and Gollier and Tirole (2015). They are similar in structure to severance taxes and are sometimes called extraction taxes (Kortum and Weisbach 2016). Sinn (2008) and recently Richter, Mendelevitch, and Jotzo (2018) propose coal taxes as part of the package of supply-side climate policies for major coal exporters.

Incentives for FFDCs to cooperate on climate action would increase if carbon tax revenues were shared through wellhead carbon tax agreements. Shifting the carbon tax base from consumption (or emissions) to production would leave importing countries with the same consumer prices but lower carbon tax revenues, effectively worsening the welfare of their consumers (Peszko, Golub, and van der Mensbrugghe 2019). In parallel, wellhead taxes would boost FFDCs' consumption because of the large influx of new revenues that could be transferred to households.

The implementation of wellhead carbon taxes will not be free of challenges (such as agreeing on the rates; dealing with fiscal sovereignty, transparency, and dispute resolution; rebates for carbon capture, utilization, and storage; and so on). Yet these challenges will be no greater than those involved in negotiating traditional, emissions-based cooperative carbon prices—such as linked emissions trading systems, and harmonized emissions-or consumption-based carbon taxes. The impact of wellhead carbon taxes on low-income, fuel importing countries would also need to be considered since it would make energy more expensive in those countries without providing their governments with a flow of resources to support their populations and smooth the adjustment process. This study argues that they are nevertheless a promising avenue worth further analysis, including the use of modeling for further investigation (Peszko, Golub, and van der Mensbrugghe 2019).

not rebated when fuel is exported. They thus would extend carbon prices to domestic consumers in FFDCs in return for the opportunity to retain revenues that would otherwise be collected abroad. Under a cooperative deal, an importer would agree not to tax the carbon embedded in the fuel from the participating country again to avoid double taxation. Revenue sharing between countries can be negotiated bilaterally or multilaterally through agreements on carbon tax rates on both sides of the border. Unlike traditional carbon prices introduced by importers, wellhead taxes would not extract profits from fuel exporters, as discussed by Franks, Edenhofer, and Lessmann (2015).

Trade Instruments to Facilitate Climate Cooperation

Trade sanctions are among the potential tools for encouraging cooperative behavior, although they pose a host of challenges. In the absence of, or in addition to "carrots" (such as financial and technology transfers), a climate action club may try to persuade nonparticipants by using BCATs or more straightforward trade sanctions. Alternative measures may include the following:

- Border carbon adjustment measures impose a carbon price at the border, based on the carbon content embedded in imported carbon-intensive goods, or provide a rebate to exporters (Kossoy et al. 2015; Roson and van der Mensbrugghe 2012). They effectively represent the extension of a carbon-pricing regime to entities outside the implementing jurisdiction. BCAs are typically discussed as a mechanism for protecting against an escape of emissions-intensive industries from countries with strong decarbonization policies to those with laxer standards (carbon leakage[8]). Their objective is to "level the playing field" between firms that are subject to a carbon price and those that are not (or not at the same level) and prevent inefficient carbon leakage (Kossoy et al. 2015).
- Nordhaus taxes are a unique form of climate-motivated BCAT. Such taxes are a uniform import tariff on all goods and services originating from a country that does not cooperate in internationally harmonized climate policy action, where uniform in this context means irrespective of their embedded carbon content. The concept was popularized by Nobel Prize winner in economics William Nordhaus (2015),[9] who argued that ambitious, price-based climate coalitions are unlikely to be stable unless plain trade sanctions are imposed on nonparticipants. By applying trade penalties on nonparticipants, a club of climate action leaders would be able to induce the formation of a large, stable coalition with higher levels of abatement. Even though such tariffs would be easy to administer, being independent of the carbon content of imports, they would be less linked to emissions because they would apply to all imports from the targeted country regardless of the emissions intensity of an imported good. Thus, the primary aim of such an instrument is to restrict nonparticipating countries' market access to overcome free-riding incentives and induce all countries to cooperate on climate action. A Nordhaus tax is controversial and, like all other border adjustment measures, would probably be subject to legal challenges under the World Trade Organization because it is only weakly linked to the carbon content of imports and can be highly discriminatory.

BCAs have been rarely applied so far, but this may change. Their threat could mitigate the risk of carbon leakage and encourage free-riding countries to cooperate and increase their climate policy ambitions. The credibility and imminence of this threat is an element of uncertainty that FFDCs face. At least two trends may attract more attention to the future role of trade instruments in climate policies.

- *Growing concern about the risk of carbon leakage.* Growing concern among countries with carbon-pricing schemes has increased their willingness to implement policies that avoid (1) saddling domestic industries with competitive disadvantages and (2) the possible relocation of emitting activities to countries without carbon pricing. As policy ambition increases, such economic, social, and political concerns are likely to grow.
- *The growth in the volume of carbon embodied in international trade flows.* It is estimated that the carbon content of traded products has increased to 24 percent of global emissions of carbon dioxide (Andrew, Davis, and Peters 2013). Many major developing countries are net exporters of embodied carbon emissions, while many developed countries are net importers of the same emissions (Peters et al. 2011). This raises concerns that the apparent decrease in emissions in many developed countries may simply reflect their “off-shoring” to third parties.

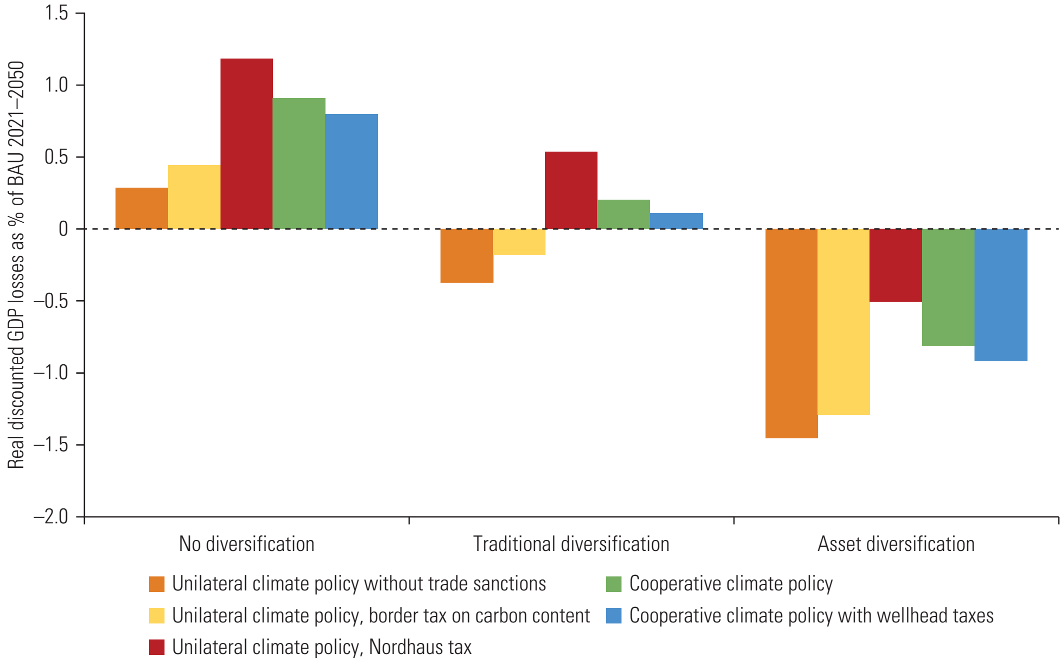
Trade instruments, in different forms, are one of many policy measures to address competitiveness and carbon leakage concerns (Kossoy et al. 2015). Countries can also encourage cooperation by adopting softer measures to ensure that benefits of club membership are exclusive, that is, they accrue only, or at least disproportionally, to the members of a club. For example, FFDCs may receive incentives to take ambitious emissions-mitigation measures by being excluded from the benefits derived from R&D and financial transfers implemented by climate leaders (Carraro 2016).

Simulations using an updated ENVISAGE model (Peszko, van der Mensbrugghe, and Golub 2020) suggest that traditional diversification and noncooperative policies are the most attractive short-term strategies for FFDCs, assuming the rest of the world does not impose climate and trade policies and disregarding the climate change impacts. These results are consistent with past diversification efforts by FFDCs, which have focused on fossil fuel–related sectors.

According to these simulations, border adjustment policies based on the carbon content of imports would not change these incentives very much and are unlikely to lead to broader cooperation by FFDCs. However, the possibility that other countries introduce unilateral climate policies and Nordhaus-type BCAs against noncooperating countries can change this assessment. Such measures would have a strong impact on FFDCs regardless of their efforts to diversify, so that participating in traditional global climate action to prevent trade sanctions would quickly become an attractive strategy for most FFDCs, especially the most advanced ones, including GCC countries, Mexico, Russia, and other large oil and gas exporting countries.

If the rest of world imposes trade sanctions on noncooperative FFDCs, asset diversification would be the only strategy that sustains growth and welfare into the future (figure 4.3). Asset diversification (with or without cooperation) becomes a robustly attractive long-term strategy for FFDCs after the external policy shock occurs and the world moves more rapidly toward decarbonization. “Robust” means that in the long run, growth and consumption with asset diversification outperform growth and consumption with

FIGURE 4.3 Long-Term Impact of Different Strategies on GDP in FFDCs under Different Climate and Trade Policy Scenarios



Source: World Bank and Purdue University (ENVISAGE).

Note: BAU = business as usual; FFDCs = fossil fuel–dependent countries; GDP = gross domestic product. The colored bars denote the difference between the cumulative discounted real GDP in FFDCs under different scenarios (over the period 2021–50) and the corresponding figures under the BAU scenario (at a 6 percent discount rate), expressed as a percentage of the BAU figures. As is usually the case with computable general equilibrium models, the percentage differences with respect to BAU are quite small under all scenarios. Asset diversification is the robust long-term hedge of GDP against low-carbon transition risks and the only no-regret economic strategy for FFDCs. Negative values indicate gain relative to BAU.

traditional diversification under all external policy shocks that have been simulated. Thus, from FFDCs' perspective, asset diversification can be considered as a long-term hedge in the worst-case scenario, as well as a robust strategy for long-term growth.

Finally, lower-income and conflict-affected countries with large proven, but not yet extracted fossil fuel reserves—many of them in Africa—pose challenges to an LCT. These FFDCs are less able to develop competitive, knowledge-based economies and implement ambitious domestic climate policies at present. Although they could eventually benefit from asset diversification, they might not be able to generate resource rents quickly enough to mitigate the impacts of an LCT and capture the opportunities that it creates. This is particularly true due to the increasingly risky global environment, marked by declining global demand for fossil fuels and diminishing access to capital for upstream and midstream development projects. Development finance institutions are also becoming more reluctant to finance fossil fuel activities. Imposing trade sanctions on these countries would have negative social repercussions without necessarily achieving the intended results because their emissions are low and the costs of cooperative climate policies relatively high.

Some middle-income coal-exporting countries may also encounter local challenges to an LCT. Creating cooperative incentive structures may require additional financial, technology, or knowledge transfers to enable investments in diversification, ease the socioeconomic implications of a transition, and encourage domestic low-carbon policy measures.

Notes

1. Saudi Arabia's Vison 2030 may be found at http://vision2030.gov.sa/en/node.
2. For more information on Russia's innovation policy, see http://economy.gov.ru/en/home/activity/sections/innovations/.
3. See http://kremlin.ru/events/president/news/57425.
4. Gill et al. (2014) even argue that output diversification may not be necessary for sustainable development. They emphasize that what countries need is sustainable improvements in efficiency and productivity, and recommend that diversification strategies should focus less on diversifying export products and more on managing the portfolio of assets from which society derives multiple forms of robust income and welfare.
5. These include Acemoglu and Robinson (2012); Barro (1998); Clague et al. (1999); Jones (1981); Knack and Keefer (1995); North (1990); Olson (1996); Olson, Sarna, and Swamy (2000); Sala-i-Martin, Doppelhofer, and Miller (2004); and Tradico (2008).
6. Some notable exceptions in this context are Mexico, which has implemented a carbon tax; Kazakhstan, which is considering implementing emissions trading; and South Africa, which is exploring the introduction of a carbon tax (World Bank, Ecofys, and Vivid Economics 2017).
7. See the NDC registry webpage here: http://www4.unfccc.int/ndcregistry/Pages/Home.aspx.
8. Carbon leakage (also known as *e*missions leakage) is a situation that may occur if businesses transfer production to other countries with laxer emissions constraints, so as to avoid having to pay for the costs related to climate policies; the leakage refers to the resulting increase in carbon dioxide emissions in countries that fail to take domestic mitigation action.
9. This book makes no judgment about the likelihood or desirability of Nordhaus taxes. Neither does it analyze their legality under international trade law. This report just assumes that the probability that they will be applied is larger than zero. Therefore, FFDCs may perceive them as a credible threat, especially if the coalition of countries applying these taxes has large market and political power.

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5. Preparedness for a Low-Carbon Transition

Some countries are better prepared for a global low-carbon transition (LCT) than others. This chapter looks at countries' varying degrees of preparedness for turning the risks of an LCT into opportunities for robust growth. Preparedness is a function of the degree to which they are exposed to climate-related trade measures, the resilience of their economies and institutions to the external impacts of an LCT, and their ability to diversify their asset bases and harness the opportunities presented by a transition.

Preparedness is measured here by composite exposure and resilience indexes that are composed of 4 and 11 indicators, respectively. Table B5.1.1 in box 5.1 presents the underlying indicators in the two indexes. The results of benchmarking fossil fuel–dependent countries' (FFDCs') preparedness for climate response measures are discussed in this chapter.

Measuring Preparedness for an LCT

Figure 5.1 maps countries' preparedness for a global LCT. The most exposed countries are located high on the vertical axis. The least flexible countries are located to the right on the horizontal axis. The least prepared countries are denoted by red dots and located in the upper-right section, whereas countries in the bottom-left section are the best prepared.

Not surprisingly, the index of preparedness suggests countries relying heavily on current and future export revenues from fossil fuels are likely to face the largest challenges in an LCT (figure 5.1). The index of preparedness developed in this study suggests that the least prepared countries, including Iraq and Libya, are exceptionally vulnerable to external shocks from an LCT, given that long-term conflicts have destroyed almost all non-oil tradable industries and tarnished already-weak institutions. Equatorial Guinea, Nigeria, and República Bolivariana de Venezuela are among the countries that are both the most exposed and the least resilient. Cambodia is vulnerable mainly because of the large share of young coal power plants in its generation mix, as is Guyana because of its large, recently discovered oil reserves. Azerbaijan, Botswana, and Kazakhstan share high exposure and relatively weak resilience. Some Gulf Cooperation Council (GCC) countries can be considered borderline cases—although significantly exposed, they also enjoy relatively high resilience. On the other

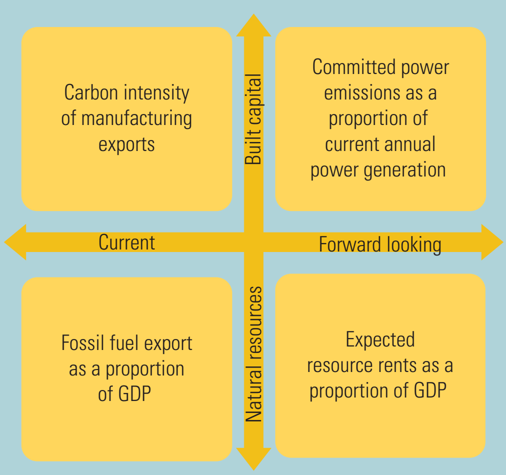
BOX 5.1 Principal Component Analysis (PCA)

PCA allows for an aggregation of indicators into one composite preparedness indicator with minimal loss of information or double counting. PCA takes a set of correlated variables (or indicators) and transforms them into a smaller set of linear, uncorrelated variables called principal components, while keeping a high amount of cumulative variance (or statistical dimensions) of the data (OECD 2008). To derive the weights for each indicator, three steps are followed:

1. *Calculation of a correlation matrix* to see if the individual indicators are correlated and therefore are likely to share common components. In addition, sampling adequacy tests exclude indicators that do not add much information because they are highly correlated with one of the other indicators.
2. *Identification of the number of the principal components* that account for the largest amount of variance of the indicators. Each principal component is a linear combination of the original indicators, where the coefficients (loadings) measure the correlation between the individual indicator and the component.
3. *Calculation of the weights for each individual indicator*, accounting for overlapping information between correlated indicators. To calculate the weights of an indicator, the loading of each component is multiplied by the proportion of the variance that the corresponding principal component represents.

TABLE B5.1.1 Structure of Index of Preparedness for Climate Response Measure

Exposure

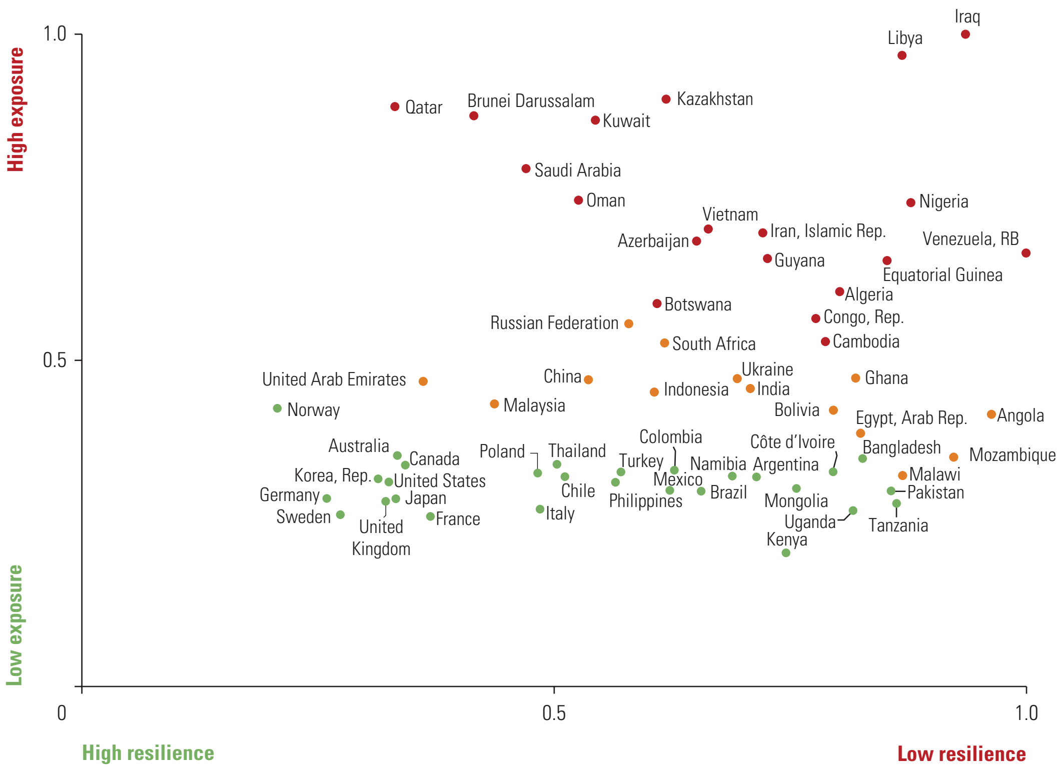


Resilience

1. Macroeconomic stability
2. Adjusted net savings
3. Financial market development
4. GDP per capita
5. Economic complexity
6. Technology adoption
7. Ease of doing business
8. Quality of infrastructure
9. Human capital
10. Institutional quality and governance
11. Position on the global supply curve[a]

Source: World Bank.
Note: GDP = gross domestic product.
a. Currently applied only to oil extraction costs.

FIGURE 5.1 Countries' Preparedness for a Low-Carbon Transition



Source: Based on several databases.

Note: Some likely poorly prepared countries are not in the figure because the full data sets were not available to the authors. Examples include Turkmenistan and Papua New Guinea.

hand, Norway is more exposed than some less-prepared countries, such as Angola, but nonetheless is well prepared for an LCT thanks to its resilience, in particular its economic flexibility and diversification and the high quality of its human capital and institutions.

The majority of countries are well prepared for an LCT (green dots in figure 5.1, or not shown). This level of preparedness is largely driven by low exposure to an LCT, meaning that their economies do not depend heavily on the export or domestic combustion of fossil fuels and related products. Especially highly developed, post-industrial economies have become increasingly knowledge-intensive and "intangible." Even net exporters of fossil fuels among them—such as Australia and Canada—are not very exposed because fuel export value is small compared with their exports of other tradable goods and services, and their power generation is relatively clean. In addition, their institutions and governance are strong and their economies are very resilient and relatively flexible, making them well placed to adapt to various external climate policy shocks.

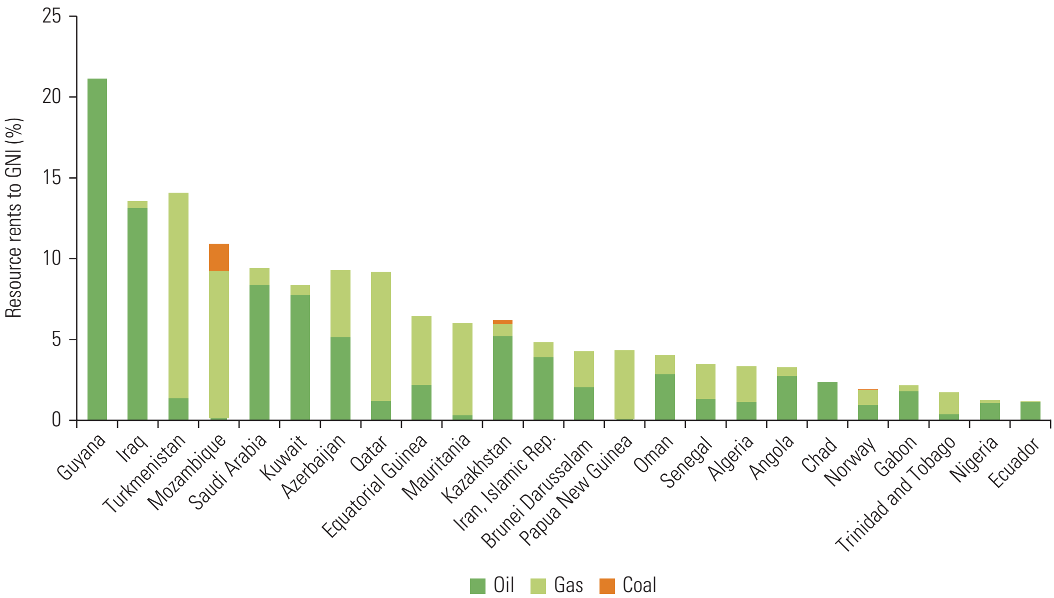
A large number of developing and emerging market economies are moderately prepared, hence potentially vulnerable to LCT risk. These economies are indicated by the orange dots in figure 5.1. Many large emerging market economies fall in this category—including China, India, Indonesia, the Russian Federation, South Africa, and Ukraine. Although some of them may be net importers of fossil fuels, they have large fuel extractive sectors and their growth is driven by carbon-intensive power and industry. The development choices currently made by these countries will determine their degree of future exposure and resilience to the impacts of an LCT. They are in development phases that require large investments in infrastructure with lifespans of decades, with concomitant risks of long-term locking-in of dependence on carbon-intensive assets. Their progress with improving governance and strengthening institutional capacity will determine their ability to deal with the external shocks of an LCT. Other moderately prepared countries include lower- and middle-income countries across Africa, including Angola, the Arab Republic of Egypt, Ghana, Malawi, and Mozambique. It is worth noting that the index of preparedness is a static snapshot of data and does not reflect the perception of LCT risk by any individual country or its revealed strategic behavior with respect to diversification and decarbonization.

Some of the investment options currently being considered by some of these countries would move them to the right along the horizontal axis, increasing their exposure to the LCT and entailing opportunity costs in that fewer funds would be available for investments to broaden the economic asset base. China is decelerating its buildup of new coal power plants, yet still hosts more than 50 percent of the world's coal power plants under construction. Bangladesh, India, Indonesia, Japan, the Republic of Korea, Malaysia, Pakistan, Poland, South Africa, and Vietnam are still building coal power generation fleets, while Mozambique (see box 3.1) is considering the expansion of coal extraction and use. The future preparedness of these countries for LCT risks will depend on the development paths they choose for the coming decades. They have an opportunity to gradually reduce their exposure while enhancing their resilience by investing judiciously, strengthening their economic and social institutions and domestic education, and providing stronger incentives for innovation and knowledge-led growth.

Figure 5.2 ranks the countries by just one of the indicators of future exposure to the LCT, that is, dependence on expected resource rents from proven reserves of oil, gas, and coal that are still in the ground.

Figure 5.2 illustrates that dependence on future fossil fuel rents is mainly driven by oil because of its high value per energy content and the sheer quantity of reserves. Natural gas is a source of future economic dependence for fewer nations, such as Mozambique, Papua New Guinea, Qatar, and Turkmenistan. Coal reserves are clearly not the source of significant exposure (except for Mozambique and Mongolia, Mongolia not presented in the figure) because they do not represent significant contributions to any country's economy.

FIGURE 5.2 Resource Rents as a Share of GNI, 2016



Source: Extracted from Rystad (2018) and Wood Mackenzie (2013).

Note: GNI = gross national income. Bars show the ratio of the net present value of oil, gas, and coal rents (at a 6 percent discount rate) to GNI in 2016. Many more low-income and conflict-affected countries depend on future oil and gas rents.

The next two sections review the results for exposure and resilience in more detail.

Exposure

Exposure captures four indicators in two dimensions (figure 5.1):

- *Type of exposed asset class.* A country can be exposed because of (1) its reliance on fossil fuel resources in the ground or (2) its significant reliance on carbon-intensive built capital, such as power or industrial plants. Some countries could be exposed because of both conditions.
- *Timing of the exposure.* A country can be exposed because it (1) currently relies on carbon-intensive exports or (2) is expected to rely on carbon-intensive rents and revenues in the future as a result of its large reserves of fossil fuels and the young age of its carbon-intensive infrastructure. Again, some countries may be subject to both conditions.

Four key indicators result:

- Current reliance on fossil fuel–export revenues as a percentage of gross domestic product (GDP), an indicator of current dependency on commodity exports. If this number is high, countries face the risk that demand for one of their key exports will structurally decline.

- Future reliance on expected resource rents from known fossil fuel reserves as a percentage of current gross national income (GNI), a forward-looking indicator of dependency on commodity rents. Countries that expect high future rents are at risk of lower-than-expected revenues. They may not be able to rely on the conversion of resource rents to other forms of economic wealth on a scale envisioned in their long-term development strategies.
- Current carbon intensity of manufactured exports is an indicator of current dependency on carbon-intensive manufactured goods and services, capturing the exposure to possible declining international demand caused by climate action or trade measures by importing countries.
- Committed (future) emissions from built capital in the power sector divided by current annual power generation is a forward-looking indicator of dependency on carbon-intensive goods and services as a function of the age and emissions intensity of electricity generation. It is calculated as the ratio of the total estimated volume of emissions of all operating plants built in or before 2020 to total electricity generation in 2013, hence it captures current plans to expand thermal generation, with an associated increase in committed emissions.

Putting these indicators together suggests that Iraq, Libya, Kazakhstan, Qatar, and Brunei Darussalam are the five countries most exposed to a possible LCT. Table 5.1 shows the assessment of these four indicators for the 20 most exposed countries out of a total of 101 for which data were available. The top five countries display high exposure in a number of areas, particularly current and expected reliance on natural resource exports.

Natural Assets in the Ground

Measuring exposure to fossil fuel reserves, the share of current net fossil fuel export revenue in GDP is particularly high in Nigeria (greater than 50 percent), closely followed by Brunei Darussalam, Kuwait, Qatar, and República Bolivariana de Venezuela. Oil and gas revenues dominate the current and expected exposure, largely because of the higher monetary value per energy content and much larger quantity traded internationally. Natural gas export revenues play an important role in Equatorial Guinea, Mauritania, Mozambique, Papua New Guinea, Qatar, and Turkmenistan.

In table 5.1 expected resource rents as a percentage of current GNI are by far highest in Azerbaijan, Guyana, Iraq, Libya, Qatar, and Saudi Arabia. Turkmenistan is also heavily exposed to risks from future fossil fuels (figure 5.2), although it is not shown in table 5.1 because of missing data in the other indicators.[1] These countries have the largest potential to use fossil fuels in the ground as a driver of economic growth for decades to come. This potential may not be fully realized if an LCT changes demand and price trends for fossil fuels. It should be noted, however, that leaving natural resources in the ground does not necessarily imply that these assets are stranded by an LCT. Known oil and gas reserves have been growing faster than demand for decades, hence the

TABLE 5.1 Exposure Indicators for Selected Fossil Fuel–Dependent Countries

	Natural resources		Built capital	
Indicator description	**Current fossil fuel export revenue as percentage of current GDP**	**Expected fossil fuel resource rents as percentage of current GNI**	**Current carbon intensity of manufacturing exports**	**Committed power sector GHG emissions over current power generation**
Indicator source	Based on UN COMTRADE 2017	Based on Rystad 2018 and Wood Mackenzie 2013	Adapted from Peters et al. 2011	Based on Platts 2016 and IEA 2015
Iraq				
Libya				
Kazakhstan				
Qatar				
Brunei Darussalam				
Kuwait				
Saudi Arabia				
Oman				
Nigeria				
Vietnam				
Iran, Islamic Rep.				
Azerbaijan				
Venezuela, RB				
Guyana				
Equatorial Guinea				
Algeria				
Botswana				
Congo, Rep.				
Russian Federation				
Cambodia				

High exposure — Low exposure

Note: GDP = gross domestic product; GHG = greenhouse gas; GNI = gross national income; IEA = International Energy Agency; UN COMTRADE = United Nations International Trade Statistics Database. Although the exposure index was calculated for 101 countries, the table shows results for only the 20 most exposed countries. The order of countries reflects the countries' composite exposure scores (in descending order of exposure). The weights for each score were calculated using principal component analysis.

reserves-to-production ratio has increased since the 1980s (BP 2018; Covert, Greenstone, and Knittel 2016; Helm 2017) (see also figures 3.4 and 3.5). Improvements in supply-side efficiency mean that new discoveries that would have been technologically and economically impossible to extract in the past can now be recovered, if there was effective demand for them. Regarding coal, the International Energy Agency observes that global proven coal reserves are so vast that most of them would stay in the ground for the next 200 years even in the business-as-usual scenario (IEA 2015). The value at risk that can be attributed specifically to an LCT relates only to the difference in the present value of resource rents (and the value added of produced capital invested in extraction and delivery to the market) between business-as-usual development and development with demand or commodity prices (or both) altered by the impacts of climate, energy, and technology policies.

Produced Assets

For produced asset exposure, eastern European countries and former Soviet republics (most notably Kazakhstan), South Africa, and industrial countries in Asia have relatively high degrees of exposed-to-built industrial capital when measured by the carbon intensity of their exports. The volume of greenhouse gas emissions associated with the production of intermediate goods, which are eventually embedded into final goods destined for export, show that Kazakhstan, Libya, and the Russian Federation are among the most carbon-intensive exporters.

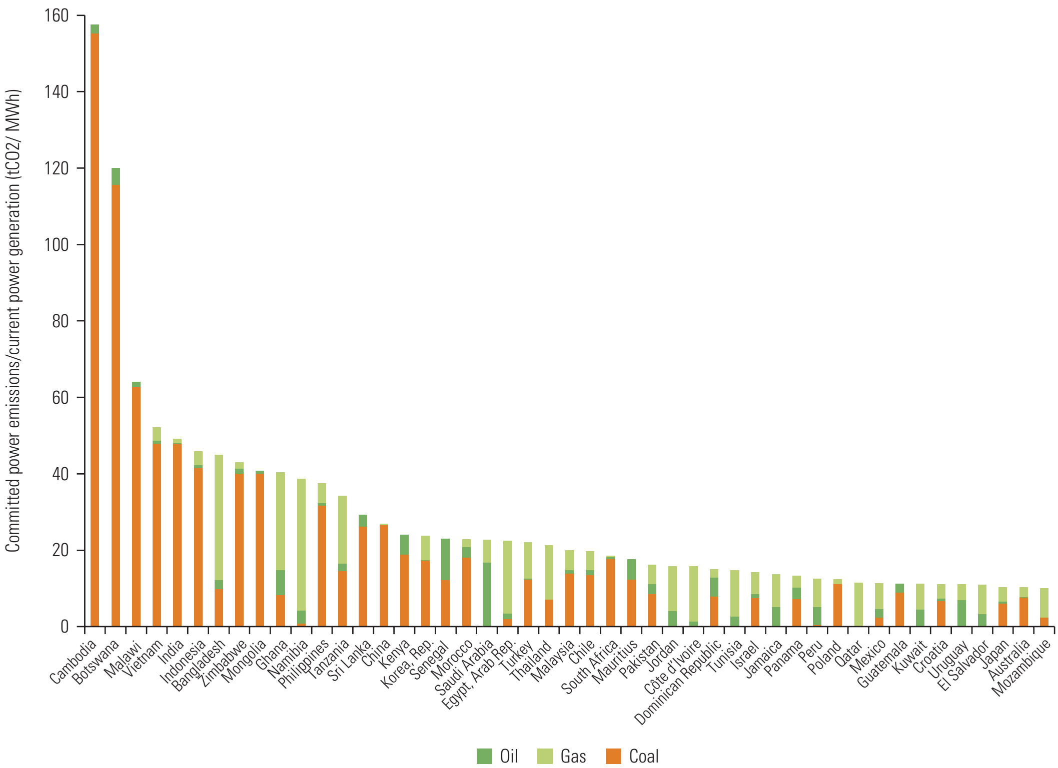
A second indicator, the ratio of committed emissions from future power generation to current power generation, shows that electricity systems in Botswana, Cambodia, and Vietnam are particularly exposed to the LCT impact.[2] Figure 5.3 shows that the committed emissions from future power generation compared with total generation are also high in Vietnam, Malawi, India, and Indonesia, mainly because of the large new and growing fleet of coal-powered plants. Countries with relatively high shares of new stocks of thermal power plants will be at greater risk of not being able to profitably exploit those facilities until the end of their useful economic lives than countries with relatively old assets.

The analysis above focuses on readily available indicators, but a number of other factors also affect exposure, such as the asset ownership structure and the prevalence of fossil fuel–dependent infrastructure. Although countries where fossil fuel assets are largely owned by the government and state-owned enterprises may try to smooth the transition by transferring budget resources from elsewhere in the economy, such ownership structures can encourage vested interests in carbon-intensive incumbents to hamper the implementation of diversification strategies that could reduce the impact of a shock. Investments in fossil fuel–dependent transport infrastructure, such as railways and ports for the transport of coal, may also be at risk if they have little value for other transport activities, for example, when located in sparsely populated regions with few alternative export goods and commodities.

Resilience

Resilience captures how well positioned an economy is to manage LCT risks. It reflects a country's capacity to adjust to the impacts and challenges associated with a structural

FIGURE 5.3 Ratio of Committed Emissions from Power Generation (to 2020) to Current Generation Capacity



Sources: Based on S&P Global Platts (2016) and IEA (2015).

Note: tCO_2/MWh = tonnes of carbon dioxide per megawatt hour. Each indicator (per fuel type) represents the ratio of the total estimated volume of emissions of all operating plants built in or before 2020 to total electricity generation in 2013. The indicator has been calculated for 92 countries.

transformation and to tap into some of the opportunities that such a transformation would offer. Countries whose economies can rely on a broader portfolio of assets will exhibit more resilience to external shocks. Countries with relatively flexible economic structures and cultures are able to respond to economic change efficiently and quickly. This flexibility enables them to minimize the costs of adjustment and harness the opportunities that changes in comparative advantages during a transition may bring. To capture countries' current economic resilience, 11 indicators across four dimensions are considered (table 5.2).

Table 5.3 summarizes the resilience indicators for the 20 most exposed countries for which data were available. Clear patterns emerge, with some exposed countries such as República Bolivariana de Venezuela, Iraq, and Libya also being among the least resilient economies. Other relatively exposed countries, such as Qatar, Brunei Darussalam, Saudi Arabia, Oman, and Kuwait, score relatively well across many or all of the resilience indicators.

TABLE 5.2 Economic Resilience Indicators

Dimensions of resilience	Indicators
Built, human, and institutional assets	1. Quality of infrastructure 2. Human capital 3. Institutional quality and good governance
Macroeconomic and financial flexibility	4. Macroeconomic stability 5. Adjusted net savings 6. Financial market development and efficiency
Economic performance and complexity	7. Gross domestic product per capita 8. Economic complexity
Business environment	9. Ability to absorb technology 10. Ease of doing business
Position on global supply curve	11. Levelized extraction costs

Source: World Bank.

Each resilience indicator is briefly discussed below.

Produced and Intangible Assets

As established in chapter 4, in addition to physical infrastructure, human and institutional assets are also crucial for long-term sustainable welfare.

- High-quality physical infrastructure facilitates the emergence of new industries by providing greater flexibility and lower costs for firms and workers to move to new opportunities, should external shocks to fossil fuels arrive. Several medium- and high-income FFDCs score well on quality of infrastructure such as air transport, ports, roads, and electricity supply.[3] But specialized infrastructure for distributed variable power generation or electrification of the vehicle fleet is poorly developed (Cust, Manley, and Cecchinato 2017). Using the World Economic Forum's Global Competitiveness Index 2017–2018, infrastructure resilience is measured as a combination of transport (road, port, and air) and electricity and telephone infrastructure, measured by both overall quality and quantity, including access.
- Human capital is crucial for a transition to a knowledge-intensive economy, but is generally at a low level in FFDCs (IMF 2016). The value of human capital is captured by multiple indicators (see, for example, Lange, Wodon, and Carey 2018), but is captured in this chapter by an educational indicator. In this assessment, the stock of human capital is measured by overall years of schooling across countries using the United Nations Development Programme's Human Development Reports. This index measures the expected average years of education across countries if prevailing patterns of age-specific enrollment rates persist throughout the child's life. These data provide a coarse picture of the stock of human capital available, and are based on survey observations.
- Quality of institutions is essential for breaking the resource curse, collecting and managing resource rents for public goods, delivering public services, and

TABLE 5.3 Indicators of Resilience to External Shocks for Fossil Fuel–Dependent Countries and Other Selected Countries

	Built, human, and institutional assets			Macroeconomic and financial flexibility			Economic performance and complexity		Business environment		Extraction cost
Indicator	**Quality of infrastructure**	**Human capital**	**Institutional quality and good governance**	**Macroeconomic stability**	**Adjusted net savings**	**Financial market development**	**Economic performance**	**Economic complexity**	**Technology absorption**	**Ease of doing business**	**Oil extraction costs**
Database source	World Economic Forum 2014–2015, Global Competitiveness Index	UNDP 2013	Worldwide Governance Indicators 2016	World Economic Forum 2014–2015, Global Competitiveness Index	World Bank World Development Indicators 2017	World Economic Forum 2014–2015, Global Competitiveness Index	World Bank World Development Indicators 2016	Observatory of Economic Complexity and MIT Media Lab 2015	World Economic Forum 2014–2015, Global Competitiveness Index	World Bank 2017	Based on Rystad 2018
Venezuela, RB											
Iraq											
Libya											
Nigeria											
Equatorial Guinea											
Algeria											
Cambodia											
Congo, Rep.											
Guyana											
Iran, Islamic Rep.											
Vietnam											
Azerbaijan											
Kazakhstan											
Botswana											
Russian Federation											
Kuwait											
Oman											
Saudi Arabia											
Brunei Darussalam											
Qatar											

High exposure – Low exposure

Source: Calculation based on multiple sources.

Note: Although the resilience indicator was calculated for 101 countries, the figure only shows the results for the 20 most exposed countries. The order of countries reflects the countries' composite resilience score (in descending order of exposure). The weights for each score were calculated using principal component analysis.

stimulating and regulating the diversification process. As contended by many authors (for example, Acemoglu and Robinson 2012; Gill et al. 2014; van der Ploeg 2011), good institutions are arguably the most important driver of economic resilience. The quality of governance is one indicator of institutional quality. According to data from the World Bank's Worldwide Governance Indicators Project, institutions in FFDCs are still more "extractive" than "inclusive," as in most net fuel importers (Acemoglu and Robinson 2012). However, significant differences between the various FFDCs exist. Some GCC states, such as Qatar and Saudi Arabia, perform better than many exposed developing countries in Africa (Equatorial Guinea, Libya, Nigeria) and Guyana and República Bolivariana de Venezuela in South America. EBRD (2014) argues that the quality of institutions has been one of the most important determinants of why some former communist countries have been more successful in economic and social transition than others. GCC states rank relatively high with regard to rule of law, control of corruption, and political stability and security, but perform less well on voice and accountability, as well as on the ability to formulate and implement policies that permit and promote private sector development. Outside of the GCC, several FFDCs are captured by fuel-dependent vested interests, notorious for corruption, disregard for the rule of law, low protection against crime and violence, low accountability, and low efficiency of public institutions (Kaufmann, Kraay, and Mastruzzi 2010).

Strong evidence indicates that the per capita incomes of some FFDCs remains a fraction of what it could be with better governance.[4] Olson (1996) finds that the quality of institutions and economic policies explains a significant part of the variation in growth rates across countries. Some studies, such as Knack and Keefer (1995), also find that the quality of governance and institutions is important for explaining rates of investment. Clemens and Williamson (2004) conclude that historically 85 percent of the wealth bias between rich and poor, whether caused by market failure or not, is domestic in origin. The authors argue that poor-country lenders are deterred from investing in poor countries to nearly the same degree as rich-country lenders. In other words, investors at the National Stock Exchange in Mumbai face much the same incentives to invest in India as do their counterparts on Wall Street. Countries with poor property rights and underdeveloped financial markets are therefore vulnerable to excessive foreign debt and have a propensity to default, with a resultant collapse in all but concessional financial inflows. By contrast, exit from excess indebtedness is accompanied by improved governance and institutions.

There are likely to be covariance and co-relationships between governance, productivity, and wealth, with causality flowing in interrelated directions and being difficult to determine. For example, it is possible that the quality of governance is the result rather than the cause of productivity growth. Rich countries with a history of civil liberties and rule of law tend to respect property, invest in education, and demand responsive government. It is likely that poor governance is both the result of poverty and an underlying driving cause. Such amplifying feedback mechanisms mean sustained, carefully targeted policy and institutional reform can trigger a reinforcing cycle of good governance and higher productivity.

Breaking into a positive growth and development cycle requires a trigger, and evidence suggests the trigger often comes in the form of a sustained improvement in governance. The changes in governance and economic policy that occurred when Deng Xiaoping reformed Maoist mainland China, the reforms in the Republic of Korea shortly after Park Chung-hee replaced Syngman Rhee, and Chiang Kai-shek's economic policy in Taiwan, China, in the early 1960s provide ready examples. Cross-sectional evidence also shows that cultures and institutions exert different economic influences on culturally similar societies. Relevant examples are the German Democratic Republic and the Federal Republic of Germany during the Cold War; the Democratic People's Republic of Korea and the Republic of Korea; and pre–Deng Xiaoping mainland China, compared with the economies of Hong Kong SAR, China, and Taiwan, China. These differences cannot be attributed to culture or any preceding differences in income or productivity.

Macroeconomic Stability and Financial Flexibility

A second major factor accounting for the economic resilience of FFDCs is their macroeconomic stability and financial flexibility.

- Macroeconomic stability provides a country with the ability to smooth any disruption caused by diversification away from fossil fuels and carbon-intensive goods and services through countercyclical fiscal and monetary policies, including exchange rates. Many of the most exposed FFDCs, in particular the GCC states, score high in the World Economic Forum's macroeconomic stability index, which consists of indicators of a country's credit rating, saving rates, fiscal position, and inflation rates (WEF 2015).
- Adjusted net savings measures the true rate of saving in an economy after taking into account investments in human capital, depletion of natural resources, and damage caused by pollution. A nation's wealth is determined by its accumulated stock of physical, human, and natural capital. Accordingly, adjusted net savings is calculated as the sum of net national savings and education expenditure minus the sum of depletion of nonrenewable natural resources (energy and minerals), net forest depletion, and damage from carbon dioxide and particulate emissions. Botswana, Brunei Darussalam, and Qatar perform quite well, whereas the Republic of Congo, Equatorial Guinea, and Iraq score low on adjusted net savings, meaning that they have not substituted other forms of capital and have rather spent the wealth on consumption.
- The maturity of financial markets is another relevant factor for FFDCs' economic resilience to LCT impacts. Transparent, sophisticated, and robust financial

institutions are capable of facilitating a shift of investment from carbon-intensive sectors to new sectors and business models. Robust capital adequacy ratios, loan-to-deposit ratios, and liquidity of the financial sector can smooth structural transformation. This stability is particularly important because lower oil and gas prices may adversely impact banks' liquidity in FFDCs, reduce fiscal revenue, and eventually affect access to finance for nonhydrocarbon sectors (IMF 2016). The banking sectors of Oman, Qatar, and Saudi Arabia score relatively well in the World Economic Forum's financial market indicator, while Algeria, Iraq, and Libya perform poorly (WEF 2015). The importance of being able to access financial markets to build resilience and support structural change can be seen from a number of historical and contemporary examples. For instance, in Southeast Asia during the late nineteenth and first half of the twentieth century, the development of regional suppliers of credit preceded and facilitated structural transformation and economic growth (Sen 2016). Also, countries with higher levels of domestic credit appear to have been more robust and better able to endure shocks with less harmful impacts on domestic production. At the level of the individual, a large number of analyses confirm that access to credit plays an important role in short- and medium-run adjustment to adverse shocks in both developed and subsistence economies (Dercon and Krishnan 2002).

- Finally, in developing countries, social safety nets to shield those who temporarily lose from transition and enable new opportunities through health care, nutrition, education (especially among women), and research and development also expand total factor productivity and raise steady-state growth, allowing them to catch up with richer societies.

Economic Performance and Complexity

Another major determinant of FFDCs' resilience to external shocks is their economic performance and complexity. Countries with high levels of economic complexity and stable and high income growth are better prepared to create new capabilities in anticipation of a decline in markets for fossil fuels and carbon-intensive goods and services. The Economic Complexity Index (ECI) captures the diversity and ubiquity of countries' exports (box 5.2; Hausmann et al. 2013). ECI scores in the 20 most exposed countries are mixed: Azerbaijan, Iraq, Libya, and Nigeria perform particularly poorly and may struggle to create new capabilities in their economies because of relatively low levels of GNI compared with other FFDCs. Guyana displays one of the lowest GNI scores but performs better on ECI.

Business Environment

The fourth major factor determining resilience is whether the business environment is conducive to generating new economic activities beyond the fossil fuel value chain.

BOX 5.2 Indicator of Economic Complexity

The measure of economic complexity developed by Hausmann et al. (2013) is derived from the number of products a country makes (diversity) and the number of other countries making the same products (ubiquity). The Economic Complexity Index (ECI) is strongly correlated with GDP per capita, as shown in figure B5.2.1. The figure shows a scatter plot of income per capita and the ECI for countries where natural resource exports make up more than 10 percent of GDP (green) and for those where natural resource exports make up less than 10 percent of GDP (orange). Noticeably, the figure shows that while countries with relatively high levels of natural resource exports tend to be significantly richer than what would be expected given the complexity of their economies, the ECI still correlates strongly with income for that group. The authors also show that there is a strong positive relationship between annualized GDP per capita growth for the period 1998–2008 and the ECI for 1998 after taking into account the initial level of income and the increase in natural resource exports during that period.

FIGURE B5.2.1 Economic Complexity and Variance in GDP per Capita

Source: Hausmann et al. 2013.

Note: GDP = gross domestic product; green = resource exports > 10 percent of GDP; orange = resource exports < 10 percent of GDP.

- The World Bank's ease of doing business index captures the ease of setting up and operating a business. FFDCs vary widely in the ease of paying taxes, efforts to start a business, ease of dealing with construction permits, and getting access to electricity. These differences reflect the fact that some countries are relatively agreeable to new business initiatives, while others keep very high bureaucratic and sometimes corrupt barriers to entrepreneurs outside of the energy sector. The same goes for the ease of cross-border trade and the enforcement of contracts. FFDCs often score poorly on the ease of accessing credit, protecting minority investors, and resolving insolvencies (World Bank 2016).

- A related factor is the capacity to absorb and adopt new technologies, which can help countries and firms respond to shocks, as described in box 5.3. According to the technology absorption index of the Economic Complexity Index, FFDCs vary widely in their technological absorption capacity. This affects their ability to attract foreign direct investment, and reduces domestic firms' ability to absorb innovation and cutting-edge technologies. Poorly performing countries have limited ability to use foreign direct investment to create positive economic spillover effects in innovation and modernization across the economy, most notably outside of fossil fuel–dependent sectors. Brunei Darussalam, Oman, Qatar,

BOX 5.3 Significance of Technological Openness

The differential recovery from the 1997 Asian financial crisis across the region can, to some extent, be explained by different capacities to absorb new technology. For example, Indonesia has disproportionally grappled with recovering from the effects of the crisis, whereas the Republic of Korea, Malaysia, the Philippines, and Thailand had already recovered to precrisis gross domestic product (GDP) levels before 2002. Indonesia recovered far more slowly and did not reach precrisis GDP levels until 2004. Its manufacturing remained weak after 1997, and its fragile recovery was based mainly on exports of primary products, including coal and palm oil. Zen (2012) argues that this slow recovery can be linked to Indonesia's growth trajectory in the three decades beginning in 1970, which was focused on low-cost, labor-intensive manufacturing, unlike the approach followed by Korea and Malaysia. This meant that the country struggled to make the lucrative move up the value chain toward trade in high-tech products to gain export traction after 1997; Indonesia has consistently lagged behind its peers in high-technology exports as a percentage of manufactured exports.

These challenges may be linked to and exacerbated by weaknesses in its human capital: Indonesia has fewer years of schooling, on average, than Malaysia and the Philippines (6 years compared with 10 and 8 years, respectively). This lack of educational attainment not only made the country relatively unattractive as a production base and investment target for multinationals—which in other countries has been conducive to absorptive capacity for new technology—but also failed to create an environment for domestic innovation and entrepreneurship in the high-tech sector.

Similar evidence on the importance of technological openness arises from a comparison of the Swedish and US pulp and paper industries in response to new social and environmental demands. Whereas the US paper and pulp companies were technologically locked in, Swedish firms took a more proactive approach to environmental research and development and established collaborative relationships with national policy makers associated with developing integrated abatement technology. Today, Swedish firms are technological leaders in the industry (Bergquist and Söderholm 2015).

the Russian Federation, and Saudi Arabia appear to have relatively high capacities for technology absorption. Algeria, the Islamic Republic of Iran, Iraq, and Nigeria, on the other hand, appear to have lower access to the latest technologies.

Another important determinant of resilience is a country's relative position on the global supply curve for gas and oil. Even relatively exposed countries are more flexible to the impacts of a transition if their extraction costs are lower than those of competitors and a large portion of development costs is already sunk. Having low extraction costs relative to other oil-producing countries is an indication of resilience, given that countries with high costs would likely be the first to halt production.

Notes

1. Column 2 of figure 5.2 and table 5.2 are two ways of presenting similar data on exposure driven by the production of fossil fuels; however, data on current fossil fuel exports as a proportion of GDP is missing for Turkmenistan, as are data on the carbon intensity of exports. Turkmenistan is therefore omitted from the composite index. Libya, on the other hand, is not currently included in the Rystad UCube database but was estimated by expert judgment of the authors in the composite index.
2. Note that this indicator is calculated as the ratio of the total estimated volume of emissions of all operating plants built in or before 2020 to total electricity generation in 2013. Hence, it captures current plans to expand thermal generation, with an associated increase in committed emissions.
3. However, some of this infrastructure may be dedicated to hydrocarbon sectors without multipurpose functionality and thus may become underutilized or need significant investment for adjustment if climate change response measures reduce demand for fossil fuels.
4. Olson, Sarna, and Swamy (2000) assume a Cobb-Douglas production function in each country to draw out differences in total factor productivity and use a fixed effects panel to relate cross-sectional country heterogeneity (assessed through fixed-country dummies) of governance.

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6. Charting the Future

Successful economic strategies in fossil fuel–dependent countries (FFDCs) will need to strike a balance between (1) managing traditional carbon-intensive assets to generate predictable revenue and (2) managing the transition to productivity-led and knowledge-intensive growth models relying on much broader portfolios of assets.

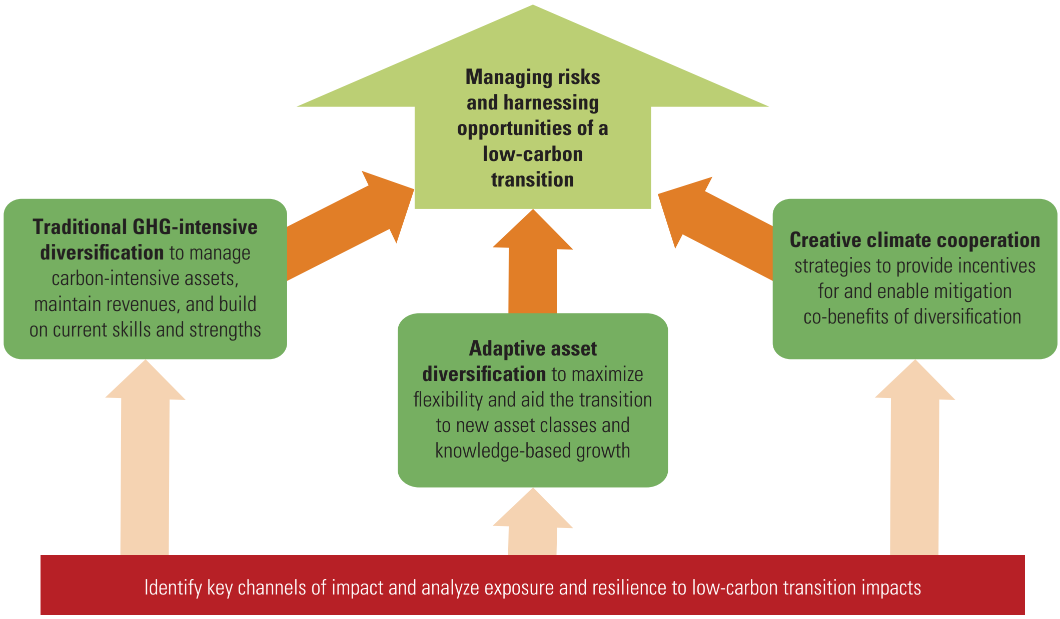
The FFDCs that successfully navigate the uncertainties of a global low-carbon transition (LCT) will be those that acknowledge the challenge head on and start preparations for the best and worst-case scenarios of an LCT. Preparation strategies include creating hedging portfolios of policies and investments to manage the risks and harness the opportunities that an LCT brings. Deep uncertainty around the timing and channels of impact emphasizes the need for robustness, flexibility, and resilience of countries' strategies. In this context, robustness refers to the ability of an economy and society to maintain or increase welfare under the largest number of plausible scenarios. Flexibility and resilience refer to the ability of an economy and society to adjust to surprising and changing external conditions. Some FFDCs and their state-owned enterprises (SOEs) have already started planning to manage the risks associated with such changes and have identified potential upsides from a low-carbon future.

This chapter explores a three-pillar framework for managing the risks and harnessing the opportunities of an LCT (figure 6.1). It consists of the following coexisting strategies:

- Managing carbon-intensive assets to maintain revenues that build on current skills and strengths through traditional carbon-intensive industrialization
- Managing a transition to new asset classes and new knowledge-intensive growth models, while maximizing flexibility and resilience to external impacts
- Finding creative ways to cooperate with other parties on climate change to provide incentives for efforts to enable and enhance the mitigation co-benefits of diversification

These three pillars need to rest on an understanding of the key channels through which an LCT can affect a country and an understanding of the strengths and weaknesses of a country's exposure and resilience to these possible impacts.

FIGURE 6.1 More than Divestment: Multiple Strategies Will Help Fossil Fuel–Dependent Countries Navigate the Risks and Harness the Opportunities of a Low-Carbon Transition



Source: World Bank.
Note: GHG = greenhouse gas.

Assessing Uncertain Impacts and Preparedness for Managing a Low-Carbon Transition

A critical first step is to identify the risks and opportunities that a country faces and the extent to which it is prepared for them. The analysis conducted in previous chapters serves as a framework for this assessment, which consists of three interrelated tasks:

- *Identify the channels and pathways through which a global LCT could affect an economy* (chapters 2 and 3)
  - Different channels of impact will have different effects on different countries depending on their sectoral composition. However, the intertwined impact of "disruptive" clean technologies and networks, shifts in consumer and investor preferences, changes in policies and institutions, and the growth of influential new business lobbies should be assessed in the context of policy and trade actions that major trading partners may consider taking.
- *Assess macro-fiscal and sectoral risks and opportunities through scenario analysis* (chapter 4).
  - Scenario analysis is an effective tool for dealing with risk (TCFD 2016). It can stress test key performance indicators against several possible combinations of external events (UCISL 2016), including best-case and worst-case scenarios.

Scenario analyses should explicitly take uncertainty into account by adopting a forward-looking assessment of alternative (but plausible) futures (for example, Peszko, van der Mensbrugghe, and Golub 2020). The challenge is to avoid scenario selection bias, and to also consider potential worst-case scenarios, even if they look unattractive from a country or sector perspective.

- *Evaluate and benchmark the preparedness of an economy and society* (for instance, using the index introduced in chapter 5).
  - Chapter 5 provides a comprehensive methodology for assessing a country's preparedness for managing the risks and harnessing the opportunities of an LCT. It helps provide an understanding of areas in which exposure needs to be decreased and resilience to external shocks increased. The index also allows a country to be benchmarked against its main fossil fuel–dependent peers and the design of the portfolio of strategies to manage the transition to be customized.

Developing Strategies to Manage an LCT

Once the impacts of, and preparedness for, an LCT have been identified, FFDCs can adjust their existing long-term strategies to account for the additional impacts and uncertainties associated with a transition. Some fossil fuel–consuming countries have already developed strategies aimed at thriving in a net-zero carbon world (for example, the United Kingdom, through the application of the Climate Change Act[1]). Fossil fuel exporters are in even greater need of doing so. These strategies should recognize uncertainty as to when and how an LCT may unfold. This uncertainty reinforces rather than invalidates the need for sophisticated strategic planning.

An array of tools and approaches are available to aid decision-making under different degrees of risk and uncertainty. These tools can improve the understanding and management of risks of an LCT and improve the flexibility and robustness of the decisions of governments, firms, investors, and financial institutions exposed to assets that may be affected by a transition (box 6.1).

BOX 6.1 Tools to Aid Decision-Making under Uncertainty

Risk can be accommodated with decision-aiding tools such as adjusted expected value or real options analysis. Such tools allow policy makers to keep as many options as possible open and limit the likelihood of regret down the line if and when new information comes to light.

In the presence of deep uncertainty, when the assignment of probabilities to different future scenario outcomes is impractical or impossible, robust decision-making can provide additional insights.

All these techniques are underpinned by scenario analysis, which identifies a range of possible future outcomes and helps navigate toward increasing the probability of the most desirable outcomes (Kalra et al. 2014).

An LCT management strategy should consider at least three critical issues:

- How to manage existing carbon-intensive assets (see section "Managing Existing Carbon-Intensive Assets")
- When and how to make a transition to new asset classes (see section "Investing in a Broader Portfolio of Assets")
- How to address the needs of citizens and firms that are most vulnerable to an LCT (see section "Protecting Vulnerable Citizens")

These issues are discussed below.

Managing Existing Carbon-Intensive Assets

Countries can choose among multiple strategies to manage their existing carbon-intensive assets. The ultimate objective of any strategy is to maintain the ability of fossil fuel reserves to generate resource rents in a world that may become more carbon constrained. The same objective applies to the ability of downstream heavy industries to generate profits or at least operational cash flows under various possible impacts of an LCT. The right combination of strategies will be different for each country, depending on the country's exposure, cost competitiveness, and market share, as well as external market conditions. The size, efficiency, and age of existing infrastructure will also play a role.

FFDCs and their SOEs can learn from the experience of firms operating in industries facing the risk of structural decline. With increasing technology disruption and policy initiatives to mitigate climate change, FFDCs and their SOEs find themselves in risky and potentially shrinking markets. In some, but not all ways (*Foreign Affairs* 1994), their situation is similar to firms in declining industries that are trying to increase their value to shareholders under deteriorating external market conditions. Therefore, the experience of firms operating in declining industries can provide important lessons for managing carbon-intensive assets under the risk of an LCT. Literature on exit patterns, for example, looks at game theory to inform successful strategies (for example, Filson and Songsamphant 2005), while studies on organizational ecology differentiate between specialists and generalists and the implications in declining environments (Zammuto and Cameron 1985). In normative management literature, which tries to provide a better understanding of the behavior of firms and industries in declining environments, Harrigan and Porter (1983) present one of the most advanced models for determining strategy.

The Harrigan-Porter model for determining firms' strategies in declining industries is particularly relevant for the strategic thinking of FFDCs (Harrigan 1980; Harrigan and Porter 1983). For some countries and SOEs, the best strategy will be to start divesting early, even when the signs of a permanent structural decline remain difficult to discern. Others may try to engage in risky leadership or niche strategies by betting on increasing their shares in the declining sectors or products. Harvesters will run down their existing carbon-intensive assets hoping to extract maximum cash when they believe that a tipping point is imminent. Box 6.2 summarizes the guidance that the Harrington-Porter model provides for companies trying to choose the most successful strategy under various external market conditions. Some initial observations can be made about how the existing behavior

BOX 6.2 Harrigan's Model of Firms' Strategies in Declining Industries

The model describes four generic strategies that firms in declining industries can choose from to manage a market transition:

- *Leadership strategy.* A company exercising this strategy attempts to become one of the few companies remaining in the industry, thereby giving the firm the market power to increase profitability and influence prices. Leadership can be achieved through aggressive competitive actions in pricing and marketing or by reducing competitors' entry and exit barriers.
- *Niche strategy.* In this strategy, a firm attempts to find a favorable segment that maintains level demand or declines more slowly than the rest of the market. Firms following this strategy act preemptively to gain a strong position in the niche, while divesting other segments.
- *Harvest strategy.* Firms using the harvest strategy maximize short-term cash flow, keep up the maintenance of facilities, but curtail new investments, reduce marketing and research, and focus on only the most profitable products. The long-term objective is an orderly exit.
- *Divest strategy.* Divesting firms sell exposed assets before they start losing value. The earlier the business is divested, the better the possibility of finding buyers for the assets because the future slide in demand is still uncertain. Although it is risky to divest early because the forecast of decline may prove incorrect, it is also risky to wait too long given that buyers will gain bargaining power.

Each strategy can be successful under specific conditions. According to Harrigan and Porter, firms in declining industries should base their selection on an analysis of their market environment, especially by answering two key questions:

- Are the structural and regulatory factors favorable?
- Does the firm have competitive strengths in the remaining demand pockets?

Depending on the answers to these two questions, different strategies have better chances of succeeding (table B6.2.1).

(*Box continues on the following page.*)

BOX 6.2 Harrigan's Model of Firms' Strategies in Declining Industries (continued)

TABLE B6.2.1 Matrix of External Determinants of Successful Strategies of Firms in Declining Industries

	Favorable industry structure	Unfavorable industry structure
Has competitive strengths	Leadership or niche	Niche or harvest
Lacks competitive strengths	Harvest or divest quickly	Divest quickly

Source: Based on Harrigan and Porter 1983.

Structural factors	Environmental attractiveness	
	Favorable	Unfavorable
Conditions of demand		
Speed of decline	Very slow	Rapid or erratic
Certainty of decline	100% certain, predictable patterns	Great uncertainty, erratic patterns
Pockets of enduring demand	Several or major ones	No niches
Product differentiation	Brand loyalty	Commodity-like products
Price stability	Stable, premium attainable	Very unstable, pricing below costs
Exit barriers		
Reinvestment requirements	None	High, often mandatory and involving capital assets
Excess capacity	Little	Substantial
Asset age	Mostly old assets	Sizable new assets and old ones not retired
Resale markets for assets	Easy to convert or sell	New markets unavailable, substantial costs to retire
Shared facilities	Few, free-standing plants	Substantial and interconnected with important businesses
Vertical integration	Little	Substantial
"Single product" competitors	None	Several large companies
Rivalry determinants		
Customer industries	Fragmented, weak	Strong bargaining power
Customer switching costs	High	Minimal
Diseconomies of scale	None	Substantial penalty
Dissimilar strategic groups	Few	Several in same target markets

Source: Harrigan 1980.

Note: Empirical evidence suggests firms had a success rate higher than 92 percent when they applied the strategy suggested by this model (Harrigan 1980).

of different FFDCs and their fossil fuel–dependent SOEs fit the Harrigan-Porter strategy model:

- *Leadership strategy.* Aim to become one of the few countries or companies remaining in a particular sector so that market power can be exercised to increase resource rents by raising global prices. Both leadership and niche strategies are likely to be inherently risky in erratic and uncertain policy environments associated with an LCT.

- In coal extraction, where a degree of product differentiation is possible (thermal versus coking, calorific value, sulphur and ash content, and so on), producers with higher chances of success when using a leadership strategy are those that will have high-quality coal with low extraction costs, and low costs of transport to nearby growing markets (for example, Southeast Asia). This is better news for Australian, East African, and Indonesian coal producers than for those in the Americas or Eurasia, especially when coal prices in the United States fall below prices in the Australian and South African hubs.
- In oil and gas markets, exercising market power is going to be increasingly difficult (Helm 2017). Leadership can be achieved only with effective cartel actions and mergers and acquisitions in other countries, where barriers to entry can be high for oil and gas industries. However, if peak oil demand becomes imminent, the efforts to exercise market power can be more difficult in the struggle for increasing slices of a shrinking pie and expected decreasing returns.
- Outside of extractive industries the most efficient and the least carbon-intensive firms in energy-intensive sectors have the best chances to play leadership strategies. Rusal, for example—the world's second-largest aluminum producer, from Russia—has been actively pursuing a global leadership strategy trying to differentiate its products by their low-carbon footprint.

- *Niche strategy.* Aim to identify a segment within the fuel-dependent industries (whether a sector, product, or geographical territory) in which a firm or a country has a comparative advantage, and which will maintain a relatively high level of demand, or which will decline more slowly than the rest of the market (for example, extractive, petrochemical industries, and aviation). Acting preemptively allows a firm to gain a strong position in the niche by investing in the most efficient technologies and processes while divesting from other segments. Domestic reforms, such as commercialization of SOEs, can strengthen their efficiency and incentives to select successful niches and products that can be resilient to LCT impacts.
  - In the coal industry niche strategies may be more successful when focused on coking coal, the demand for which comes from the steel industry where substitution for other products and fuels is more challenging than for thermal coal used in power plants. Various coal countries are betting on "clean coal" technologies such as carbon capture and storage or carbon capture, usage, and storage, where progress has been very limited so far. It is still easier to build a coal power plant that is locally clean, with significant improvements of generation efficiency and efficacy of local pollution control equipment, than a plant that is globally clean, although minimizing local pollution comes at high capital and operating costs. South African Sasol demonstrated that under extreme economic conditions (such as trade sanctions during apartheid), a range of

innovative chemical products can be derived from coal, but doing so becomes commercially challenging, although not impossible, under competitive market conditions. Some countries, such as Indonesia and Poland, are developing niches for coal demand in domestic markets by supporting vertical integration of coal mines and generation companies to expand national coal power generation. This strategy may not be sustainable in the longer term under competitive market pressures and the high fiscal costs of providing state aid.

- In the oil and gas sector, Qatar and the United Arab Emirates, for example, identified aviation as a niche, with access to cheap fuel and government support. Saudi SABIC became the third-largest petrochemical company in the world and is aggressively pursuing research and development and commercialization of new material technologies derived from recycled plastics, as well as those that can be produced from carbon dioxide by carbon capture and use. This may add value to and extend the noncombustible demand for oil, given that several traditional petrochemical products may become exposed to the risk of border adjustment measures. Niche strategies are inherently risky and can only succeed for selected countries and fuel-dependent companies under specific conditions, for instance, where there are clear barriers to entry for late movers (hub airports, although they can be easily established now, are examples for which the value to followers is marginal). Again, a cooperative policy environment can reduce the risk of stranding investments in fossil fuel–derivative products, for example, by reducing the probability of surprising trade sanctions.

- *Harvesting strategy.* These strategies aim to generate cash flows from existing mines, downstream industries, and thermal power plants; curtailing new investments; minimizing maintenance costs; reducing marketing and research; and gradually limiting production to only the most profitable products in conjunction with establishing a mid- to long-term exit strategy.
  - In the coal sector, for example, many European power companies are opting for derogations from European Union (EU) environmental performance standards for old coal power plants, which allows them to operate for a limited time with capped operating hours per year without investing in expensive pollution control equipment. The Czech private firm EPH has bought a number of lignite, hard coal, and gas power plants across Europe, betting that they will be able to generate a cash flow for at least the next decade or so.[2] Harvesting strategy has to yield large short-term returns to be successful in the fast-moving European power market, where coal faces particularly strong policy headwinds. Across Europe, countries are pulling out of coal in power generation. In April 2020, Austria and Sweden closed their last coal power plants. Existing plants are experiencing record-low utilization rates, with the United Kingdom and Portugal keeping their entire fleets of coal power plants idle for several weeks during the COVID-19 crisis. The German government and regional leaders have agreed on a plan to phase out coal-fired power stations by 2038.

- In oil and gas extraction, a harvesting strategy may include off-loading new upstream business to foreign investors under production-sharing contract structures that frontload the government take and share the LCT risks more equally between the host country and the foreign developer.

- *Divestment strategy*. These strategies aim to dilute government ownership in exposed assets by selling shares in SOEs or by opening new extractive operations to international investors while the assets still have high market value.
  - In the coal sector, most governments around the world have been continuously downsizing state-controlled coal mining by restructuring production and leaving only the most efficient mines operating (Mehling et al. 2017). Indonesia has been decentralizing and privatizing its coal-mining operations since 1990, well before an LCT became an issue. As part of its COVID-19 stimulus package, India broke up the Coal India monopoly and opened commercial coal mining to private companies, including foreign ones. The Swedish state-controlled energy company Vattenfall is divesting all its thermal assets abroad. E.ON, one of the world's largest investor-owned electric utility providers, completed the split of its fossil fuel and renewable operations.
  - In the oil and gas sector, the divestment movement is mainly driven by institutional investors (pension funds, university trust finds, and so on) in major international listed companies. Established national oil and gas companies are slower to be floated, partly amid concerns about national security and partly because the governments are often uncomfortable about transparency associated with foreign investments. For example, it is difficult to determine whether the planned floating of Saudi Aramco, the largest crude oil exporter in the world, was part of a divestment or a leadership strategy.

The success of each strategy will depend on the competitive advantages and capabilities of individual firms and countries, as well as market and social conditions. For example, the leadership or niche strategies can be less risky for extractive firms with strong international comparative advantages in certain fuels or products, relatively low production costs, strong market power (individually or through a cartel), unique product characteristics (such as a relatively low-carbon content), large sunk costs, low marginal cost of production, flexible capital schedules (for example, shale oil and gas), easy access to capital and markets, and a predictable policy environment. On the other hand, companies that operate less efficient assets, face bulky capital needs for field development and access to market infrastructure, and those operating in countries with a low level of preparedness for an LCT may prefer to gradually divest to reduce exposure to LCT risks or harvest short-term cash from existing assets. Table 6.1 summarizes the overall guidance on customizing a successful strategy to the internal and external conditions of a firm and a country.

TABLE 6.1 Matrix of Determinants of Success of the Strategies of Fossil Fuel–Dependent Firms

	Cooperative, smooth LCT	Noncooperative, disorderly LCT
Has comparative advantage and high level of preparedness	Leadership or niche	Niche or harvest
Lacks competitive advantage and has low level of preparedness	Harvest or divest	Divest

Source: World Bank based on Harrigan 1980.
Note: LCT = low-carbon transition.

The chance of success for the inherently risky leadership or niche strategies will increase if the LCT pathways are relatively smooth and predictable in the medium to long term. Countries that are better prepared for an LCT will create a more enabling environment for their SOEs and private fossil fuel–dependent companies to exploit elements of leadership and niche strategies, whereas firms operating in countries with inconsistent climate strategies and a low level of preparedness may find it difficult to take risks associated with these strategies.

Improved governance and commercialization of fuel-dependent SOEs will be essential to their ability to use smart strategies during an LCT. Currently, many SOEs in developing countries are less efficient and less flexible than their private competitors. Often burdened with social mandates and subject to political pressures, SOEs are less able to prepare for and respond to possible market disruptions. A study on China concludes that the reform of state-owned coal power plants is crucial to managing an LCT. It recommends that the least efficient, old coal assets be put in a coal sector "bad bank," amortized, and retired as quickly as possible (Spencer, Berghmans, and Sartor 2017).

Few countries or companies pursue a single strategy in its pure form. Each country and SOE may consider and pursue elements of different strategies simultaneously across different market segments and change strategy over time. Doing so can help reduce the risk of surprising shifts in external market conditions. For example, Statoil (now Equinor) is arguably playing a combination of leadership, niche, and divestment strategies in the oil and gas sector. The firm's strategy also emphasizes efforts to support cooperative climate policy actions, including through carbon pricing, and the broader policy environment toward the LCT (box 6.3). As Eldar Saetre, chief executive of Statoil, said, "Diversification into renewables makes sense. We have a lot of skills which we can apply directly into offshore wind. It can deliver good returns, [with] a much lower cost of capital than oil and gas would require" (*Financial Times* 2017a).

Determining the appropriate strategy for fuel-dependent SOEs will require monitoring of global technology, policy, and market trends. Governments and SOEs will need to periodically conduct a scenario analysis of how an LCT might evolve and how it may affect their businesses and diversification strategies.

BOX 6.3 **Statoil (Now Equinor) Strategic Framework**

"We aim to set an example for how the oil and gas industry must develop, show leadership, and point the way to bolder and better solutions. We are an energy company committed to long-term value creation in a low-carbon future. We believe a low-carbon footprint will make us more competitive in the future. We also believe there are attractive business opportunities in the transition to a low-carbon economy.

"Our strategy focuses on three main areas. We are building a high-value and low-carbon oil and gas portfolio, we are building a material industrial position in renewable energy and low-carbon solutions, and we embed climate risk and performance into our decision-making. Our Climate Road Map explains how we plan to achieve our goals and how we will develop our business, in support of the ambitions set out in the Paris Climate Agreement:

- *Build a high-value and lower-carbon oil and gas portfolio* (CO_2 emission reductions of 3 million tons per year by 2030; Portfolio carbon intensity of 8 kg CO_2/boe by 2030; Methane emissions from the Norwegian gas value chain below 0.3%; Eliminate routine flaring by 2030)
- *Create a material industrial position in new energy solutions* (New energy solutions with potential to represent around 15–20% of capex by 2030; Up to 25% of research funds to NES and energy efficiency by 2020; Invest $200 million through our new energy ventures fund; Partner in the $1 billion OGCI)
- *Accountability and collaboration* (Continued support for carbon pricing; Minimum internal carbon price of $50 per tonne CO_2; Climate risk and performance embedded into strategy, incentives, and decision-making; Amplifying our climate actions through collaboration)"

Source: Extracts from Statoil. 2017. *Shaping the Future of Energy* (https://www.statoil.com/en/how-and-why.html #shaping-the-future-of-energy).

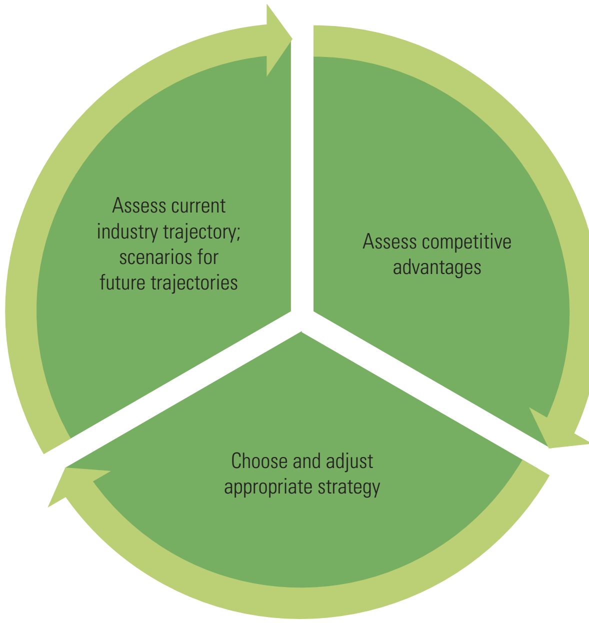
Note: boe = barrel of oil equivalent; capex = capital expenditure; CO_2 = carbon dioxide; NES = new energy solutions; OGCI = oil and gas climate investments.

A strategy-development process can involve three cyclical steps (figure 6.2). First, decision-makers need to understand the current industry trajectory (McGahan 2004) and develop scenarios for possible future trajectories depending on technology, policy, and market trends. This step creates a context for assessing the individual competitive advantages and level of preparedness for LCT impacts within the industry. Based on the findings, the appropriate strategy can be chosen and adjusted iteratively as external factors change or internal capacities increase.

One key lesson that emerges from past studies of declining industries is that it is notoriously difficult to identify in real time when a temporary fluctuation is developing into a structural transformation. A tipping point typically becomes evident only after it has happened.

While managing existing carbon-intensive assets during the transition period, policy makers will also need to see beyond the interests of their carbon-dependent

FIGURE 6.2 Strategy-Development Process for Countries and Fossil Fuel–Dependent SOEs



Source: World Bank.

SOEs. The robust development challenge will be to protect the long-term interests of citizens by steering the entire economy toward more diversified, less carbon-dependent assets through pricing and other consistent policy signals.

Investing in a Broader Portfolio of Assets

As discussed earlier in this chapter, managing existing fossil fuel assets is crucial to generating continuous revenue flow to enable asset diversification. However, equally challenging is avoiding locking the economy into a fuel-dependent growth model. A prerequisite for a robust and viable economic transformation is the creation of incentives and institutions to facilitate asset diversification. As demonstrated in this study, asset diversification maximizes productivity, economic flexibility, and the capacity to diffuse and absorb knowledge and innovation. It also marks a transition to an "intangible" growth model, one that is less dependent on underground and produced assets, and more so on human and institutional capital. But its benefits to society do not manifest immediately and carbon-intensive incumbents may resist change.

Successful diversification and climate cooperation strategies will need to be dynamic and adaptive, recognizing the value of flexibility. Flexibility means leaving governments and economic agents with as much freedom of choice as possible at different decision points, while staying focused on taking early advantage of opportunities as they emerge. FFDCs must build "hedging portfolios" of policies and investments customized to the country context. Flexibility in the face of uncertain external shocks will require better economic institutions and policies, including openness to the private sector, better regulations (such as environmental and energy efficiency regulations), consistent pricing signals that make economic agents see the true social cost of the energy they use, and enabling conditions for diffusing and absorbing knowledge and innovation.

Facing the possibility of a rapid LCT, FFDCs will need to make decisions about investment in new, unfamiliar assets. This requirement reinforces the importance of collecting resource rents from extractive companies and using them wisely for the benefit of the entire society, including future generations. Institutions and incentives will be needed to level the playing field between carbon-intensive incumbent companies and innovative new entrants, both national entrepreneurs and foreign direct investors. Investment in new assets could generate an environment conducive to asset diversification and investment in the sources of wealth that FFDCs are traditionally weak in, especially human capital, knowledge, and institutional capacity. Removing the barriers to diversification—such as policy and fiscal incentives to continue investing in high-carbon assets and infrastructure—will be a challenge. These detrimental incentives include fossil fuel subsidies and energy pricing structures that fail to internalize the environmental damage and social costs of energy production and use. More specifically, the framework for converting resource rents into accumulation of new asset classes, less exposed to LCT risk, can consist of the following elements:

- *Increasing the fiscal take of resource rents and reducing public revenue risks.* Countries differ in how much fossil fuel rent they collect though royalties, taxes, dividends, fees, or production-sharing contracts. Rents that are left in the extractive sectors are usually reinvested by extractive companies (mainly SOEs in FFDCs) in further expansion of fuel-dependent businesses; converted to high salaries, bonuses, lobbying expenses, and luxury facilities; or siphoned off to offshore accounts (Devarajan 2018). Similar patterns can sometimes be seen in the dividend policies of SOEs in refineries or the thermal power sector. The risk of an LCT requires increased government efforts to collect resource rents from the extractive sectors to enhance the fiscal space to maneuver. Over time, preparedness for an LCT requires that governments gradually shift their fiscal revenues from relying on resource rents toward instruments that are more resilient to LCT impacts. Devarajan (2018) also argues that “extractive” state institutions may become more accountable to citizens at large if resource rents are distributed as dividends directly to citizens and then collected by governments through traditional taxes.
- *Incentives and medium- to long-term public expenditure frameworks to reinvest the fiscal take of fossil fuel rents in a diverse range of assets.* At the core of robust strategies are institutions and incentives that favor saving over consumption. Such strategies reinforce the importance of genuine saving and investments

rather than spending fossil fuel–derived revenues on purchasing foreign consumer goods. A transparent medium- to long-term public expenditure framework could help redirect fiscal resources toward building economic resilience. The delivery mechanisms of the longer-term expenditure frameworks will vary depending on country preferences and circumstances. Some will strengthen the political independence of their wealth funds or establish new ones. Others will establish longer-term fiscal frameworks and budget rules that require the evaluation of public expenditure programs through the lens of climate sustainability, along with increased disclosure on carbon dependency and climate risk.

Equally important is to invest the savings in the asset classes that are traditionally underfunded in FFDCs—especially human capital, knowledge, institutional capacity, and ecosystem services. Renewable natural capital delivers sustainable ecosystem services underpinning the value of human capital and substituting for services of produced or nonrenewable natural resources. The value of natural capital is increasingly being recognized and measured in the frameworks of national accounts (Hamilton and Hepburn 2014; Helm 2015; Lange, Wodon, and Carey 2018; World Bank 2011). Intangible assets, such as institutions, good governance, and knowledge, are responsible for increasing the productivity of all other forms of capital (see chapter 4). They help increase economic flexibility and the economy's ability to absorb, generate, and diffuse knowledge and innovation. The institutional and regulatory protection of disruptive private entities entering the markets dominated by state-controlled incumbents is crucial for managing successful transitions. Good governance of the transition also prevents unintended negative effects, such as rebound effects (especially if prices are inappropriate), misallocation of capital, or capture and rent-seeking behaviors (Hallegatte, Fay, and Vogt-Schilb 2013).

- *Regulatory incentives to minimize irreversible capital-intensive investments in fossil fuel–dependent sectors and infrastructure.* Effective hedging strategies include the removal of distortive regulations and policies that perpetuate dependency on fossil fuels and the introduction of policies that minimize excessive and irreversible capital-intensive investments in exposed assets, paving the way for the discovery of new sources of national comparative advantage. During transition, vertical industrial policies need to be rooted in horizontal pricing incentives that reflect the value of flexibility and discourage increasing the systemic risk of an LCT. Such horizontal incentives are the inevitable backbone of national innovation systems that facilitate innovation and creativity across the economy and smooth relocation of assets across classes should external impacts become apparent (Lee 2013; Malerba 2004).

The most distortive regulations involve various forms of subsidies to fossil fuels and the industries that use them, and energy pricing structures that fail to internalize the social costs of energy. Systemic risk is also increased by different, often nontransparent forms of protection of fossil fuel–dependent incumbents from competitive challenge by new players (Whitley and van der Burg 2015). Although, as discussed earlier, subsidies can be among the tools for managing the transition through traditional diversification, they carry the risk of masking the warning signals in the sectors that are most exposed, hence making them even less prepared for disruptive external impacts. Withdrawal of subsidies is more difficult than their introduction. Removing subsidies is always politically sensitive and may require measures to mitigate unwanted social distributional impacts, and to overcome the rent-seeking habits of incumbents (Kojima and Koplow 2015). Different methodologies exist to measure fossil fuel subsidies. In pretax value, these subsidies were estimated at $296 billion in 2017 (0.37 percent of gross domestic product [GDP]). When unpriced externalities were included—from accidents to air pollution to climate change—the global value of these subsidies was estimated at $5.2 trillion in 2017, or 6.5 percent of global GDP (Coady et al. 2019).

Another horizontal incentive structure is fiscal reform that aligns fuel taxation with the social and environmental (global and local) costs of extracting and using fossil fuels (Bovenberg and de Mooij 1994; Parry et al. 2014). The fiscal reform can, for example, link the rates of excise duties to external costs, or introduce explicit Pigouvian environmental taxes (Pigou 1954). Increasing the tax burden on economic "bads," such as pollution, can raise additional revenues from carbon-intensive activities and allow the fiscal burden of sustainable economic "goods," such as knowledge- and labor-intensive activities, to be lowered (Fullerton 1997). A wide-ranging review of the extensive debate on the so-called double-dividend hypothesis is provided by Jaeger (2013). Alternatively, additional revenue can be invested in sources of new, sustainable comparative advantage. Price signals can help direct private flows of finance and technologies toward low-emissions investments while giving economic agents flexibility as to what to invest in. It is often easiest to introduce energy pricing changes at the same time as undertaking broader energy sector reforms that liberalize energy markets and make them more flexible. The combination can create a virtuous circle whereby energy sector reform makes price changes more effective, thereby encouraging the growth of new energy sector players with an interest in maintaining and accelerating reform (World Bank 2016). At the same time, shifting taxes toward carbon-intensive activities exacerbates the risk of rapid erosion of the tax base if an LCT accelerates. Therefore, fiscal risk management frameworks are needed to ensure public revenue stability.

- *Innovation policies and the role of the state.* Traditional export diversification can be combined with broad asset diversification. Investing in human capital, better regulations, and infrastructure supported by horizontal incentives and policies may not be able to ignite new sustainable tradable production growth engines, especially among major oil and gas exporters, because of pervasive market failures (Cherif and Hasanov 2014). Sunset industrial policies can be combined with careful application of sunrise industrial policies building on existing strengths. This combination could accelerate the discovery of new comparative advantages. Facing deep uncertainty, the state sometimes needs to take a more active “entrepreneurial” role in discovering new sources of comparative advantage, shouldering the risks that private firms and venture capitalists are not willing to take on but avoiding unfair competition with, and crowding out of, private initiatives (Mazzucato 2013).

Countries at different stages of development vary in their capacity and the conditions to create, absorb, and access new technologies. Historically, many innovation policies in developing countries were not successful because they focused too much on the creation of technology (government-funded upstream research and development, labs, and technology incubators) and too little on the absorption and deployment of technology (EBRD 2014).

- *Managing the politics of transition and established vested interests.* Recognizing political economy realities and challenges when making a transition is crucial. Political risk will apply more to the losses of incumbents than to the equally valuable opportunities of new entrants because, in most political systems, “old” vested interests will initially be more effective at lobbying politicians (Baldwin and Robert-Nicoud 2007). Policy makers need to use their political capital to facilitate the entry of new, innovative firms that can challenge the dominant position of the powerful incumbents, including those that are owned or controlled by the state. Institutional arrangements that actively promote openness to change, creativity, and flexibility can generate great value.

Indeed, this is not just a problem of distribution between pioneers and losers. Even those who perceive themselves as losers may, in fact, act against their own interests by blocking or delaying change. For example, Peszko, van der Mensbrugghe, and Golub (2020) suggest that even though cooperative climate policies in some circumstances are actually in the interest of oil companies in FFDCs, many of them are still lobbying against more ambitious domestic climate actions. Similarly, policies and regulations that firms claim will damage them can turn out to encourage productive innovation (Combes and Zenghelis 2014). For example, in 2009 the European Union introduced a fleet average target of 130 grams of carbon dioxide per kilometer by 2015. This target was opposed by the motor industry but was met two years early. By contrast, in the United States, car and consumer-industry lobbying kept gasoline taxation low. The consequence was that the US car industry was much less prepared for higher oil prices and the global financial crisis than the EU industry, an important contributor to the bankruptcies of Chrysler and General Motors in 2009 (Bassi and Zenghelis 2014).

Protecting Vulnerable Citizens

Managing the social impact is an important aspect of structural transformation. Change requires adjustment, and with adjustment come winners and losers. Caring about those who stand to lose and enabling them to partake in the opportunities associated with a more diverse and flexible economy is a key part of successfully managing an economic transition. Managing the transition involves assisting the people and regions directly affected by it, and retooling and reskilling workers rather than protecting declining industries dominated by incumbents who often obstruct change. This aspect is not covered in depth in this book because it is addressed in the parallel research program initiated by Climate Strategies (https://coaltransitions.org) and the World Bank (Stanley et al. 2018).

In particular, assistance may be needed for workers and communities directly affected by the LCT (such as stranded coal labor). For example, a transition away from using coal for power generation has been found to deprive regions dependent on mining for a long time. Substituting solar or wind energy for coal power may be economically and commercially efficient, but often reduces local jobs because coal mining and power generation are more labor intensive. Even in advanced economies that have undertaken significant policy efforts and fiscal transfers, revitalizing affected communities can be difficult (box 6.4).

BOX 6.4 The Decline of the UK Coal Industry

The abruptness and social consequences of the demise of coal in the United Kingdom is seen by some international observers as a model of how not to wind down a declining industry.

The UK's coal industry has experienced a prolonged decline since the 1920s, but the accompanying social malaise was exacerbated by British postwar industrial policy. The industry was nationalized in 1947. By the early 1960s it was suffering from overcapacity and low productivity, which resulted in its sharp contraction. The spread of natural gas, fuel switching in the railway network, and new sources of oil all contributed to rapidly falling demand. In addition, in the 1970s coal became an increasingly internationally traded commodity, leading to competition from imports. Overoptimistic demand projections in the nationalized industry went unchallenged and overproduction ensued, but coal mines were insulated from heavy losses by tolerant government support, subsidies, and debt cancellation.

During the 1970s, the United Kingdom suffered from considerable industrial unrest, which resulted in the election of a government led by Margaret Thatcher with the aim of confronting the coal industry, which it saw as a politicized monopolist damaging national interests. In the heightened political climate and the flashpoint strike that followed in 1984–85, compromise and support packages for unemployed miners were not high on the political agenda. Nor was shoring up the long-term feasibility of coal; rather, there was an impetus to find alternative sources of energy. The production of deep-mined coal fell by half in 10 years, and the number of employees shrank by a factor of 10. This confluence of factors left coal-dependent communities ill-prepared for the reality of pit closures, which left them with a legacy of poorly paid, unskilled jobs; petty crime; substance abuse; and health problems. The last deep mine was closed in 2015.

Strategies for Cooperation in International Climate Initiatives

FFDCs can hedge LCT risks not only with various diversification strategies, but also various strategies for international cooperation. Cooperation on climate action could help FFDCs avoid abrupt shocks to income, consumption, and asset values. Cooperative domestic climate policies in FFDCs would help prevent a threat of trade measures being implemented by trading partners with significant market power. Cooperation enhances the benefits of asset diversification and can also increase oil rents in FFDCs, compared with noncooperative scenarios in which other countries take unilateral actions to stabilize climate at safe levels and impose trade sanctions. However, cooperative climate policies can reduce output and growth in the short term, and therefore are vulnerable to the tragedy of the horizon (Peszko, van der Mensbrugghe, and Golub 2020).

FFDCs need to consider creative ways in which they could contribute to international climate cooperation and implementation of the Paris Agreement in line with their special national circumstances and capabilities. Proactive cooperation in international climate action offers access to cooperative instruments under Article 6 of the Paris Agreement, and an opportunity to design instruments and modalities beneficial to all parties. For example, when a credible threat emerges that a Nordhaus border adjustment tax will be levied by trading partners with substantial market power, policy makers in FFDCs may want to have a few alternative designs for potential cooperative mechanisms ready in their back pockets.

This study suggests that one option for encouraging broader coalitions for climate change mitigation is to agree on a cooperative regime that involves sharing carbon tax revenues between exporters and importers. Wellhead taxes are a special form of carbon price imposed on the carbon content of fossil fuels and collected at the point where oil, gas, and coal are extracted from the ground. They do not discriminate between fuels consumed domestically and fuels exported (unlike traditional upstream carbon taxes, which are imposed in only the country that releases greenhouse gases). Wellhead taxes deliver incentives to cooperate as well as pricing incentives and revenues to accelerate asset diversification in FFDC economies. The analysis shows that global cooperation with wellhead taxes turns cooperative domestic climate policies into new development opportunities, boosting the net present value of consumption in FFDCs well above business as usual over time. Thus, they overcome the tragedy of the horizon because carbon revenues are retained domestically instead of being collected by fuel importers.

Cooperative wellhead carbon taxes could help align diverging incentives between and within countries and climate policy clubs. They could be an effective means for pricing carbon in a way that prevents the growth of emissions in FFDCs and enables the broader diversification of assets in those countries. Retained revenues can also help mitigate the social and political challenges of transition. Wellhead taxes would have the same incentive effect on demand and terms of trade as traditional carbon prices, but would allow wealth sharing between fuel exporters and importers. Although the design and implementation of an international wellhead carbon tax regime deserves more analysis, it would not necessarily be more challenging than any other international cooperative outcome—for instance, those based on harmonization of traditional carbon prices, carbon markets, or financial and technology transfers (Gollier and Tirole 2015; Jakob, Steckel, and Edenhofer 2014; Weitzman 2014, 2016). Wellhead taxes can be combined with national traditional carbon prices and strategic financial transfers in the framework of bilateral or multilateral deals. As many others have proposed for emissions-based carbon taxes, a portion of wellhead carbon tax revenue can also be transferred to the Green Climate Fund to assist the lowest-income and most vulnerable countries in meeting the challenges of adaptation to climate change.

With or without wellhead carbon taxes, international climate cooperation will always reinforce the long-term benefits of asset diversification. A diversified, flexible, knowledge-based economy is the stated aspirational objective of virtually all FFDCs, and intelligently designed international cooperation can provide incentives and resources to enhance the climate co-benefits of diversification. It can unlock new green growth models for FFDCs and serve as their unique contribution to the global effort to decarbonize the world economy and stabilize global warming.

Notes

1. The UK Climate Change Act 2008 is the basis for the United Kingdom's approach to tackling and responding to climate change. It requires that emissions of carbon dioxide and other greenhouse gases be reduced and that climate change risks be prepared for. The act also establishes the framework for delivering these requirements. See https://www.theccc.org.uk/tackling-climate-change/the-legal-landscape/the-climate-change-act/.
2. See *Financial Times* 2017b.

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7. Conclusions

As the world grapples with ways to mitigate and adapt to climate change, the role of fossil fuel–dependent countries (FFDCs) is increasingly attracting attention. The potentially distressing impact of a low-carbon transition (LCT) on their economies is still sometimes disregarded as collateral damage. More and more people, however, are trying to understand these concerns and to create a space for these countries to proactively engage in the global efforts to decarbonize the world economy and stabilize the climate in a way that enhances their sustainable growth while managing the risks of transition. This book provides the analytical underpinnings to support this approach.

An LCT can affect FFDCs through several mutually reinforcing channels over which they have little control. These channels include global mega-trends in "disruptive" clean technologies and business models, networks that lock them in, shifts in consumer and investor preferences, changes in policies and institutions in other countries, and the growth of influential new global business lobbies. While the tipping points after which fundamental shifts in economies occur are unpredictable, their possibility can no longer be ruled out in policy makers' and business leaders' mid- to long-term planning horizons. They represent a qualitatively new type of risk that the FFDCs have not faced so far—a risk of structural and permanent decline of the entire fossil fuel value chain.

No one can predict the future, but one can prepare for it. FFDCs can manage the risks and tap into emerging opportunities of an LCT with two broad strategic choices:

- Whether and how to diversify their economies
- Whether and how to cooperate on global efforts to stabilize the climate

High exposure and low resilience of many FFDCs to an LCT underscores the importance and urgency of new approaches to diversification. Traditional output diversification underpinned by the fossil fuel value chain decreases reliance on fossil fuel export revenues by developing fossil fuel–dependent industrial, transport, and power systems. It can help hedge the risks of cyclical commodity price volatility familiar from the past, but at the cost of increasing exposure to the structural impacts of an LCT.

On the other hand, diversifying assets—the inputs being used by an economy—is essential to building competitive knowledge economies that are more flexible, innovative, and resilient to external shocks, including those associated with an LCT. A more diverse set of assets can be achieved by reinvesting resource rents into broadening the wealth foundation of an economy, including renewable natural capital and intangible assets such as human capital, innovation, and institutions. In the long term, asset diversification stimulates sustainable, faster, and more resilient growth driven by productivity improvements rather than fossil fuel resource rents.

Cooperative domestic climate policies enhance the benefits of asset diversification. They effectively hedge LCT risks to growth and welfare in FFDCs by preventing surprising external policy shocks and providing economy-wide price signals to better prepare for a transition.

However, asset diversification and cooperative climate policies are victims of the tragedy of the horizon. The combination of asset diversification and international climate cooperation maximizes output and welfare in FFDCs, but only in the long run. Asset diversification and cooperative climate policies give FFDCs the highest upside in best-case scenarios over the long term, and the lowest losses in worst-case scenarios. However, in a short time frame—one relevant for most policy makers, business leaders, and investors—asset diversification is costly and risky for FFDCs. Traditional diversification, on the other hand, builds on existing strengths, abundant domestic resources, and skills, and hence generates higher immediate revenues and consumption than asset diversification. Suddenly abandoning the strengths and capabilities accumulated over decades is an unsettling proposition for many countries and regions that have depended on them for decades. Delaying domestic energy reforms and climate policies can harness the short- and medium-term benefits of attracting energy- and emissions-intensive industrials (emissions leakage). This challenge is amplified by the prevailing regulatory capture by powerful, vested interests in fossil fuel–dependent industries and the relative weakness of new emerging lobbies.

FFDCs have the weakest short-term incentives of all countries to join global climate action on a voluntary basis. The incentives to increase climate action ambitions are not built into the letter of the Paris Agreement. But, unlike the Kyoto Protocol, the open, bottom-up architecture of the Paris Agreement explicitly permits a group of parties under Article 6 to form a "climate action club" to pursue voluntary cooperation to allow for higher ambition in mitigation and adaptation actions. This analysis finds that Organisation for Economic Co-operation and Development (OECD) countries, China, India, and several other net fuel importers enjoy a primary-mover advantage in a low-carbon, knowledge-based economy and have fundamental incentives and enough market power to form such a club and encourage the cooperative behavior of FFDCs.

Economic literature argues that a climate action club can become effective when its members complement their individual Nationally Determined Contributions with collectively determined (but individually binding) commitments to specific policy packages, such as minimum rates of carbon pricing. To make a climate club stable, its members should enjoy exclusive benefits and privileges (financial, technology transfers, trade preferences) that prevent them from defecting and allow effective enforcement based on reciprocity ("I will if you will"). Exclusions from privileges and credible threats of sanctions would attract nonparticipants and further increase the market power of the club.

Cooperative instruments can be designed to encourage formation of a coalition of climate action between fuel importers and exporters and can overcome the tragedy of the horizon. One way to align incentives for the type of cooperation that increases climate policy ambition and avoids trade sanctions is through cooperative climate policy agreements between fossil fuel exporters and importers. Cooperative alignment of traditional carbon taxes imposed on emissions from consumption of fossil fuels is not likely to attract FFDCs, since such carbon prices extract resource rents from fuel exporters and transfer them to importing countries. One cooperative carbon pricing design that can be a win-win for both importers and exporters of fossil fuels is a cooperative wellhead carbon tax treaty with a revenue-sharing agreement. Under such an agreement, both parties apply a carbon price on fossil fuels when they are first extracted from the ground. Tax revenues are not rebated when the fuel is exported, but under a cooperative deal the importer agrees to reduce a domestic carbon tax on the carbon embedded in the fuels imported from the countries that put a carbon tax on fuel producers to avoid taxing the same carbon twice. These types of taxes thus extend carbon prices to domestic emissions in FFDCs in return for the opportunity to retain a portion of revenues otherwise collected by importers. Such price-based cooperative policy agreements can be complemented by international technology cooperation to accelerate and enable asset diversification. Credible, strategic financial and technology transfers could help the countries that are least able to diversify and adapt or that face a significant social cost of a transition, such as low- and lower-middle-income countries that have not yet been able to extract and monetize their underground fuel reserves.

The incentives for FFDCs to seek cooperative climate policy agreements are reinforced by the possible implementation of border adjustment taxes (BATs). FFDCs' competitive advantage in energy- and emissions-intensive industries is so large that traditional border adjustment measures based on the carbon content of imported goods may not be strong enough to encourage cooperative domestic climate policies. But flat trade sanctions on all imports from noncooperating countries would have a large impact on FFDCs. The mere possibility that flat trade sanctions could be implemented in the future creates a short-term incentive for FFDCs to collaborate and diversify their economies.

Successful economic strategies in FFDCs need to include a diverse portfolio of hedging policies and investments that strike a balance between (1) managing traditional carbon-intensive assets to capture resource rents, maintain revenues, manage price volatility risk, and keep social peace and justice during a transition; and (2) reinvesting these revenues in the broader asset base to strengthen economic flexibility and preparedness for the multiple possible impacts of an LCT. In the global endgame for fossil fuels, different strategies for managing existing fossil fuel assets can be successful for different countries and firms. Some will choose to divest quickly, while others will choose to increase the market share in declining industries. There will be losers and winners for each strategy chosen. Therefore, instead of focusing on the risk of stranded assets in the dialogue on climate action in FFDCs, this book suggests a shift toward focusing on managing the risks and tapping emerging opportunities. Changes in the value of underground and produced assets are less relevant indicators of economic performance during an LCT than changes in asset structure and in income and welfare of whole countries.

One of the key messages of this study is that asset diversification represents a fundamental shift toward a dematerialized long-term growth model, in which fewer material inputs generate higher economic output and welfare. This underlying mega-trend can have strong environmental co-benefits. Concerns about climate change just make it more urgent, and climate mitigation policies both hedge the risks and pave the way for asset diversification. In this new growth model the people, their collective know-how, and renewable natural capital, as well as knowledge and institutions, increasingly substitute for produced traditional capital assets and exhaustible natural resources in driving prosperity.

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This book is the first stocktaking of what the decarbonization of the world economy means for fossil fuel–dependent countries. These countries are the most exposed to the impacts of global climate policies and, at the same time, are often unprepared to manage them. They depend on the export of oil, gas, or coal; the use of carbon-intensive infrastructure (for example, refineries, petrochemicals, and coal power plants); or both. Fossil fuel–dependent countries face financial, fiscal, and macro-structural risks from the transition of the global economy away from carbon-intensive fuels and the value chains based on them. This book focuses on managing these transition risks and harnessing related opportunities.

Diversification and Cooperation in a Decarbonizing World identifies multiple strategies that fossil fuel–dependent countries can pursue to navigate the turbulent waters of a low-carbon transition. The policy and investment choices to be made in the next decade will determine these countries' degree of exposure and overall resilience. Abandoning their comfort zones and developing completely new skills and capabilities in a time frame consistent with the Paris Agreement on climate change is a daunting challenge and requires long-term revenue visibility and consistent policy leadership. This book proposes a constructive framework for climate strategies for fossil fuel–dependent countries based on new approaches to diversification and international climate cooperation. Climate policy leaders share responsibility for creating room for all countries to contribute to the goals of the Paris Agreement, taking into account the specific vulnerabilities and opportunities each country faces.

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