CHAPTER 1

HOW TO MITIGATE CLIMATE CHANGE

Introduction

Without substantial mitigation of greenhouse gas emissions, global temperatures are projected to rise by around 4°C above preindustrial levels by 2100 (they have already increased by 1°C since 1900).[1] Global warming causes major damage to the global economy and the natural world and engenders risks of catastrophic and irreversible outcomes such as rising sea levels, extreme weather events (already more frequent) leading to loss of life, and the possibility of much higher warming scenarios.[2] Carbon dioxide (CO_2) emissions from fossil fuel combustion account for a dominant (63 percent) and growing share of global greenhouse gas emissions and are the most immediately practical to control (Figure 1.1, panel 1).[3] Policy action is thus urgently needed to curtail emissions. The longer that action is delayed, the greater the accumulation in the atmosphere, and the more abrupt and costly will be the necessary action to stabilize global temperatures.

The transition toward cleaner energy sources and reduced energy consumption requires overcoming externalities both at home and internationally. (Externalities occur when individuals affect others through their actions but do not pay a price for doing so.) Domestically, firms and households are not charged for the greenhouse gases they release through the combustion of fossil fuels and other sources. Likewise, greenhouse gases released by individual countries affect the global climate, and no country can solve the problem alone. Domestic policies are thus needed to give people and businesses greater incentives (through pricing or other means) to reduce emissions, without derailing economic growth. And international cooperation is key to ensure that all countries do their part. Supporting the case for such cooperation, curbing fossil fuel use is also desirable on domestic grounds, for example, to reduce deaths from local air pollution saving millions of lives: as this *Fiscal Monitor* shows, for many countries, including large emerging market economies, the gains from fewer premature deaths caused by air pollution outweigh the costs of mitigation policies.

The shift from fossil fuels will not only transform economic production processes, it will also profoundly change the lives of many people and communities. Firms and their employees in energy-dependent sectors (such as aluminum, glass, chemicals, plastics, petroleum refining, pulp and paper, and steel), as well as people living in areas poorly served by public transportation, are vulnerable to higher energy prices. Some coal-mining communities and regions are especially at risk because of a lack of other jobs and sources of fiscal revenues. Industries, workers, and communities whose livelihoods depend on fossil fuels may thus oppose reforms to mitigate climate change. Policymakers should design appropriate assistance and measures to build a better future for groups especially affected by drastic changes associated with mitigation policies.

Beyond finding ways of cooperating in the common interest and building domestic political consensus, mitigating climate change requires greater attention to the future. National governments, subject to short-term political cycles, may lack incentives to act, because the benefits of temperature stabilization extend beyond their horizon. Taking a long-term view is also challenging for voters who live paycheck to paycheck, and the gains from policies that limit global warming may seem imperceptible, at least in the near term. Businesses considering longer-term investments, such as for power generation, need certainty about future tax and regulatory policies. Stabilizing global temperature calls for an urgent shift of energy supply investments toward low-carbon sources, because the infrastructure built today will determine emission

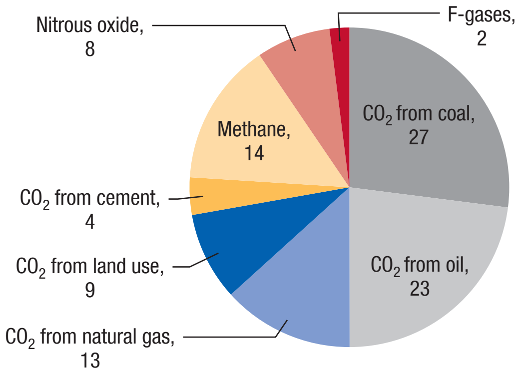
[1] For temperature projections, see Stocker and others (2013), who predict warming of 3.4°C to 5.6°C by 2100 in a scenario of high future emissions growth; and Nordhaus (2018).

[2] See, for example, IPCC (2018), Murray (2019), NAS (2018), Nordhaus (2018), and WEF (2019). Kahn and others (2019) show that all regions (cold or hot, advanced or developing) would experience a major decline in GDP per capita by 2100 in the absence of mitigation policies. The poor would be disproportionately hurt (Hallegatte and others 2017; IMF 2017; World Bank 2012). Rising sea levels, storm surges, droughts, and lower water availability would cause hundreds of millions of people to migrate both within countries and across borders (IOM 2009; IPCC 2014; World Bank 2018).

[3] See Online Annex 1.1 as well as IMF (2019c) for CO_2 emission projections for 135 countries.

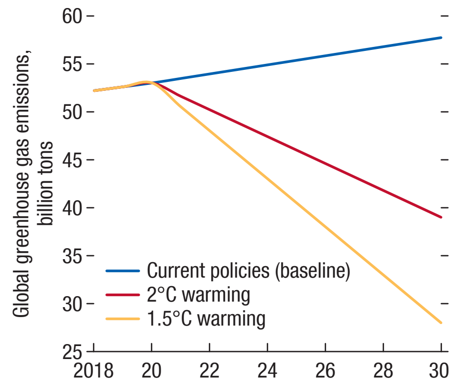
Figure 1.1. The Global Mitigation Challenge

1. Global Greenhouse Gas Emissions Share, 2016 (Percent)



Sources: Le Quéré and others 2018; and Tollefson 2018.

2. Emission Pathways and Warming Goals, 2018–30



Source: CAT 2018 (based on scientific studies of the relationship between emissions, atmospheric greenhouse gas concentrations, and temperature summarized in IPCC 2018).

Note: In panel 1, the oil category includes international aviation and maritime emissions. Methane emissions are from extractive industries, landfills, and agriculture; nitrous oxide is from agriculture and industrial processes; and fluorinated (F-) gases are used in refrigerants and aerosols. "Land use" refers to net CO_2 emissions from forestry and agricultural practices. CO_2 = carbon dioxide.

levels for several decades (Box 1.1). Policymakers thus need to consider ways of locking-in mitigation policies for as long as possible, including commitments to the global community.

The long-term goal of the 2015 Paris Agreement is to limit projected global warming to 2°C, with an aspirational target of 1.5°C, the level deemed safe by the Intergovernmental Panel on Climate Change (IPCC 2018). Meeting even the 2°C goal requires starting to reduce greenhouse gases immediately, bringing them to a third below baseline levels by 2030 (Figure 1.1, panel 2). As a first step, 190 parties submitted climate strategies (Nationally Determined Contributions) containing mitigation targets for the Paris Agreement. (Online Annex 1.2 provides more details on mitigation aspects of the agreement.) Many developing economies pledged more aggressive action contingent on external financial and technical support, and it is essential that advanced economies honor their commitments under the Paris Agreement to mobilize, from 2020 onward, $100 billion a year from public and private sources for climate projects (both mitigation and adaptation) in developing economies.[4] However, even if current mitigation commitments are fully implemented—many countries are not on track to achieve these targets, and the United States intends to withdraw from the Paris Agreement in 2020—these commitments are consistent with warming of 3°C (UNEP 2018): emission reductions by 2030 would be one-third of those required for 2°C. Implementation of existing commitments is therefore a first-step priority, but mechanisms to boost action at the global level are urgently needed.[5]

The key role of fiscal policies in climate change mitigation is increasingly recognized, and this *Fiscal Monitor* suggests how to design, and enhance the acceptability of, such policies and scale them up at the domestic and global levels.[6] Specifically, this chapter:

- Provides a conceptual and quantitative framework for understanding the environmental, fiscal, and economic impacts of carbon taxation and the trade-offs between carbon taxes and alternative mitigation instruments. The chapter argues that

[4]Quantifying financial flows is difficult, however, not least because they may partially substitute for other forms of official development assistance. For further details on the Paris Agreement, see Stern (2018) and UNFCCC (2016, 2018).

[5]The next opportunity for parties to make their mitigation pledges more ambitious is in 2020 when they must submit revised Nationally Determined Contributions (Online Annex 1.2).

[6]Growing interest in sharing experiences and promoting collective action in fiscal policies is reflected, for example, in the Finance Ministers Coalition for Climate Action, launched in April 2019 (www.worldbank.org/en/news/press-release/2019/04/13/coalition-of-finance-ministers-for-climate-action). Beyond mitigation, fiscal policies for adaptation and resilience building in countries vulnerable to climate impacts are also needed: these are discussed in IMF (2019b, 2019c).

fiscal policies are a key tool to mitigate climate change and that a higher price tag on carbon emissions is the most powerful and efficient way to do so; it gives people and businesses an incentive to find ways to conserve energy and switch to greener sources (see "Policies to Reduce Fossil Fuel CO_2 Emissions").

- Discusses how to facilitate international agreement on more ambitious targets, by proposing a carbon price floor arrangement among large emitters (see "How to Increase Ambition in Global Mitigation Targets").
- Discusses strategies for enhancing the domestic acceptability of mitigation policy and estimates how accompanying fiscal measures can alleviate the overall burden of mitigation policy on key groups (see "Making Mitigation Policy Acceptable in Domestic Politics").
- Recommends support (for example, technological and financial) for the policies necessary to mobilize investment in clean energy (see "Supporting Policies for Clean Technology Investment"; and Chapter 6 of the October 2019 *Global Financial Stability Report*).

Policies to Reduce Fossil Fuel CO_2 Emissions

Carbon taxes—charges on the carbon content of fossil fuels—and similar arrangements to increase the price of carbon, are the single most powerful and efficient tool to reduce domestic fossil fuel CO_2 emissions (Akerlof and others 2019; CAE and GCEE 2019; Farid and others 2016; Parry, de Mooij, and Keen 2012; Parry, Morris, and Williams 2015). (For greenhouse gases stemming from sources other than domestic use of fossil fuels, see Box 1.2.) Raising the price of coal and other fossil fuels is desirable not only to mitigate climate change but also to reduce local problems such as air pollution.[7] Carbon pricing can: provide across-the-board incentives to reduce energy use and shift toward cleaner fuels; mobilize a valuable source of new revenue; and be straightforward administratively if it builds on fuel tax systems. Many countries and subnational governments have implemented carbon pricing initiatives (Table 1.1). Even so, the global average carbon price is $2 a ton (based on World Bank 2019a), a tiny fraction of the estimated $75 a ton price in 2030 consistent with a 2°C target (discussed later in this section). Without consensus to raise the carbon price to the necessary

[7]In most countries, the price of fossil fuels is lower than desirable (and thus subsidized) owing to various factors: fuel and electricity prices in some countries are provided at prices below cost recovery; prices should be higher to reduce global warming and local problems such as air pollution as well as traffic congestion and accidents; and the consumption of fossil fuels is sometimes not taxed as much as are other goods. The combined value of underpricing from all these sources for all countries globally has been estimated at $5.2 trillion for 2017, with coal and oil accounting for 85 percent of the subsidy (Coady and others 2019). The quantitative analysis in this *Fiscal Monitor* considers the need for higher carbon pricing only from the perspective of global warming.

Table 1.1. Selected Carbon Pricing Arrangements, 2019

Country or Region	Year Introduced	2019 Price ($/Ton CO_2)	Coverage of GHGs, 2018: Million Tons	Coverage of GHGs, 2018: Percent
Carbon Taxes				
Chile	2017	5	47	39
Colombia	2017	5	42	40
Denmark	1992	26	22	40
Finland	1990	65	25	38
France	2014	50	176	37
Ireland	2010	22	31	48
Japan	2012	3	999	68
Mexico	2014	1–3	307	47
Norway	1991	59	40	63
Portugal	2015	14	21	29
South Africa	2019	10	360	10
Sweden	1991	127	26	40
Switzerland	2008	96	18	35
Emissions Trading Systems				
California, United States	2012	16	378	85
China	2020	na	3,232	
European Union	2005	25	2,132	45
Korea	2015	22	453	68
New Zealand	2008	17	40	52
Regional Greenhouse Gas Initiative[1]	2009	5	94	21
Carbon Price Floors				
Canada	2016	15	na	70
United Kingdom	2013	24	136	24

Sources: Stavins 2019; World Bank 2019a; and IMF staff calculations.
Note: CO_2 = carbon dioxide; GHG = greenhouse gas; na = not available.
[1] The Regional Greenhouse Gas Initiative is a market-based program in 10 states in the eastern part of the United States.

level, other less-effective instruments should complement carbon pricing to reduce domestic fossil fuel CO_2 emissions.[8]

Which Mitigation Policies Work Best?

Policymakers can use various fiscal tools, as well as regulatory policies, to encourage firms and households to reduce CO_2 emissions. The most effective and efficient policies make it costlier to emit greenhouse gases and allow businesses and individuals to choose how to conserve energy or switch to greener sources through a range of opportunities. These opportunities include reducing the emission intensity of power generation (for example, switching from high-carbon-intensive coal to intermediate-carbon-intensive natural gas or coal with carbon capture and storage,[9] and from these fuels to carbon-free renewables or, with appropriate safeguards, nuclear); curbing electricity demand (for example, through adoption of energy-efficient appliances, air conditioners, and machinery and less use of products using electricity); limiting demand for transportation fuels (for example, through better fuel economy of gasoline and diesel vehicles, increased use of electric and alternative-fuel vehicles, and less driving); and less direct fuel use in homes and industry (mainly for heating).

A carbon tax—a tax on the supply of fossil fuels (for example, from oil refineries, coal mines, and processing plants) in proportion to their carbon content—leads people and firms to use all such avenues to reduce emissions, conserve energy, or switch to greener power sources because it is passed forward into higher prices for carbon-based fuels and electricity. People and firms will identify which changes in behavior reduce emissions—for example, purchasing a more efficient refrigerator versus an electric car—at the lowest cost. Carbon tax paths can be set in line with mitigation objectives based on projections of fuel consumption and estimates of how consumption responds to higher prices. Online Annex 1.3 explains how the emission reductions and economic costs of the tax relate to its impact on fuel and electricity markets.

Alternative mitigation instruments, whose features are summarized in Table 1.2, include the following:

- Emission trading systems in which firms must hold an allowance for each ton of their emissions, and the government sets a cap on total allowances or emissions; market trading of allowances establishes the emissions price. If the system comprehensively covers emissions, and the government charges for the initial allowances (for example, by issuing them through an auction), emissions and revenues are in principle the same as under an equivalent carbon tax. In practice, the coverage of emission trading systems has usually been limited to power generators and large industrial firms.[10]
- "Feebates," which impose a sliding scale of fees on products and activities with above-average emission rates (per unit of energy or miles driven) and provide rebates (subsidies) on a sliding scale for products or activities with below-average emission rates. Under a feebate, for example, power generators would pay a fee (or receive a rebate) in proportion to their output times the difference between their emission rate per kilowatt-hour (averaged across their plants) and the industry average emission rate. The structure of fees and rebates would usually be set to make the system revenue-neutral (self-financing). Online Annexes 1.4 and 1.5 explain how feebates can be implemented in practice (thus far they have been applied to vehicles in several countries) and how they differ from carbon taxes.
- Regulations—for example, standards for the emission rates of vehicles and power generators, or for the energy efficiency of electricity-using products, or minimum requirements for the use of renewables in power generation.

[8]Proposals for decarbonizing the economy far more rapidly than currently envisioned are being debated in the United States under the banner of a "Green New Deal." Other countries are considering, or have already enacted (for example, France, Norway, Sweden, and the United Kingdom), zero net emissions targets for the middle of the century—a valuable roadmap that should inform, but not detract from, the need for immediate action. Regulations, such as banning new coal plants and sales of gasoline or diesel vehicles, are often more prominent than pricing in such approaches. Even under such approaches, however, carbon pricing could play a role—for example, in promoting retirement of existing (emissions-intensive) capital and allowing firms to pay out-of-compliance fees if regulatory requirements are costlier than anticipated.

[9]Carbon capture and storage is the process of separation, cleaning, and compression of carbon from fuel combustion and industrial processes and its permanent storage underground (IEA 2013).

[10]Although carbon taxes sometimes include exemptions, their overall coverage of emissions is often greater than that of emission trading systems. See Goulder and Parry (2008), Hepburn (2006), and Stavins (2019) for a general discussion of similarities and differences between carbon taxes and emission trading systems.

Table 1.2. Features of Alternative Mitigation Approaches

Alternative Mitigation Approaches	Potential for Exploiting Mitigation Opportunities	Use of Price/ Market Mechanism	Efficiency across Mitigation Responses Induced by Policy	Energy Price Impacts and Acceptability	Price Predictability	Revenue Generation	Administrative Burden
Carbon Tax	Full, if applied comprehensively (in practice, may contain exemptions)	Yes	People and firms choose most efficient way of reducing emissions	Higher energy prices can be challenging politically	Yes (if trajectory is clearly specified)	Yes (though exemptions may limit revenue base)	Small (if building on existing fuel or royalty tax systems)
Emissions Trading Systems	Full, if applied comprehensively (in practice, often limited to powerful/ large industries)	Yes	People and firms choose most efficient way of reducing emissions	Higher energy prices can be challenging politically	No (unless it includes price floors or similar mechanisms)	Maybe (if allowances are auctioned, but revenue base may be limited)	New capacity needed to monitor CO_2/trading markets
Feebates	Similar to regulations	Yes	People and firms choose most efficient approach within only one activity	Avoiding significant energy price increases may enhance acceptability	Yes (if trajectory is clearly specified)	No (recommended design is revenue neutral)	New capacity needed (for example, to apply fees/ rebates to power generators)
Regulations	Can exploit some key opportunities but not all (for example, reductions in vehicle use)	No	No automatic mechanism	Avoiding significant energy price increases may enhance acceptability	No (implicit prices vary with technology costs, energy prices, and so forth)	No	New capacity needed (for example, to monitor and enforce emission rate standards for power generators)

Source: IMF staff.
Note: CO_2 = carbon dioxide.

These mitigation policies work in different ways and may be compared as follows:

- *Range of emission mitigation mechanisms and impact on end-user energy prices:* Carbon taxes and emission trading systems lead people and firms both to shift to greener energy and to cut back on the use of energy-consuming products or capital. Feebates and regulations, however, do not discourage activities that use energy. Fossil-fuel energy producers pass the cost of a carbon tax (or of tradable emission permits) to end users through higher prices for, say, electricity or gasoline.[11] In contrast, a feebate consisting of an extra fee on vehicles with lower-than-average fuel efficiency and a rebate on more efficient vehicles would lead consumers to purchase more efficient vehicles, but it would not reduce vehicle miles driven. Likewise, although a feebate would lead power-generating firms to shift to lower emission technologies, there would be little impact on energy consumption (Online Annex 1.3). Thus, to deliver the entire emissions cut by switching to greener energy while continuing to use approximately the same amount of energy, feebates or regulations would need to be used more aggressively. The ensuing greater disruption to choices of energy source would imply larger economic costs than those incurred through carbon pricing,

[11]The cost of the carbon tax is largely passed forward because domestic fuel supply curves tend to be elastic relative to demand curves, not least because most countries are price takers in international fuel markets.

which allows people to identify and exploit all available avenues to reduce emissions in the most efficient way (Online Annex 1.3).[12]

- *Use of the price mechanism:* In addition to carbon taxes and emission trading systems, feebates also rely on the market system, though within a narrower set of activities. For example, under a feebate that charges power-generating firms a fee (or gives them a rebate) for each kilowatt-hour that emits more (or less) than the industry average, firms will use the most efficient technology.[13] In contrast, regulations might not leave sufficient flexibility for households and firms to find least-cost options. Moreover, regulations must keep up with rapidly changing technology. Excessive reliance on a regulatory approach could also motivate firms to collude with officials to alter or evade the regulations.[14]
- *Likely political opposition:* In the absence of accompanying measures, carbon pricing may face stiffer opposition from energy-using industries and the public at large, compared with arrangements, such as feebates and regulations, which have a much smaller impact on energy prices. (All approaches may face resistance from carbon-intensive energy-producing firms, workers, and regions.) If a comprehensive and equitable strategy to make carbon pricing more acceptable is not politically feasible, a less efficient strategy would be less ambitious carbon taxes or emission trading systems complemented by, or even substituted with, more forceful use of feebates or regulations.
- *Predictability of prices and fostering investment in green energy:* To mobilize investment (for example, in renewable energy plants) with high upfront costs and long-range payoffs, a transparent pricing plan for the years ahead is necessary (as well as supporting policies—see "Supporting Policies for Clean Technology Investment"). With carbon taxes and feebates, such a plan is possible. With emission trading systems, prices vary with energy market conditions (although volatility can be contained, for example, by combining emission trading systems with price floors—as in California, where allowances are auctioned to the market with a minimum price—see, for example, Flachsland and others 2018). Regulations may offer the weakest investment incentives because they do not reward investment that exceeds the standard (for example, Fischer, Parry, and Pizer 2003; and Jaffe and Stavins 1995).
- *Ability to raise revenues:* From the standpoint of mobilizing general revenues, a carbon tax with no exemptions will have the broadest tax base. In principle, governments could collect the same amount of revenues by charging for emission trading permits. In practice, however, revenue available for general use under emission trading systems could be diminished by (1) the narrower base for emissions pricing; (2) the possibility that the government would allocate some permits for free—for example, initial allocations to incumbent firms; and (3) potential earmarking of revenues from allowance auctions.[15] Regulations do not raise revenues, and feebates are generally revenue neutral (Online Annex 1.3). The revenues collected through a carbon tax (or, to a lesser extent, the sale of emission trading permits) could be redeployed through cuts in other taxes or additional investment or assistance to improve economic efficiency and enhance political acceptability of mitigation measures. The overall benefits of carbon pricing are greater the more productively and efficiently these revenues are used (for example, cutting taxes that discourage work effort and investment and promote informality and other tax-sheltering behavior, or funding socially productive investments for United Nations Sustainable Development Goals, such as education, health, and infrastructure).
- *Ease of administration:* Carbon taxes can be integrated into existing fossil fuel taxes or possibly into fiscal regimes for extractive industries.[16] For

[12]Firms and households would cut back on emissions as soon as a carbon tax is introduced, but increasing the tax gradually allows them time to adapt and be less opposed to change. Emission trading systems likewise have an immediate impact, which often leads governments to give some free permits to incumbents to ease their adjustment. Whereas a feebate for power generation could be applied quickly, in many areas—such as for vehicles—feebates would realistically be applied to new products and equipment only, so it would take years for their effect to fully permeate existing fleets and capital stocks.

[13]To maintain efficiency across feebate programs (for example, power generation versus vehicle choice), fees and rebates would need to be set in a way that harmonizes the incremental cost of emission reductions across sectors (Online Annex 1.4).

[14]The flexibility of regulations can be enhanced by combining them with pricing mechanisms by, for example, allowing firms that exceed a standard to sell credits to firms that fall short of the standard.

[15]Globally, 63 percent of emission trading system revenues have been used for environmental spending, 16 percent for general funds, and 21 percent for development—the corresponding percentages for carbon tax revenues are 23, 59, and 4, respectively, while a further 10 percent has been used for tax cuts and 4 percent for transfers (World Bank 2019b).

[16]For a discussion of administrative modalities, see Calder (2015) and Metcalf and Weisbach (2009).

emission trading systems, new government capacity is needed to monitor trading markets and firms' emissions: in some countries, this could be impractical given capacity constraints and limited trading. Feebates could be integrated into existing vehicle tax systems in many countries (Online Annex 1.4), but new institutions may be needed to apply them more extensively (for example, to appliance distributors and power generators). Many countries already have some energy efficiency regulations and building codes (IEA 2018), though the administrative workload and complexity would rise to apply them more extensively. Although the coverage of feebates and regulations could be expanded, it would be administratively challenging to apply them to the full range of energy-consuming products or types of equipment.

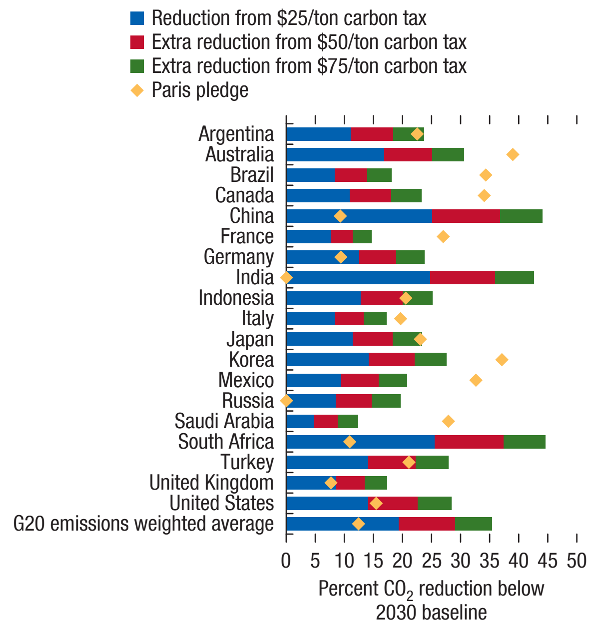
On balance, carbon pricing approaches seem to be the most promising, although mitigation through other approaches is better than inaction. The efficiency costs of different mitigation policies, and the burden of these policies across income groups, are discussed later in this section and in "Making Mitigation Policy Acceptable in Domestic Politics," respectively.

Quantitative Analysis: Cross-Country Assessments of Carbon Pricing and Other Mitigation Approaches

To analyze how fiscal policy tools can help deliver mitigation commitments, emissions projections under baseline scenarios (with no new mitigation measures) are compared with those under current pledges and with carbon tax scenarios. CO_2 emission reductions below baseline levels in 2030 that will meet countries' Paris mitigation pledges range widely, from essentially zero to 40 percent (Figure 1.2).[17] As noted, current pledges globally are consistent with warming of 3°C.

To illustrate the extra effort needed by each country to attain current, or more ambitious, mitigation targets by using only carbon taxes, and to trace the implications for firms and household budgets, three scenarios are considered, with tax rates of $25, $50, and $75 a ton of CO_2 in 2030.[18] The $75 tax is estimated by the IMF staff to lead to the amount of emissions scientists (see Figure 1.1, panel 2) estimate will lead to 2°C warming (if applied globally and combined with investment policies—see "Supporting Policies for Clean Technology Investment"—as well as measures for nonfossil CO_2 emissions).[19] The less ambitious scenarios, $25 a ton and $50 a ton, are also analyzed given the lower prices consistent with many countries' mitigation pledges and the possibility that less ambitious carbon tax pricing may be combined with other instruments.[20]

Figure 1.2. Reduction in Fossil Fuel CO_2 from Carbon Taxes in 2030, Selected Countries



Source: IMF staff calculations.
Note: Paris pledges indicate the percent reduction in CO_2 emissions below the baseline (that is, no mitigation) levels in 2030 if countries' mitigation pledges submitted for the Paris Agreement are met. Bars indicate the percent reduction in CO_2 emissions below baseline levels under carbon taxes with alternative tax levels. CO_2 = carbon dioxide; G20 = Group of Twenty.

[17]See IMF (2019c) for details on how these reductions were calculated.
[18]These tax amounts are in addition to any preexisting energy taxes addressing fiscal or domestic environmental considerations. All monetary figures throughout the chapter are in constant 2017 US dollars.
[19]Stern and Stiglitz (2017) estimated global carbon prices consistent with 2°C at $50–$100 a ton in 2030.
[20]Projecting the impact of carbon taxation on emissions requires assumptions about how much people and firms would cut back on energy use and switch energy sources. Since carbon taxation has generally been low in the past, such assumptions are more uncertain the higher the level of tax. It is especially difficult to predict how rapidly low-emission technologies would be deployed in response to higher carbon prices. These uncertainties should be kept in mind.

Considering the estimated cut in emissions from uniform carbon prices of $25, $50, and $75 a ton for the Group of Twenty (G20) countries individually and as a group (Figure 1.2), three results stand out:

- First, uniform carbon prices of $25, $50, and $75 a ton reduce CO_2 emissions by 19, 29, and 35 percent, respectively, for the G20 group (with countries weighted by their future emission shares).
- Second, whereas a $25 a ton price would be more than enough for some countries (for example, China, India, and Russia) to meet their Paris Agreement pledges, in other cases (for example, Australia and Canada) even the $75 a ton carbon tax falls short. This dispersion reflects cross-country differences in the stringency of mitigation pledges, as well as in the price responsiveness of emissions—for example, emissions are more responsive to pricing in coal-reliant countries such as China, India, and South Africa than in other countries.
- Third, the large cross-country differences in carbon prices consistent with individual country pledges underscore the case for greater international price coordination.

Under carbon taxation on a scale needed to mitigate climate change, the price of essential items in household budgets, such as electricity and gasoline, would rise considerably but such increases have been experienced in the past. With a $75 a ton carbon tax, coal prices would typically rise by more than 200 percent above baseline levels in 2030, because coal has a high carbon content and its baseline price per unit of energy is currently low (Table 1.3). This is indeed the purpose of a carbon tax: promoting a switch from carbon-rich fuels by making them costlier. But coal is largely an intermediate product rather than one consumed by households. The price of natural gas, which is used not only for power generation but also directly by households (mostly for heating and cooking) would also rise significantly, by 70 percent on average; the proportionate impact would be larger in North and South America, where baseline prices are much lower, compared with prices in Europe and Asia. The proportional increase in retail electricity prices would vary across countries depending on the emission intensity of generation: less than 30 percent in Canada and in several European countries, where the use of coal has already declined compared with a few decades ago and ranging between 70 and 90 percent in Australia and several large emerging market economies, which reflects how heavily they rely on coal-fired generation. Gasoline prices would rise by 5–15 percent in most countries. For retail electricity and gasoline, price changes of this size are well within the bounds of price fluctuations experienced during the past few decades.[21] As shown in Table 1.3, the impact on prices is lower under less ambitious scenarios. For the remainder of the chapter, most of the analysis will use the $50 a ton tax scenario as an illustration.

Carbon taxes (on domestic fuel consumption) can mobilize significant new revenues, ranging widely across countries (between ½ and 3 percent of GDP for the G20 countries for the $50 a ton tax in 2030—see Figure 1.3), depending on factors such as reliance on coal, efficiency in using energy, and importance of energy between sectors in the economy.

Analyzing the merits of different mitigation policies requires estimating their costs on economic efficiency. (For the purpose of this discussion, the term "economic efficiency costs" excludes the global climate and domestic environmental impacts of mitigation policies.) Economists (and many governments around the world) measure such costs by how much worse off people are as a result of the policy action, excluding the benefits it brings (Online Annex 1.3). In the case of mitigation policies, the costs occur because the policies cause (1) a shift to cleaner but costlier technologies and equipment than people or firms would otherwise prefer; and (2) a decline in overall economic activity because of higher energy prices.[22] The estimated economic efficiency costs of mitigation responses induced by carbon taxes are first compared with the domestic environmental benefits and then with the costs of other mitigation instruments.

The economic efficiency costs of a $50 a ton carbon tax[23] are equivalent to less than 0.5 percent of GDP in 17 countries (Figure 1.4). For most G20 countries, these costs are lower than the domestic environmental benefits

[21]For example, real electricity prices in the United States declined 30 percent between 1993 and 2003; real gasoline prices increased 75 percent between 2003 and 2006 (calculated from Haver Analytics and IMF, International Financial Statistics).

[22]This aggravates distortions in labor and capital markets created by broader taxes on the returns to work effort and investment (Online Annex 1.3).

[23]Measured by the shift to cleaner but costlier technologies and equipment. Costs from the decline in overall economic activity are calculated for the United States in "Making Mitigation Policy Acceptable in Domestic Politics."

Table 1.3. Impact of Carbon Taxes on Energy Prices, 2030

	Coal		Natural Gas		Electricity		Gasoline	
Country	Baseline Price ($/GJ)	Price Increase (%)	Baseline Price ($/GJ)	Price Increase (%)	Baseline Price ($/kWh)	Price Increase (%)	Baseline Price ($/liter)	Price Increase (%)
$75/Ton Carbon Tax								
Argentina	3.0	297	3.0	133	0.10	48	1.4	13
Australia	3.0	263	9.6	44	0.11	75	1.3	15
Brazil	3.0	224	3.0	131	0.12	7	1.4	13
Canada	3.0	251	3.0	128	0.10	11	1.1	17
China	3.0	238	9.6	41	0.09	64	1.2	13
France	5.0	123	8.3	49	0.12	2	1.8	9
Germany	5.2	132	8.4	52	0.12	18	1.8	8
India	3.0	230	9.6	25	0.09	83	1.3	13
Indonesia	3.0	239	9.6	36	0.12	63	0.6	32
Italy	5.3	134	8.3	50	0.14	18	2.0	9
Japan	3.0	230	9.6	48	0.13	42	1.4	11
Korea	3.0	220	9.6	47	0.16	42	1.5	6
Mexico	3.0	226	3.0	132	0.10	74	1.0	18
Russia	3.0	169	7.0	54	0.14	25	0.9	12
Saudi Arabia	3.0	234	7.0	56	0.22	40	0.6	28
South Africa	3.0	205	7.0	23	0.08	89	1.2	16
Turkey	3.0	232	7.0	59	0.09	40	1.5	9
United Kingdom	6.1	157	8.3	51	0.13	16	1.7	8
United States	3.0	254	3.0	135	0.08	53	0.8	20
Simple average	3.5	214	7.0	68	0.12	43	1.3	14
$50/Ton Carbon Tax								
Simple average	3.5	142	7.0	45	0.1	32	1.3	9
$25/Ton Carbon Tax								
Simple average	3.5	71	7.0	23	0.1	19	1.3	5

Source: IMF staff calculations.

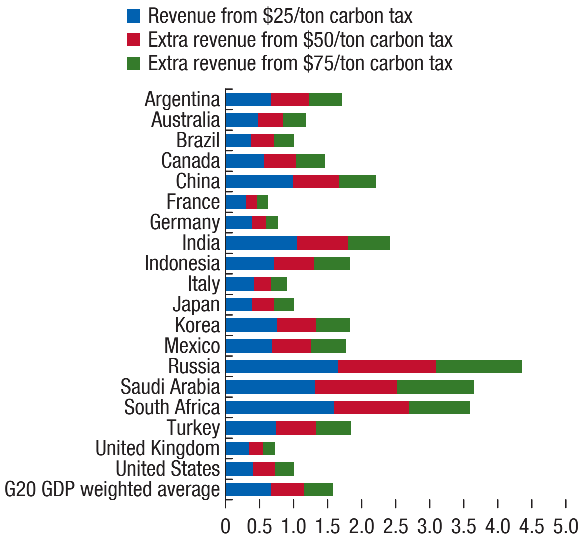
Note: Baseline prices are retail prices estimated in Coady and others (2019) and include preexisting energy taxes. Baseline prices for coal and natural gas are based on regional reference prices. Baseline prices for electricity and gasoline are from cross-country databases. Impacts of carbon taxes on electricity prices depend on the emission intensity of power generation. Carbon tax prices are per ton. GJ = gigajoule; kWh = kilowatt-hour.

stemming from the same measure—fewer deaths from air pollution as well as reductions in traffic congestion and accidents—before even counting climate benefits. The domestic environmental benefits are especially large for countries with especially severe air pollution, such as China, India, and Russia (Figure 1.4). In fact, for G20 countries together, a $50 carbon tax would prevent 600,000 premature air pollution deaths in 2030 (the bulk of them in the largest emerging economies—60 percent in China alone); a $75 tax would prevent 725,000 premature deaths. Despite uncertainty in measuring the size of the domestic environmental benefits, carbon pricing benefits many countries because it reinforces efforts to address the aforementioned domestic environmental problems.[24]

The economic efficiency costs of carbon taxes are considerably lower than those of other mitigation

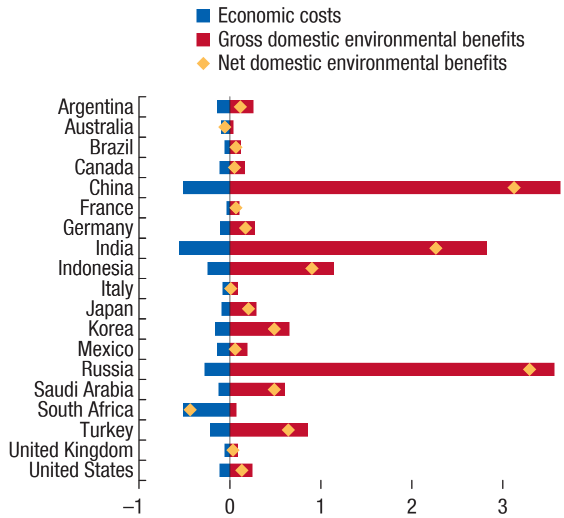
[24]The estimates in Figure 1.4 make some allowance (for example, through declining air pollution emission rates) for future initiatives to address domestic environmental problems. See Coady and others (2019), Parry and others (2014), and Parry, Veung, and Heine (2015) for further discussion. Another potential co-benefit of carbon mitigation, not counted in Figure 1.4, is reduced dependence on volatile energy markets.

Figure 1.3. Revenue from Comprehensive Carbon Taxation in 2030, Selected Countries
(Percent of GDP)



Source: IMF staff calculations.
Note: G20 = Group of Twenty.

Figure 1.4. Unilateral Costs and Domestic Net Benefits of a $50/Ton Carbon Tax in 2030, Selected Countries
(Percent of GDP)



Source: IMF staff calculations.

instruments, such as (1) feebates or regulations promoting reductions in the emission intensity of power generation and vehicles, as well as the main opportunities for improving energy efficiency across the household, industrial, and electricity-consuming sectors; and (2) an emission trading system applied to power generation and large industry combined with feebates and regulations for the household and transportation sectors (Table 1.4).

For the second and third columns in Table 1.4, the policies are scaled to provide the same incentive for reducing CO_2 by an extra ton as under a $50 a ton carbon tax (for the emission sources each policy affects). In this case, the feebate/regulation and hybrid packages achieve emission reductions of 50–70 percent and 65–80 percent, respectively, of those under the carbon tax. For the two columns on the right, the policies are scaled to achieve the same economywide emission reduction as under a $50 a ton carbon tax. In this case, the costs of mitigation responses are 50–100 percent and 20–40 percent larger, respectively, for the feebate/regulation and hybrid packages. The mitigation cost is lower for the carbon tax because the emission reduction can be achieved by switching to cleaner technologies for a wider range of products and activities, as well as by consuming less energy. In contrast, under the feebate package, for example, the burden of adjustment is not spread as widely, and it becomes more and more difficult to attain emission savings through a narrower range of actions.

How to Increase Ambition in Global Mitigation Targets

The success of the Paris Agreement in meeting its long-term temperature goals will hinge critically on substantially scaling up mitigation efforts above what is currently pledged. This section discusses how an international carbon price floor could muster consensus among key countries on greater mitigation ambition.[25]

Promoting an International Carbon Price Floor

Any mechanism to induce scaling up of global mitigation needs to address three obstacles:

- First, a country may be reluctant to be the only one to scale up ambition, not only because the

[25]Global mitigation policies will cause large declines in revenues for fossil-fuel-rich countries—estimated in Online Annex 1.10. A complementary, more tentative proposal is thus put forward in that annex, calling for further analysis of how fossil-fuel-rich countries can share in the revenues from carbon taxation by increasing royalty payments, so as to encourage these countries to support an international carbon price floor.

Table 1.4. Comparing Other Mitigation Policies with Carbon Taxes, 2030

Country	CO_2 Reduction from Other Policies as a Fraction of CO_2 Reduction under $50/Ton Carbon Tax (for Same Carbon Price)		Mitigation Cost of Other Policies Relative to Cost of $50/Ton Carbon Tax (for Same CO_2 Reduction)	
	Feebate/Regulatory Combination	ETS/Feebate/Regulatory Hybrid	Feebate/Regulatory Combination	ETS/Feebate/Regulatory Hybrid
Argentina	0.51	0.66	1.94	1.51
Australia	0.67	0.90	1.50	1.11
Brazil	0.59	0.67	1.70	1.49
Canada	0.57	0.62	1.74	1.60
China	0.70	0.88	1.44	1.13
France	0.45	0.50	2.23	1.99
Germany	0.64	0.73	1.56	1.36
India	0.69	0.93	1.44	1.07
Indonesia	0.62	0.85	1.61	1.18
Italy	0.56	0.66	1.79	1.52
Japan	0.59	0.80	1.69	1.24
Korea	0.66	0.82	1.52	1.22
Mexico	0.51	0.76	1.98	1.32
Russia	0.53	0.65	1.87	1.54
Saudi Arabia	0.36	0.70	2.78	1.42
South Africa	0.64	0.84	1.56	1.19
Turkey	0.63	0.78	1.59	1.28
United Kingdom	0.57	0.63	1.75	1.60
United States	0.64	0.81	1.55	1.24
Simple average	0.59	0.75	1.75	1.37

Source: IMF staff calculations.

Note: Feebate and regulatory policies promote reductions in emission rates in power generation and transportation and two-thirds of other opportunities for higher energy efficiency. CO_2 = carbon dioxide; ETS = emission trading system.

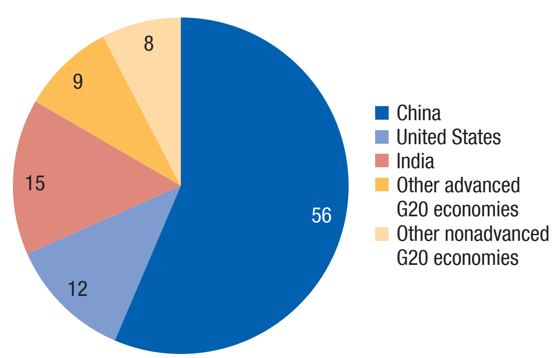
benefits accrue mostly to other countries but also because it may be concerned that higher energy costs would harm its firms' international competitiveness.

- Second, current mitigation pledges are not expressed using a common measure for all countries, thus hindering international comparisons.[26]
- Third, most future low-cost mitigation opportunities are in large, rapidly growing emerging market economies, especially those that rely heavily on coal. For example, with a globally uniform $25 a ton carbon price in 2030, China and India would

[26]Current pledges vary (for example, IMF 2019c, Appendix I) in terms of (1) target variables (for example, emissions, emission intensity, clean energy shares); (2) nominal stringency (for example, percent emission reductions); and (3) baseline years against which targets apply (for example, historical versus projected baseline emissions).

Figure 1.5. Country Shares of G20 CO_2 Reductions below Baseline under a Uniform $50/Ton Carbon Price in 2030, Selected Countries

(Percent)



Source: IMF staff calculations.
Note: CO_2 = carbon dioxide; G20 = Group of Twenty.

account for an estimated 56 and 15 percent, respectively, of CO_2 reductions (compared with baseline levels) from G20 countries, the United States for 12 percent, and all other G20 countries combined for 18 percent (Figure 1.5). However, advanced economies may have greater responsibilities for mitigation.[27] Indeed, on a per capita basis, projected baseline emissions in India in 2030 are only one-seventh of those for the United States (Online Annex 1.1).

An international carbon price floor for high-emitting countries (given the concentration of emissions in those countries), as a complement to the Paris process, might address these obstacles:

- An internationally coordinated approach would provide reassurance against losses in competitiveness and address free-rider issues—in fact, country participants may support robust floor prices as this reduces the emissions of other participants, thereby conferring collective benefits for all (for example, Cramton and others 2017; Weitzman 2016).
- A common emission price requirement improves the transparency of countries' actions.
- A common price floor (ideally a global price floor) is most efficient because emissions are cut where it is cheapest to do so on a global scale.[28] If the floor is lower for countries where it is cheaper to reduce emissions than for countries where cutting emissions is more expensive, many opportunities to cut emissions at the lowest cost could be missed.
- Despite the efficiency case for a uniform price, an option to ensure equity would be for advanced economies to be subject to a higher floor price. An alternative (or complementary) option would be for advanced economies to provide enhanced financial or technological support to emerging market economies in exchange for their commitment to more ambitious targets. The latter mechanism would be more efficient, because the emerging market economies have more opportunities to reduce emissions at low cost, although agreeing on international transfers might be more challenging.

Although an international floor price approach would require meeting operational challenges, such as monitoring and ensuring sustained participation (Box 1.3), it presents several advantages:

- It retains flexibility for countries to exceed the floor if they need to do so to meet their Paris mitigation pledges or other policy targets.
- It may encourage nonparticipants, and participants for which the minimum price is not binding, to raise carbon prices (for example, Kanbur and others 1995).
- It can be designed to accommodate strategies based on emission trading systems and feebates and regulations. Although the price floor is most naturally met through carbon taxes, emission trading systems could be accommodated (for example, by setting the emission cap such that the expected emission price is at least equal to the required price, or by including a mechanism that withdraws allowances from the system if prices would otherwise fall below the floor). Feebate and regulatory approaches could also be accommodated if the floor price were converted to an emission target for each country (that is, what emissions would be with the price floor).

Precedents for cooperation over price floors suggest that this approach is feasible. For example, under federal requirements introduced in Canada in 2016, provinces and territories are required to phase in a minimum carbon price, rising to Can$50 (US$38) a ton by 2022 using a carbon tax or an emission trading system.[29] More broadly, some progress has been made in combating excessive competition for internationally mobile tax bases through tax floor arrangements, for example, for excises on gasoline, cigarettes, and alcohol in the European Union.

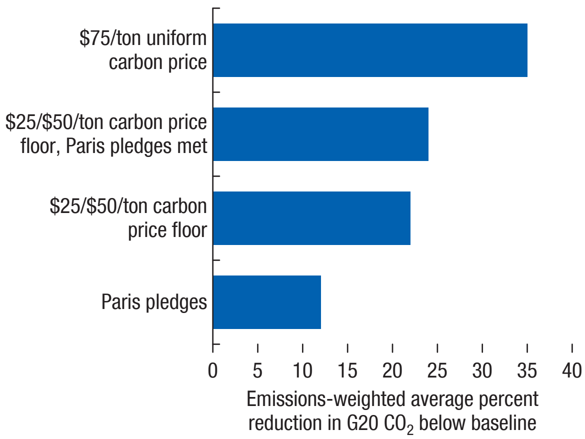
Under a price floor arrangement in which advanced and nonadvanced G20 member countries were, for illustration, subject to minimum prices of $50 and $25 a ton, respectively, on their domestic CO_2 emissions in 2030, combined G20 CO_2 emission reductions would be 24 percent below baseline levels (if either the floor prices or current mitigation commitments, whichever are more stringent, were met), doubling emission reductions over and above those implied by meeting

[27]Under the principle of "common but differentiated responsibilities," countries have varying responsibility for their contributions toward global greenhouse gas mitigation in recognition of their economic status and respective capabilities (UN 1992, Article 3.1).

[28]Following similar logic, CAE and GCEE (2019) recently made the case for a common price floor in Europe.

[29]The federal government will step in, where needed, to ensure regional governments meet the requirement (Government of Canada 2018a, 2018b; Parry and Mylonas 2018). The system is currently under legal challenges from some provincial governments.

Figure 1.6. CO_2 Reduction for G20 Countries under Alternative Ambition Scenarios, 2030



Source: IMF staff calculations.
Note: Carbon prices are per ton. For some emerging market economies (advanced economies), the $25 ($50) floor is not enough to meet the Paris pledges. In the second scenario from the top, countries meet the price floor or the Paris pledge, whichever is more stringent; in the third scenario from the top, all countries meet their respective price floor, but some may not meet their Paris pledges. CO_2 = carbon dioxide; G20 = Group of Twenty.

current pledges (Figure 1.6). Under that scenario, however, mitigation would still fall a third short of consistency with the 2°C target, so other measures, or higher price floors—an estimated $75 a ton across all G20 country emissions—would still be needed.

Making Mitigation Policy Acceptable in Domestic Politics

At a domestic level, implementing mitigation policy will likely require a comprehensive strategy that confronts the political challenges to enact and keep a high and broad-based carbon tax or similar measures. This section discusses common obstacles to reform and general strategies for overcoming them; the distributional burden of carbon pricing across household and industry groups in selected countries; options for use of carbon pricing revenue, considering their impact on income distribution; and measures to assist vulnerable groups.

Obstacles and Potential Solutions

Voters and particular groups often oppose carbon pricing because it increases their costs for energy and their cost of living. They may also oppose carbon pricing because of the misperception that these taxes impose a very disproportionate burden on low-income households; will not be effective in reducing emissions; and are a backdoor way to increase the size of government (Carattini, Carvalho, and Fankhauser 2017). Energy-intensive firms, especially those in trade-exposed sectors (that cannot easily pass on higher energy costs in product prices), labor groups, and regions that depend on energy production are often the most forceful opponents of carbon taxation.

Past attempts to introduce carbon pricing and energy pricing reform more generally point to the importance of four elements in successful strategies:[30]

- Increasing carbon prices in the near term and locking in subsequent price hikes through legislation to provide clarity and certainty (thereby allowing time for firms and households to adjust through, for example, energy efficiency investments);
- Extensive consultations with stakeholders to garner support and a public communication campaign that provides the facts underlying the case for reform and addressing possible misperceptions;
- Transparent, equitable, and productive use of revenues; and
- An upfront package of targeted assistance for vulnerable households, firms, workers, and disproportionately affected communities.

For example, Sweden successfully implemented a tax on carbon emissions starting at $28 a ton in 1991 and progressively rising to $127 a ton in 2019. The tax was introduced as part of a broader reform including the reduction of taxes on energy, labor, and capital. Higher social transfers and reductions in the basic rate of income taxes helped to offset burdens for low- and middle-income households, while competitiveness concerns were addressed through a lower initial rate for industries (progressively phased out by 2018). Businesses and other stakeholders were involved in the decision-making process through public consultations. In France, on the other hand, the rapid ramping up of a similar carbon tax was suspended in 2018 at $50 a ton, following a public backlash against the perceived unfairness of the tax, which was introduced at the same time as broader tax reductions seen as benefiting

[30]For more detail on suggested reform strategies see Clements and others (2013) and Coady, Parry, and Shang (2018).

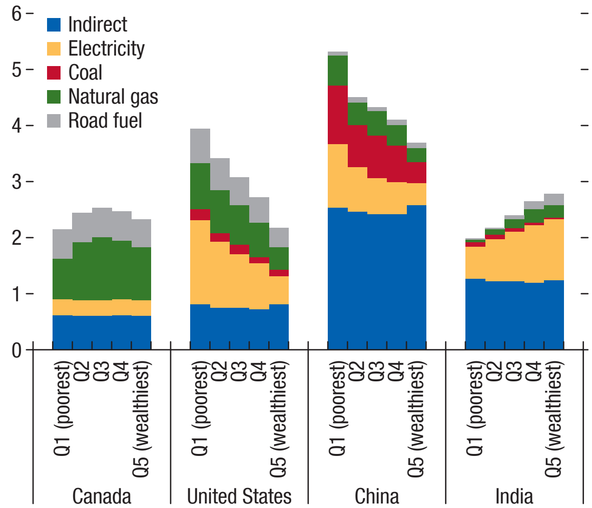
the wealthy. Online Annex 1.7 summarizes additional experiences with carbon taxation.

Beyond these general elements, overcoming the political challenge may require building a broad enough coalition in favor of reform; for example, by using a portion of the revenues to finance policies that will mobilize support from environmental groups, green industrial interests, and households. Where this is not feasible, avoiding higher energy prices in favor of feebate and regulatory policies may be more practical, even if less effective.[31]

The Distribution of Income across Households and Businesses

Before considering the use of revenues from carbon pricing, carbon taxes would undoubtedly add to the cost of living for all households, and the burden as a share of total household consumption would range from moderately regressive to moderately progressive in selected countries. (A regressive policy imposes a larger burden as a share of consumption on lower-income households than on higher-income households; a progressive policy does the opposite.) If no accompanying measures were taken, carbon taxes would be moderately regressive in China and the United States, distribution-neutral in Canada, and moderately progressive in India for a $50 a ton carbon tax in 2030 (Figure 1.7). The reason is that in China and the United States, the poor spend a greater share of their budget for electricity, but the opposite applies in India.[32] In most countries, one-third to one-half of the burden of increased energy prices on households comes indirectly through higher general prices for consumer products, and these burdens are approximately proportional to total consumption across households (distributed evenly across consumption quintiles). The absolute burden on the bottom consumption quintile ranges from 2.2 percent of household consumption in Canada to 5.3 percent in China. Moreover, in all four countries, 90 percent of the total burden is borne by the top four consumption quintiles. Underpricing energy associated with carbon emissions is therefore an inefficient way to help low-income households, because most of the benefits accrue to wealthier groups.

Figure 1.7. Burden of Carbon Taxation on Households, by Income Quintile, $50/Ton Carbon Tax in 2030, Selected Countries
(Percent of total household consumption)



Source: IMF staff calculations.
Note: See Online Annex 1.7 for methodology and data sources. "Indirect" refers to the increased price of consumer goods from higher energy costs. Burdens are estimated prior to the use of carbon tax revenue; a full pass-through of taxes to consumer prices is assumed. Q = quintile.

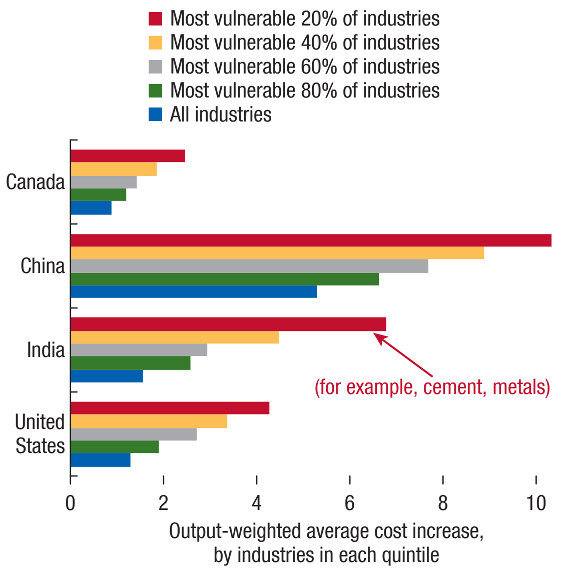
Although, over the longer term, efficient allocation of an economy's scarce resources implies that firms unable to compete when energy is efficiently priced (including to address emissions) should be allowed to go out of business, impacts of higher energy prices on firms, especially those in energy-intensive trade-exposed sectors, is a political concern with carbon pricing.[33] Carbon taxes have uneven impacts across countries and economic sectors (Figure 1.8). The average impact on industry costs of a $50 a ton tax in 2030 ranges between 0.9 percent in Canada and 5.3 percent in China. However, the most energy-intensive industries can be affected significantly: cost increases for the 20 percent most vulnerable industries are 10.3 percent in China and 6.8 percent in India.

[31]This would be more likely, for example, if political opposition to higher energy prices is especially severe, raising energy prices is at odds with promoting energy access, energy prices are already high compared with neighboring countries, or emissions respond modestly to prices (which is the case, for example, if they come mostly from the transportation sector).

[32]In India, the burden of carbon pricing would be somewhat larger for urban households than for rural households because of lower availability of, and less spending on, electricity in rural areas.

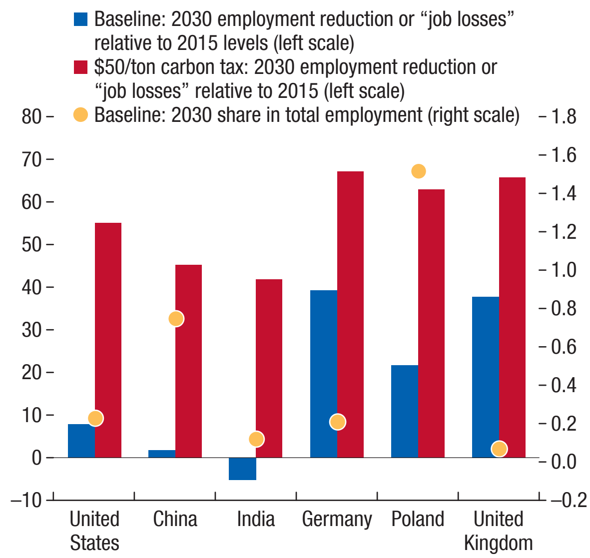
[33]A related concern is that if domestic firms reduce emissions, firms abroad could increase emissions as they gain competitive advantage. However, estimates suggest when emissions are cut by 100 units at home, they increase abroad by no more than 5–20 units (Böhringer, Carbone, and Rutherford 2012; Burniaux, Chateau, and Duval 2013).

Figure 1.8. Burden of a $50/Ton Carbon Tax on Industries in 2030, Selected Countries
(Percent)



Source: IMF staff calculations (see Online Annex 1.8).
Note: The figure shows production cost increases from higher energy prices as a result of the carbon tax (assuming no pass-through of higher costs to producer prices).

Figure 1.9. Impact of a $50/Ton Carbon Tax on Employment in the Coal Sector in 2030, Selected Countries
(Percent)



Source: IMF staff calculations.
Note: "Employment" includes coal mining and related activities—primarily coal transport and processing. The baseline assumes no new mitigation measures.

Carbon mitigation might also have large impacts on certain groups of workers and regions. Coal-related employment is projected to decline in many countries under baseline policies. A $50 a ton carbon tax in 2030 would substantially accelerate this process; for example, increasing estimated job losses in this sector relative to 2015 levels from 8 to 55 percent in the United States (from small changes) and up to 42–45 percent in China and India (Figure 1.9). These job losses would amount to 0.3–0.9 percent of economywide employment in China and Poland and less than 0.15 percent in other countries; employment would increase in other sectors, such as renewables, but—in the absence of specific policies—the new jobs would likely become available in other regions.[34]

Typically, coal- (or fossil-fuel-) related jobs are highly geographically concentrated, accounting for a disproportionately large share of local employment in a few regions in a country (Online Annex 1.6). Winding down production in these regions would lastingly reduce output and employment prospects for local communities. In addition, extractive activities may cause scarred local landscapes and impaired waterways, and bankrupt extraction firms may be unable to meet their obligations to clean up the abandoned mines, reducing prospects for attracting new industries (Morris 2016).

Options for Use of Carbon Tax Revenue

For carbon pricing reforms to be economically and politically viable, and for the burden of adjustment to be distributed in a fair manner, policymakers need to consider how to best allocate the revenues considering both economic efficiency and implications for income distribution. Key considerations will usually include fiscal needs for environmental or general spending or deficit reduction, the existing income distribution, and the effectiveness of transfer programs, as well as the design, efficiency, and progressivity of the broader tax system.

[34]In 2017, global employment in the renewables sector was 11 million (Roberts 2019). Although jobs in renewables require more specialized skills in general, those jobs have lower educational requirements and better pay than the national averages (for example, fewer than 20 percent of workers in clean energy production and energy-efficient occupations have college degrees—Muro and others 2019).

For example, universal transfer payments (that is, equal dividends to all households regardless of income) might help with political acceptability but would forgo potentially sizable efficiency benefits from productive revenue use. Environmental investments (low-carbon infrastructure, energy networks, R&D) may also be favored by voters as part of a package; however, these investments would need to be balanced against competing investment priorities and scrutinized to ensure high quality, as with other important investments (for example, basic education and health). As regards to options for lowering other taxes, cutting personal and corporate income taxes likely provides significant efficiency gains for the economy (through better incentives for work effort, investment, and lowering incentives for tax-sheltering behavior), although benefits tend to be skewed toward better-off households (for example, poor households may not pay income taxes). Reducing payroll or consumption taxes can also promote some of these efficiency gains and would benefit households roughly in proportion to their income. See Table 1.5 for a summary of options.

Figure 1.10 illustrates some of the efficiency tradeoffs for the United States in 2030 for a $50 carbon tax, with all revenues returned to everyone in the population as an equal dividend, the same tax with three-quarters of revenues used for income tax cuts and one-quarter for assistance to lower-income groups, and

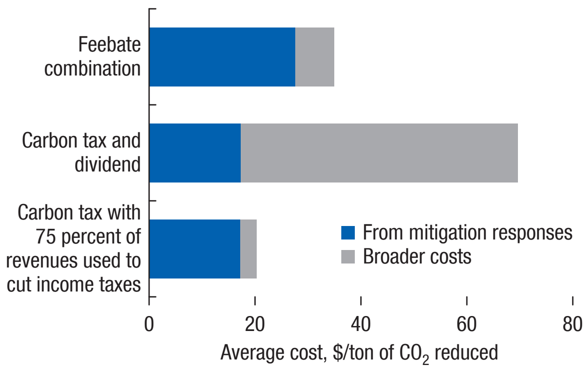
Table 1.5. Options for Use of Carbon Tax Revenues

	Metric		
Instrument	**Impacts on Income Distribution**	**Impact on Economic Efficiency**	**Administrative Burden**
General Revenue Uses			
Environmental investment	May disproportionately benefit low-income households (for example, if their vulnerability to natural disasters is reduced)	May be less efficient than broader uses of revenue	Modest
General investments	May disproportionately benefit low-income households (for example, if basic education, health, and infrastructure are provided)	Potentially significant	Modest
Universal transfers	Highly progressive (disproportionately benefits the poor relative to higher-income)	Forgoes efficiency benefits[1]	New capacity needed (but should be manageable)
Payroll tax	Benefits are largely proportional across working households	Improves incentives for formal work effort	Minimal
Personal income tax	Typically, benefits are skewed to higher-income groups	Improves incentives for formal work effort, and saving reduces tax sheltering	Minimal
Consumption tax	Largely proportional to household consumption	Some improvement in incentives for formal work effort	Minimal
Corporate income tax	Benefits skewed to higher-income groups	Improves incentives for investment	Minimal
Deficit reduction	Benefits accrue to future generations	Significant (lowers future tax burdens and macro-financial risk)	Minimal
Targeted Assistance			
Means-tested cash, in-kind transfers	Effective at helping low-income groups if social safety nets are comprehensive	Efficiency impacts unclear but likely modest[1]	Low, if builds on existing capacity, otherwise significant
Assistance for household energy bills	Provides partial relief for all households (for example, does not help with indirect pricing burden)	Modest reduction in environmental effectiveness	Low, if builds on existing capacity, otherwise significant

Source: IMF staff calculations.

[1] Transfers to low-income households could lead to a small increase in human capital investment.

Figure 1.10. Efficiency Costs of Alternative Carbon Mitigation Instruments for the United States ($50/Ton Carbon Tax), 2030



Source: See Online Annex 1.3, updating Parry and Williams (2010).
Note: All policies reduce economywide carbon dioxide emissions 22 percent below baseline levels. Cost estimates exclude global climate and domestic environmental benefits from carbon mitigation.

a feebate package achieving the same economy-wide emission reduction as the carbon tax. Accounting for the broader costs of higher energy prices on economic activity and the economic efficiency benefits from use of carbon tax revenues—in addition to the costs of mitigation responses (discussed in Policies to Reduce Fossil Fuel CO_2 Emissions)—on balance, the carbon tax is the least costly approach overall, with costs of $20 a ton of CO_2 reduced, if three-quarters of the revenues are deployed to cut existing income taxes, which have their own efficiency costs.

The carbon tax with revenues funding equal dividends for the entire population has much larger efficiency costs—estimated at $70 a ton of CO_2 emission reduction, twice as high as under the feebate (which has limited impacts on energy prices) and 3½ times as high as a carbon tax with three-quarters of revenues used to lower income taxes. The size of the gap in economic efficiency costs between using carbon tax revenues for equal dividends versus income tax cuts depends on country circumstances and might be larger, for example, in countries where tax systems lead to greater avoidance or evasion behavior, such as informal sector activities (see Online Annex 1.3 for details on the methodology).

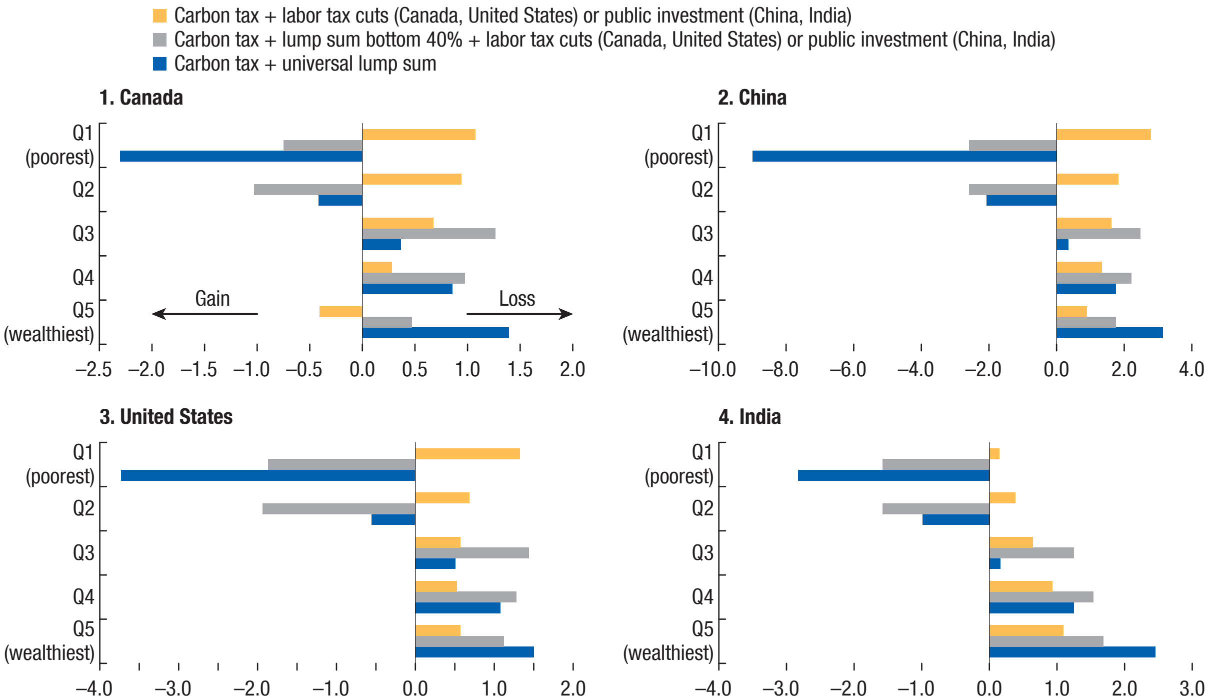
When analyzing distributional effects, it is important to consider the impact on all income groups because carbon pricing affects all households. Indeed, opposition to reform often comes from groups of people who are closer to the median of the income distribution—members of the middle class. Still, reform packages will usually need to include assistance to lower-income households as well as assistance and compensation to workers and communities experiencing widespread job losses. In some cases, support to groups of disproportionately affected firms may be appropriate, although in this area measures are often inefficient.

Imposing carbon taxes with revenue returned in equal dividends to everyone is a highly progressive policy, with the bottom two consumption quintiles better off on net and the top two quintiles worse off for all countries in Figure 1.11. Alternatively, using the revenues to enhance economic efficiency—reducing labor taxes in Canada and the United States and funding public investment in China and India—is a regressive policy on net, aside from in India, though net burdens on each household group are reduced considerably (compared with Figure 1.7) as a result of the revenue use. An intermediate approach, in which the bottom two quintiles are compensated for higher energy prices through equal dividends, and the remaining revenue—60–70 percent of the total—is used for public investment (China and India) or reductions in labor taxes (Canada and the United States) is also highly progressive and can still generate large gains in economic efficiency.[35]

A political consideration in favor of combining carbon taxation with equal dividends is that such an approach creates a large constituency in favor of enacting and keeping the plan (because about 40 percent of the population gains, and those gains rise if the carbon price increases over time) and the public may feel that the government does not have the option to "waste" the carbon tax revenues. Policymakers will have to consider the weight of the arguments against the backdrop of their country's particular economic and political circumstances. From a practical standpoint, however, to give investors, firms and households certainty and predictability, it would seem appropriate to lock-in a gradual increase in carbon taxation—over a decade or more, if possible—ideally backed by an international commitment. An equal dividend could be provided on

[35]All households face a small burden under a package of indirect pricing policies such as feebates, but the burdens are less than 1 percent of consumption for all groups in Canada, India, and the United States.

Figure 1.11. Burden of a $50/Ton Carbon Tax in 2030 under Alternative Revenue Uses, Selected Countries
(Percent of total consumption)



Source: IMF staff calculations.
Note: Positive numbers denote a loss; negative numbers denote a gain. Q = quintile.

distributional grounds and to enhance political acceptability. In subsequent years, further reforms to other taxes would likely take place and, as always, would be informed by the new economic and distributional pattern resulting from the carbon tax and dividend approach as well as by many other developments in the meantime.

Targeted Assistance

Assistance to lower-income households. Several options are available to alleviate the impact of carbon pricing on the poor (Table 1.5). In principle, targeted assistance (for example, cash or food vouchers following means testing) is an efficient way to help lower-income households. However, if administrative capacity is not up to the task, targeting can be inaccurate—leading some poor households to be excluded or nonpoor households to be included. Providing relief for household energy bills through a lifeline (discounted price for basic energy needs of poor households) can also help, although it would not offset the significant indirect burden from generally higher consumer prices. Expanded eligibility for support that provides incentives to find and retain a job (for example, the Earned Income Tax Credit in the United States) also helps people remain in the labor force and maintain basic job skills. Compared with targeted assistance, universal transfers would close coverage gaps and perhaps build broader support for reform, but they would be much costlier for the public finances.[36]

Support for displaced workers and coal-mining regions. In view of the major economic transformation experienced by workers and communities whose livelihoods depend on fossil fuels, assistance will be appropriate to help them transition to a better future and to enhance the political viability of carbon pricing. While the exact design would depend on country circumstances, measures for displaced workers could center around extended unemployment benefits, training and reemployment services, and financial assistance related to job search, relocation, and health care. Potentially useful features include outreach to increase awareness and take-up of the program, tailoring of job training to the needs of coal-related sector workers, and wage

[36]For further discussion of universal transfers versus targeted assistance, see IMF (2019a).

insurance or tax credits, especially for older workers. For the success of the program, beyond good design, the scale of support needs to be sufficiently generous. Even so, the estimated cost of programs providing comprehensive benefits is less than 2 percent of carbon tax revenues for China, India, the United Kingdom, and the United States under a $50 a ton carbon tax. (Online Annex 1.6). Support to affected regions needs to go beyond assistance to displaced workers, because mine closures often take a toll on communities with limited alternative employment opportunities, and declining home values make it difficult for people to move. Assistance for reclaiming abandoned mining and drilling sites and temporary budget support for local governments could help to create jobs and to bridge the transition for adversely affected communities.[37] Additional investments or other geographically targeted policies (such as subsidies or grants to individuals or firms in the affected regions) may also be warranted to help the regions engage in economically viable and sustainable opportunities (World Bank 2018).[38]

Assistance to firms. Absent agreement on an international carbon price floor—the best way to preserve international competitiveness—policymakers could consider several options to cushion the blow to domestic firms from higher energy prices, especially for energy-intensive, trade exposed firms (Table 1.6). However, these options are for the most part inefficient and their design may need careful attention. A general cut in corporate income taxes would reach all firms, not just energy-intensive, trade-exposed firms. Border carbon adjustments, levying charges on the unpriced carbon emissions embodied in imports (and perhaps remitting domestic carbon taxes on exports) might be judged compatible with World Trade Organization (WTO) rules if they are viewed as meeting environmental (rather than protectionist) objectives.[39] They would, however, require significant administrative capacity (for example, to assess the carbon embodied in products imported from various countries) and might work against the spirit of the Paris Agreement if they penalize countries implementing their mitigation pledges through non-pricing means. Providing rebates to trade-exposed firms in proportion to their output preserves their incentive to reduce emissions per unit of output, but this also requires additional administrative capacity.

Supporting Policies for Clean Technology Investment

Even with robust carbon pricing, investment in low-carbon technologies—essential for the transition to the cleaner energy systems necessary for lower emissions—may be insufficient because of various technology-related market failures and impediments, including the following:[40]

- Knowledge spillovers from research and development (R&D) and technology diffusion that may prevent firms from capturing the full social benefits of developing and using new technologies;[41]
- Scale economies that may deter firms from investing in a clean technology until they are confident about the size of the market;
- Network externalities where additional infrastructure needed for one investor (for example, to connect a remote renewables site to the power grid) could potentially benefit other firms;
- Market distortions that might impede low-carbon investment (for example, regulated energy pricing or incomplete property rights that hinder land acquisition for renewable plants); and
- Financial market imperfections reflecting limited financial instruments for low-carbon investments and the shorter-term horizons of investors.

[37]For example, China established a restructuring fund in 2015 (0.15 percent of GDP), mainly for training and job search assistance, to facilitate the shutdown of coal mines and other overcapacity for sectors.

[38]Germany, for example, is planning to allocate €40 billion over the next 20 years to coal-mining regions to support activities such as developing infrastructure; expanding public transportation; and promoting R&D, science, and innovation. Reclaiming mining sites and protecting retiree benefits of coal-related sectors are estimated at a one-time cost 0.03 percent of GDP in the United States (Morris 2016).

[39]For more discussion on compatibility issues, see Flannery and others (2018) and Trachtman (2017).

[40]For further discussion of nonpricing measures to complement carbon pricing and the underlying rationale, see Stern and Stiglitz (2017) and Stiglitz (2019). These studies emphasize the importance of strategic choices in investment in public transportation infrastructure and urban planning, as well as the governance of the energy system; they also point, for example, to the success of regulations in promoting the development of cheap LED by banning incandescent light bulbs and the reduction in lead-based pollution by banning lead in gasoline.

[41]These spillovers are common to emerging technologies across all sectors of the economy and to some extent may be addressed by intellectual property protection, but the deterrent may be especially severe for long-lived, low-carbon technologies whose future returns are uncertain because of changing mitigation policies. See, for example, Acemoglu and others (2012); de Serres, Murtin, and Nicoletti (2010); Fischer and Preonas (2010); and Newell (2015).

Table 1.6. Instruments for Offsetting Burdens on Trade-Exposed Firms

Instrument	Rebates for Direct/ Indirect Emissions	Output-Based Rebate	Border Carbon Adjustments	General Corporate Tax Cut	International Carbon Price Floor
Addresses Competitiveness of Trade-Exposed Industries	Yes	Yes	Yes	Poorly targeted at exposed industries	Yes
Preserves Mitigation Incentives for Trade-Exposed Industries	Removes all incentives	Maintains incentive for reducing emission intensity	Maintains all incentives	Maintains all incentives	Maintains all incentives
Revenue Loss from Instrument	Moderate	Moderate	Increases revenue	High cost	Not applicable
Added Administrative Burden	Small	Need to identify industries and monitor their output	Need to identify imported products and measure their embodied carbon	Not applicable	Monitoring by international organization required
Compatible with World Trade Organization Rules	Yes, if carefully designed	Yes, if carefully designed	Yes, if carefully designed	Yes	Yes, if carefully designed
Compatible with Paris Agreement	Yes	Yes	May penalize countries using indirect pricing	Yes	Yes

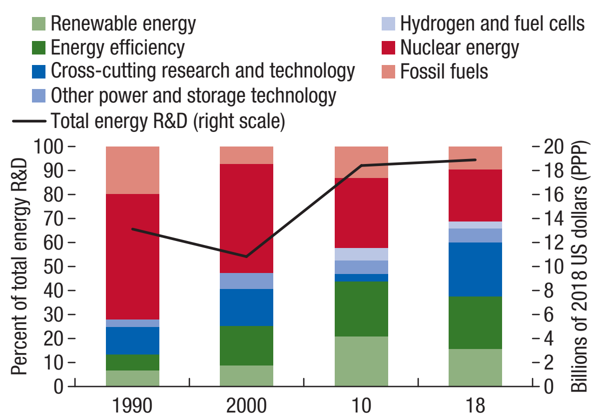
Source: IMF staff.

Approaches for addressing these market impediments include public R&D support (IMF 2016), targeted fiscal incentives (for example, capital grants, tax credits, per-unit subsidies, feed-in tariffs), and regulations (for example, on renewable generation shares) to deal with knowledge spillovers and provide more certainty over the demand for clean technologies; public infrastructure investment (for example, on charging stations for electric vehicles) to tackle network externalities; price liberalization and land reforms to reduce market distortions; and financial sector policies. Over the past three decades, public R&D spending in the energy sector in advanced economies has increasingly shifted from fossil fuels and nuclear to cross-cutting research and technologies, renewables, and energy efficiency from 25 percent of total energy R&D spending in 1990 to 61 percent in 2018 (Figure 1.12).

Supporting policies should be part of a comprehensive strategy to promote supply-side investment in low-carbon technologies and demand-side energy-efficiency measures—including carbon pricing (Ang, Röttgers, and Burli 2017); fiscal incentives that are appropriately scaled, targeted, and designed; and direct public infrastructure investment. In this regard,

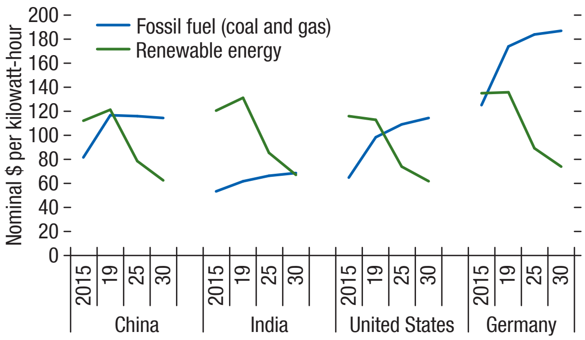
- Governments should increase R&D support now and then gradually reduce support over time when technologies are widely deployed and used by firms and households (Acemoglu and others 2012, 2016). For example, some have called for a gradual

Figure 1.12. Composition of Global Public Energy Research and Development Expenditure, 1990–2018



Sources: IEA 2018; and IMF staff estimates.
Note: The public energy R&D spending covers 30 OECD member countries in the IEA. IEA = International Energy Agency; OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity; R&D = research, development, and demonstration.

Figure 1.13. Electricity Cost, by Energy Source of Production, Selected Countries, 2015–30



Source: Bloomberg New Energy Finance.

doubling of public spending on energy R&D in advanced economies ($10 billion in 2018),[42] focused on needed technologies currently furthest from the market that have strong social benefits (for example, carbon capture and storage, smart grids, infrastructure for electric vehicles, and batteries to store intermittent renewable power). Subsidies that promote widespread deployment and use of new technologies by firms and households should also be temporary—for example, as the electricity generated from renewables approaches cost parity with fossil-fuel-generated power (Figure 1.13), subsidies could be shifted from R&D to deployment and then progressively phased out (as in the phasing out of subsidies for solar power in China; see Online Annex 1.9).

- Production-based fiscal incentives, such as fixed subsidies per kilowatt-hour of renewable energy, are more flexible than (1) investment-based incentives (see Online Annex 1.9 on India); (2) regulations that force in the adoption of new technologies regardless of their future costs; and (3) (commonly used) feed-in tariffs guaranteeing minimum prices per kilowatt-hour that do not permit supply responses to changing market conditions (Löschel and Schlenker 2017). Many countries, including Germany, Mexico, South Africa, and the United Kingdom, have moved away from predefined feed-in tariffs and have adopted tendering processes to reduce costs. Moreover, some regulations might deter low-carbon investment from new entrants because they impose disproportionately higher costs on them relative to incumbent firms—such as the 2015 rule in Canada that requires investment in carbon capture and storage in new coal plants while allowing a long adjustment period for existing firms (OECD 2017). Moreover, studies find that policies that support upstream development and manufacturing of clean technologies can be more cost effective than policies to support downstream consumption, because upstream providers face less competition (Fischer 2016; Requate 2005). And provisions in corporate income tax codes, such as the amount and duration of loss carryovers, should be appropriately calibrated to account for the upfront costs of renewable investments (OECD 2017).
- The current dominance of carbon-based systems may perpetuate incentives for R&D in fossil fuel technology. Escaping the carbon lock-in can be facilitated by public funding of R&D in renewables, as well as by public infrastructure investment to tackle network externalities (for example, funding of smart electricity grids to accommodate an intermittent supply of renewables) and removing market distortions for low-carbon private investment.
- Policies in the financial sector can help mobilize financing for climate change mitigation. Recent proposals have focused on fostering the financing of green projects and companies through (1) the establishment of standards, prototype green bond contracts, and benchmark indices of securities that meet environmental norms; (2) amendment of prudential regulations and collateral eligibility criteria; and (3) shifts in the portfolio choices of central banks and institutional investors (Online Annex 1.12).

Policy inconsistencies and redundancies should be avoided. For example, many countries currently subsidize renewables and fossil fuels at the same time.[43] Incentives for energy efficiency and renewables have

[42]For example, Dechezleprêtre and Popp (2017), IEA (2019), and Newell (2015).

[43]Globally, subsidies for fossil fuels (measured by underpricing for supply costs) were estimated at $270 billion in 2016 compared with $150 billion for renewables (Coady and others 2019; IEA 2016). In addition, other forms of subsidies are important, albeit more difficult to quantify. For example, despite coal's adverse impact on greenhouse gas emissions and local air pollution, a recent study indicates that government support to the production and consumption of coal through investment by state-owned enterprises and financing by the public sector (including state-owned banks) is sizable among G20 countries (Gençsü and others 2019).

no impact on emissions when imposed on top of an emission trading system with a binding emissions cap; similarly, tax incentives for electric vehicles may have no effect on average vehicle emission rates in the presence of binding fuel economy standards (Krupnick and others 2010). Fossil fuel generators are sometimes awarded long-term purchase agreements that insulate them from the improving competitiveness of renewables. Uncertainty about renewable investment policies could also impede investment. For example, the US tax preferences related to fossil fuels are permanent features of the tax code, while most of the incentives for R&D, and investment in renewables and energy efficiency are temporary and will continue to be available only if extended. Providing more predictability on R&D tax credit policies could bolster incentives for innovation. And policy inconsistencies sometimes arise at different levels of government. Thus, greater coordination would be appropriate across ministries, levels of government, and other public sector agents.[44]

The shift of investment composition toward renewables also creates new job opportunities. Global employment in the renewables sector reached about 11 million in 2017 (IEA and IRENA 2017; Roberts 2019), the bulk of which was in solar energy. More than 40 percent of worldwide jobs created in the renewables sector since 2012 have been in China. Employment in the renewables sector is projected to grow to 24 million by 2030 under a 2°C scenario (IEA and IRENA 2017; IRENA 2018).

Conclusions

Climate change is threatening the planet and the global economy, calling for urgent policy action to secure a better future. Promoting the transition to low-carbon growth is a challenge faced by all countries and there is much to be done in designing the right incentives at the domestic and international levels and in navigating the practical obstacles to putting them in place. This *Fiscal Monitor* emphasizes the critical role of fiscal policies in climate change mitigation with an emphasis on improving their social and political acceptability (for example, through judicious use of revenues) and effectiveness (for example, through international carbon price floors and supporting technology policies).

Carbon taxation or other systems that use price signals provide the most powerful and efficient incentives for households and firms to reduce CO_2 emissions. If these instruments are not feasible on the scale that is needed, alternative instruments such as feebates and regulations could be used. These instruments would have to be implemented more aggressively to achieve the same emission reductions, implying little increase in energy prices, but greater inefficiency and disruption. Still, the cost of achieving emissions reductions through these approaches would be lower than the costs to people and the planet from climate change. Finance ministers can play a key role by undertaking carbon taxation or similar pricing, adjusting broader tax and expenditure policy as part of a comprehensive strategy, ensuring adequate budgeting for investment in R&D and support for cleaner technologies, and coordinating strategies internationally. Actions in high-emitting countries are especially urgent, not just for their own sake but also for their potentially catalyzing impact in other countries. These actions also bring domestic benefits such as lower mortality from air pollution. Finance ministers in all countries are central to designing and implementing policies to meet emissions reductions in the most efficient, equitable, and socially and politically acceptable way.

[44]OECD (2015). For example, federal production tax credits for renewables in the United States may have no impact in states where generators are already subject to binding requirements on renewable generation shares.

Box 1.1. Investment Needs for Clean Energy Transitions

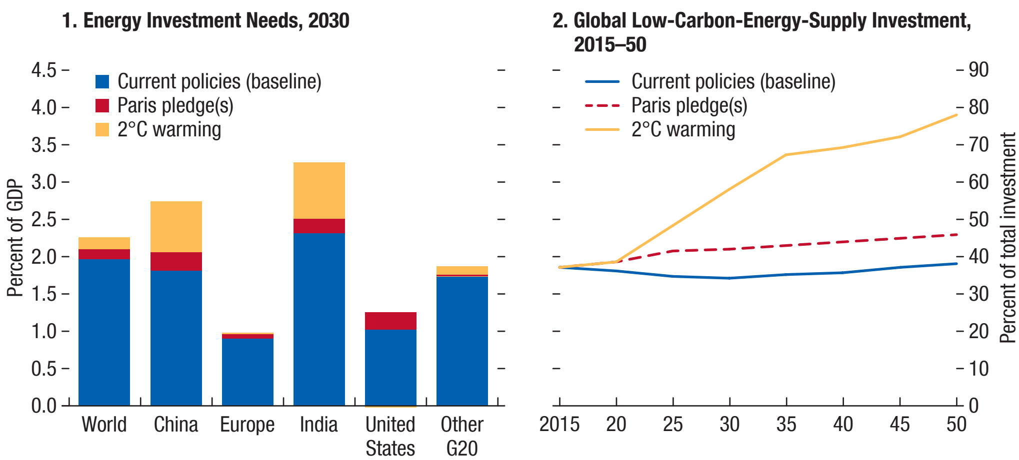
Model estimates suggest that reducing emissions to a level consistent with a 2°C temperature target would require increasing the projected global energy investment in 2030 (encompassing both public and private) from 2.0 percent of GDP to 2.3 percent of GDP, with most of the increase concentrated in China and India (Figure 1.1.1, panel 1).[1]

The more important challenge for all countries, however, is to overhaul the composition of new investment, with the share of low-carbon energy supply (renewables, nuclear, improved transmission and distribution networks, carbon capture and storage in power generation) rising from 40 percent in 2020 to 70 percent in 2035 and 80 percent in 2050 (Figure 1.1.1, panel 2). Energy infrastructure—for example, power plants and power grids—has an expected lifetime of 30–60 years. Choices made today will thus determine emissions for decades. This is especially important for rapidly growing emerging market economies, where new infrastructure will be built or expanded in the coming decades. Sizable extra investment in energy efficiency is also needed for buildings (for example, design, heating, cooling, appliances), transportation (for example, electric cars), and industry (Online Annex 1.9). These demand-side investments can speed up the reduction in carbon emissions because of their shorter life cycles compared with energy infrastructure (IEA 2018). Online Annex 1.9 elaborates on investment needs for individual Group of Twenty (G20) countries. Shifting investment to a low-carbon supply would help ensure that more carbon remains in the ground.

Incremental investment needs would be even greater if they also covered transportation and other infrastructure (water, sanitation, and telecommunications) that are essential to deliver the Sustainable Development Goals (SDGs), including SDG7 on clean energy access, and enhance the adaptive capacity to climate change (IPCC 2018; OECD 2017; SEI 2018).

[1]These numbers represent multi-model averages and are subject to large uncertainty. The faster the transition to low-carbon technologies, the higher the risk of stranded assets and investment costs.

Figure 1.1.1. The Investment Challenge



Source: IMF staff calculations based on McCollum and others (2018).
Note: Paris pledges are those made by each country as part of the Paris Agreement in 2015. Two degrees Celsius is the more ambitious scenario of keeping global warming below 2°C. G20 = Group of Twenty.

Box 1.2. Fiscal Instruments to Reduce Broader Sources of Greenhouse Gases

Fiscal instruments could promote many greenhouse gas mitigation opportunities beyond those for reducing domestic fossil fuel carbon dioxide (CO_2) emissions. Potential applications include the following (for general discussions, see Calder 2015, IMF 2019c, and Metcalf and Weisbach 2009):

- *CO_2 emissions from fuel use in the international aviation and maritime sectors:* The UN agencies overseeing these industries are responsible for developing and implementing strategies to mitigate their emissions. A tax on the carbon content of fuels, administered by these agencies, could form the centerpiece of these efforts while also raising sizable revenue—for example, for climate finance (for example, Keen, Parry, and Strand 2013).
- *Net CO_2 emissions from the forestry sector:* These could be reduced through slowing deforestation and planting new trees to increase the amount of carbon stored in forests. In countries where property rights are reasonably well established at the forestry and agricultural border, a national-level feebate program could be introduced. It would tax landowners who store less carbon on their property relative to storage in a baseline year and give rebates to landowners who increase carbon storage (Parry 2019).
- *Methane leakage during the extraction, processing, and transport of oil, natural gas, and coal:* Technologies for monitoring these emissions are evolving, but in the meantime fuel extraction could be taxed in proportion to a default leakage rate, with rebates for firms that demonstrate a leakage rate below the default rate.
- *Fluorinated (F-) gases:* These highly potent greenhouse gases are used primarily in refrigerants, foams, aerosols, and fire extinguishers. Some countries (for example, Denmark, Norway, Poland, Slovenia, and Spain) have introduced taxes on these gases with rates of about \$5–\$40 a ton of CO_2 equivalent emissions (for example, Brack 2015).
- *CO_2 emissions released during the production of clinker* (from limestone): Clinker is used to manufacture cement. Taxes could be levied on clinker production in proportion to a default emission rate (van Ruijven and others 2016).
- *Agricultural greenhouse gases, which include methane emissions from cows, nitrous oxide emissions from soil and fertilizer practices, and CO_2 emissions from forest clearance for agriculture:* Taxes could be imposed per head of cattle, on fertilizer inputs, and on profits for farming involving deforestation (for example, where ill-defined property rights preclude the direct pricing of forestry emissions) (Batini forthcoming). Administration, however, might be limited to large-scale operations.

There are precedents for successful international cooperation over reducing these types of gases. The 1987 Montreal Protocol set up a framework that essentially eliminated, by the mid-1990s, production of chlorofluorocarbons (CFCs) and other substances that had been depleting the ozone layer, thereby elevating risks of cancer from ultraviolet light (Hammitt 2010). F-gases were largely developed in response to the phaseout of CFCs. Unlike other greenhouse gases in the Paris Agreement, however, F-gases are subject to other international negotiations—under the 2016 Kigali Agreement, all countries are required to largely phase out these chemicals over the next 25 years (Mulye 2017).

Box 1.3. Operationalizing International Carbon Price Floors

Turning an international carbon price floor into reality would require agreement among participants, preparatory work, and independent monitoring in several areas, such as the following.

Ensuring that carbon prices are measured using a consistent approach across countries: Some countries may provide favorable rates to selected (perhaps politically sensitive) emission sources, or they may partially offset carbon taxation by reducing preexisting energy taxes. To ensure cross-country comparability of effort, the arrangement might thus focus on countries' "effective" carbon prices. These can be calculated by (1) expressing existing fuel taxes on a carbon dioxide (CO_2)-equivalent basis (that is, dividing them by the fuel's CO_2 emission factor); and (2) weighting CO_2-equivalent fuel taxes, and any direct carbon pricing, by their relative effectiveness at reducing CO_2 emissions compared with a comprehensive carbon price and then aggregating across these tax and pricing systems. First-pass estimates of effective carbon prices for 135 countries are provided in IMF (2019c).

Recognizing past efforts: There is little efficiency basis for equating effective carbon prices across countries since these vary, for example, according to fiscal needs and the share of economy-wide emissions from fuels subject to excise. Instead, the arrangement could focus on a required uniform *increase* in countries' effective carbon prices relative to prices in an earlier year—for example, before the recent proliferation of carbon pricing programs to avoid penalizing those who have already acted.

Ensuring sustained participation—carrots? Besides granting them a lower price floor, participation in the agreement among emerging market economies might be encouraged through side payments, technology transfers, or credit trading opportunities. The Paris Agreement (UNFCCC 2016, Article 6.2) recognizes internationally transferred mitigation outcomes across national governments. Countries needing prices lower than the floor price to meet their mitigation pledges could benefit from setting the floor price and selling internationally transferred mitigation outcomes at this price to other countries (for which the floor price would be insufficient to meet their pledge).

Ensuring sustained participation—sticks? Some authors have suggested that nonparticipants could be coerced into joining the agreement through trade sanctions (for example, Nordhaus 2015) or border carbon adjustments (levying charges on the unpriced carbon emissions embodied in imports from nonparticipant countries to match the domestic carbon tax). Ideally these penalties should account for progress on meeting mitigation commitments (through pricing and other measures) in nonparticipating countries. This approach would likely impose a considerable administrative burden.

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