Report of the High-Level Commission on Carbon Prices

CARBON PRICING
LEADERSHIP COALITION

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This booklet contains the overview of the Report of the High Level Commission on Carbon Pricing. A PDF of the final, full-length book is available at https://www.carbonpricingleadership.org. Please use the final version of the book for citation, reproduction, and adaptation purposes.

THE COMMISSION: OBJECTIVES

During the 22nd Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) held in Marrakech, Morocco, in 2016, at the invitation of the Co-Chairs of the Carbon Pricing Leadership Coalition (CPLC) High-Level Assembly, Ségolène Royal and Feike Sijbesma, Joseph Stiglitz, Nobel Laureate in Economics, and Lord Nicholas Stern, accepted to chair a new High-Level Commission on Carbon Prices comprising economists, and climate change and energy specialists from all over the world, to help spur successful implementation of the Paris Agreement.

The Commission's objective is to identify indicative corridors of carbon prices that can be used to guide the design of carbon-pricing instruments and other climate policies, regulations, and measures to incentivize bold climate action and stimulate learning and innovation to deliver on the ambition of the Paris Agreement and support the achievement of the Sustainable Development Goals.

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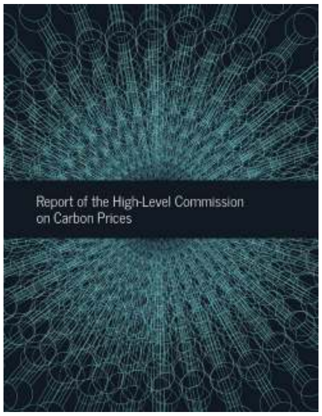
ACRONYMS

CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CDP	Carbon Disclosure Project
CDM	Clean Development Mechanism
COP	Conference of the Parties
CPLC	Carbon Pricing Leadership Coalition
DDPP	Deep Decarbonization Pathways Project
EMF	Energy Modeling Forum
ETS	Emissions Trading System
EU	European Union
GHG	Greenhouse Gas
$GtCO_2e$	Giga (metric) tons of Carbon Dioxide equivalent
HDI	Human Development Index
IAM	Integrated Assessment Model
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
IPCC	International Panel on Climate Change
MDB	Multilateral Development Bank
MW	Megawatt
NDC	Nationally Determined Contribution
PMR	Partnership for Market Readiness
PPP	Purchasing Power Parity
R&D	Research and Development
SDG	Sustainable Development Goal
SSP	Shared Socioeconomic Pathway
tCO_2	(Metric) tons of Carbon Dioxide
tCO_2e	(Metric) tons of Carbon Dioxide equivalent
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

EXECUTIVE SUMMARY



The purpose of this Commission is to explore explicit carbon-pricing options and levels that would induce the change in behaviors—particularly in those driving the investments in infrastructure, technology, and equipment—needed to deliver on the temperature objective of the Paris Agreement, in a way that fosters economic growth and development, as expressed in the Sustainable Development Goals (SDGs). This report does not focus on the estimation and evaluation of the climate change impacts that would be avoided by reducing carbon emissions. While the Commission also covers other policies relevant and important to carbon-pricing design and delivery on the Paris agreement, its primary focus is on pricing.

This report has been prepared based on the Commission's assessment of the available evidence and literature as well as on its members' judgment, developed through their extensive international policy experience. While the commissioners are in broad agreement on the overall thrust of the arguments presented in the report, they may not necessarily support every single assertion and conclusion.

1. Tackling climate change is an urgent and fundamental challenge. At COP21 in Paris, in December 2015, nearly 200 countries agreed to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C." The goal of stabilizing the temperature increase well under 2°C is largely motivated by concerns over the immense potential scale of economic, social, and ecological damages that could result from the failure to manage climate change effectively. These temperature targets require a large-scale transformation in the structure of economic activity—including a major change in energy systems (especially power generation); industrial processes; space heating and cooling systems; transport and public transportation systems; urban forms; land use (including forests, grasslands, and agricultural land); and the behaviors of households. However, climate policies, if well designed and implemented, are consistent with growth, development, and poverty reduction. The transition to a low-carbon economy is potentially a powerful, attractive, and sustainable growth story, marked by higher resilience, more innovation, more livable cities, robust agriculture, and stronger ecosystems. To succeed, that is, to deliver efficiently and fully realize the potential benefits of climate policies, careful policy design is essential.

2. A well-designed carbon price is an indispensable part of a strategy for reducing emissions in an efficient way. Carbon prices are intended to incentivize the changes needed in investment, production, and consumption patterns, and to induce the kind of technological progress that can bring down future abatement costs. There are different ways to introduce a carbon price. Greenhouse gas

(GHG) emissions can be priced explicitly through a carbon tax or a cap-and-trade system. Carbon pricing can also be implemented by embedding notional prices in, among other things, financial instruments and incentives that foster low-carbon programs and projects. For instance, specific project-based credits, building upon the experience of the Clean Development Mechanism (CDM) of the Kyoto Protocol and on the mechanism established under Article 6 of the Paris Agreement, can provide similar incentives by applying a price to a unit of GHG emissions. Explicit carbon pricing can be usefully complemented by shadow pricing[1] in public sector activities and internal pricing in firms. Reducing fossil fuel subsidies is another essential step toward carbon pricing—in effect, these subsidies are similar to a *negative* emissions price. Governments can enhance the effectiveness of carbon pricing by establishing an enabling environment, building technical and institutional capacity, and establishing an appropriate regulatory framework. As carbon-pricing mechanisms take time to develop, countries should begin doing so immediately.

3. Achieving the Paris objectives will require all countries to implement climate policy packages.

These packages can include policies that complement carbon pricing and tackle market failures other than the GHG externality. These failures are related to knowledge spillovers, learning and R&D, information, capital markets, networks, and unpriced co-benefits of climate action (including reducing pollution and protecting ecosystems). Some countries may conclude that the carbon-pricing trajectories required, if carbon pricing were the sole or dominant instrument, could entail excessive distributional or adjustment costs. Others may conclude that, given the uncertainties, requirements for learning, and scale and urgency of the transformation, rapid and more equitable change could be achieved more efficiently and effectively in other ways. The design of these policies will thus vary and always have to take into account national and local circumstances.

International cooperation—including international support and financial transfers, carbon-price-based agreements, and public guarantees for low-carbon investments—to promote consistency of action across countries can help lower costs, prevent distortions in trade and capital flows, and facilitate the efficient reduction of emissions (as well as the achievement of other Paris Agreement objectives, such as those related to the "financial flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development").

4. The Commission explored multiple lines of evidence on the level of carbon pricing that would be consistent with achieving the temperature objective of the Paris Agreement, including technological roadmaps, analyses of national mitigation and development pathways, and global integrated assessment models, taking into account the strengths and limitations of these various information sources. Efficient carbon-price trajectories begin with a strong price signal in the present and a credible commitment to maintain prices high enough in the future to deliver the required changes. Relatively high prices today may be more effective in driving the needed changes and may not require large future increases, but they may also impose higher, short-term adjustment

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[1] *Shadow pricing*, the assignment of a dollar value to an unpriced commodity in a cost-benefit analysis or an impact assessment.

costs. In the medium to long term, explicit price trajectories may need to be adjusted based on the experience with technology development and the responsiveness to policy. The policy dynamics should be designed to both induce learning and elicit a response to new knowledge and lessons learned. Price adjustment processes should be transparent to reduce the degree of policy uncertainty.

5. Explicit carbon-pricing instruments can raise revenue efficiently because they help overcome a key market failure: the climate externality. The revenue can be used to foster growth in an equitable way, by returning the revenue as household rebates, supporting poorer sections of the population, managing transitional changes, investing in low-carbon infrastructure, and fostering technological change. Ensuring revenue *neutrality* via transfers and reductions in other taxes could be a policy option. Policy decisions will need to duly take into account the country's objectives and specific circumstances, while keeping in mind the development objectives and commitments agreed in relation to the Paris Agreement objectives.

6. Carbon pricing by itself may not be sufficient to induce change at the pace and on the scale required for the Paris target to be met, and may need to be complemented by other well-designed policies tackling various market and government failures, as well as other imperfections. A combination of policies is likely to be more dynamically efficient and attractive than a single policy. These policies could include investing in public transportation infrastructure and urban planning; laying the groundwork for renewable-based power generation; introducing or raising efficiency standards, adapting city design, and land and forest management; investing in relevant R&D initiatives; and developing financial devices to reduce the risk-weighted capital costs of low-carbon technologies and projects. Adopting other cost-effective policies can mean that a given emission reduction may be induced with lower carbon prices than if those policies were absent.

Conclusion

Countries may choose different instruments to implement their climate policies, depending on national and local circumstances and on the support they receive. Based on industry and policy experience, and the literature reviewed, duly considering the respective strengths and limitations of these information sources, this Commission concludes that the explicit carbon-price level consistent with achieving the Paris temperature target is at least US$40–80/tCO$_2$ by 2020 and US$50–100/tCO$_2$ by 2030, provided a supportive policy environment is in place.

The implementation of carbon pricing would need to take into account the non-climate benefits of carbon pricing (such as the use of revenues derived from it), the local context, and the political economy (including the policy environment, adjustment costs, distributional impacts, and political and social acceptability of the carbon price). Depending on other particular policies implemented, a carbon price could have powerful co-benefits that go beyond climate, for instance, potential improvements in air pollution and congestion, the health of ecosystems, access to modern energy, and so on. Further, in a realistic context where domestic and international compensatory transfers are limited, imperfect, and costly, it is impossible to disregard distributional and ethical considerations when designing climate policies. In view of this, the appropriate carbon-price levels will vary across countries. In lower-income countries they may actually be lower than the ranges proposed here, partly because complementary actions may be less costly and the distributional and ethical issues may be more complex.

It is of vital importance to the effectiveness of climate policy, particularly carbon pricing, that future paths and policies be clear and credible. New data will emerge continually and new knowledge be generated, and these facts and lessons learned should be taken into account—indeed, carbon pricing should foster learning and technological progress. It will be important to monitor and regularly review the evolution of emissions, technological costs, and the pace of technological change and diffusion so that carbon prices can be adjusted, particularly upward, if actual prices fail to trigger the required changes. Policy adjustments should be made based on criteria that are transparent and sound: policies should be "predictably flexible." It is desirable that the carbon-price range across countries narrow over the long term, in a time frame that depends on several factors, including the extent of international support and financial transfers, and the degree of convergence in living standards across countries.

The temperature objective of the Paris Agreement is also achievable with lower near-term carbon prices than indicated above if needed to facilitate transitions; doing so would require stronger action through other policies and instruments and/or higher carbon prices later, and may increase the aggregate cost of the transition. The carbon pricing and complementarity measures indicated here are substantially stronger than those in place at present (85 percent of global emissions are currently not priced, and about three quarters of the emissions that are covered by a carbon price are priced below US\$10/tCO_2). This statement is consistent with the observation that the Nationally Determined Contributions (NDCs) for 2030 associated with the Paris Agreement represent emission reductions that are substantially smaller than those necessary for achieving the Paris target of "well below 2°C."

1 INTRODUCTION

At the 21st session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) held in Paris in December 2015, nearly 200 countries agreed to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C." The High-Level Commission was established by the Carbon Pricing Leadership Coalition (CPLC), with the remit of examining the role of carbon pricing in achieving the Paris objectives.

The goal of limiting the global temperature increase to well under 2°C is largely motivated by concerns over the immense potential scale of economic, social, and ecological damages that could result from the failure to manage climate change effectively. Unmanaged climate change could pose a grave threat to the well-being, socioeconomic development and prosperity, and economic growth and stability of societies, as well as to the overall goal of poverty reduction. It would create severe obstacles to the achievement of the medium- and longer-term objectives reflected in the Sustainable Development Goals (SDGs) (Stern 2006; Bhattacharya, Oppenheim, and Stern 2015; Bhattacharya et al. 2016; IPCC 2014a; Hallegatte et al. 2015; World Bank 2010; and World Bank 2015).

Natural disasters—intensified by climate change in many regions—threaten the infrastructure that is necessary to modern economic production and to provide basic and essential services such as education, clean drinking water, and access to energy. They can also wipe out poor people's decades of savings in an instant, and often force people to cope by reducing their food intake or health care expenditures, or by taking children out of school (Hallegatte et al. 2017). Sea level rise, storm surges, and salinization may ruin land used for agriculture or other purposes. These phenomena may make the world's coastal cities highly vulnerable or force them to invest heavily to protect themselves against coastal floods. And carbon emissions do not only affect the global climate, they also lead to ocean acidification, which affects marine ecosystems. All of these forces, in combination with higher temperatures, are likely to reduce overall agricultural yield and food production, thereby threatening food security in vulnerable regions (IPCC 2014a). Making matters even worse, the poor people living in poor countries will be the ones hit earliest and hardest.

While the impacts of climate change are already visible, both in developed and developing countries, the total potential impact to be felt in the later part of this century is much larger and could have a profound effect on our daily lives and livelihoods, among other things, where human settlement would still be possible. Unmanaged climate change could, over the next century, reverse the development gains of the last seven decades, possibly lead to large-scale migration and sustained and severe conflicts, and threaten the prosperity of countries at every income level.

The recognition of the immensity of the potential impacts was a key element of the international agreement reached in December 2015 that laid down the target of “well below 2°C.”

There is an urgency to act as only a limited carbon budget remains available to keep global temperature change well below 2°C. While greenhouse gases (GHGs) other than CO_2 also contribute to climate change, the anthropogenic temperature rise is largely caused by CO_2 emissions accumulated over time (IPCC 2013). What is more, the carbon budget once available to keep the global temperature increase below 1.5°C may already have been fully used up—and even to keep the temperature rise below 2°C, the remaining budget is at most a few decades of current emission levels, and close to the emissions associated with the remaining life of the existing energy infrastructure (Davis, Caldeira, and Matthews 2010; Pfeiffer et al. 2016; Rozenberg et al. 2015).

Achieving the Paris Agreement temperature target requires a large-scale transformation of economic activity and the underlying systems. This includes major changes in the energy system (especially power generation), industrial processes, heating and transportation systems, urban forms, land use (including forests, grasslands, and agriculture), and the behavior of households. To stabilize the rise in temperature at any given level requires reducing net emissions to zero (or “balancing sources and sinks,” in the Paris Agreement language) in the second half of this century. The lower the targeted temperature increase, the sooner net emissions will have to reach zero. Achieving the broader Paris goals also requires increasing the ability to adapt to adverse climate change impacts, and making financial flows consistent with a pathway toward low-carbon emissions and climate-resilient development.

The global scenarios that achieve zero net emissions and maintain the temperature rise below 2°C *in a cost-effective way* show four parallel changes in the global economy, which involve the transformation of capital-intensive systems with long-lived assets (IDDRI and UNSDSN 2014; IEA 2014; Krey et al. 2014; Williams et al. 2012; Clarke et al. 2014; IPCC 2014c; Fay et al. 2015; NCE 2014, 2016, ETC 2017a, 2017b):

- ***Decarbonizing electricity production*** is necessary to stabilize climate change, through the use of either renewable energy or other zero-carbon forms of energy, or fossil fuels combined with carbon capture and sequestration/storage (CCS);
- ***Promoting electrification*** by increasing the use of carbon-free generated power, or (at least in a transition phase) switching to cleaner or zero-carbon fuels, is necessary in the housing, industry, and transport sectors;
- ***Enhancing efficiency***, by improving energy efficiency and reducing waste in all sectors (among others, manufacturing, services, agriculture, food consumption, residential energy use, and through reduced congestion in urban areas), contributes to reducing emissions and facilitates (and reduces the cost of) the transition to net-zero emissions;

- ***Optimizing landscapes***, by preserving and improving natural carbon sinks—through the creation of "climate-friendly" landscapes, the management of forests and other kinds of vegetation and soils, and changes in agricultural practices. This element is particularly important in countries where much of the emissions are linked to land use changes and is likely to play a critical role if negative emissions have to be achieved in the second part of this century.[2]

Current climate action is insufficient to achieve the main Paris Agreement objective. Further, as recognized in the Agreement, current plans or "Nationally Determined Contributions" (NDCs) up to 2030 fall substantially short of what is necessary. This explains the incorporation in the Agreement of the need to revise those plans by 2020 and raise ambitions for further reductions. All scenarios that are consistent with maintaining temperature rise "well below 2°C" and minimizing aggregate transition costs show emissions that are much lower than those reflected in current plans and trends.

The required action implies structural change, learning, experimentation, and technological changes, and involves large uncertainties. These uncertainties include those related to the availability and cost of various technologies (e.g., the availability of CCS at scale, at reasonable cost), the social and political acceptability of some technologies (e.g., nuclear energy or large-scale land mobilization for biofuel production), the quality of policies, and possible changes in consumption patterns or social norms (e.g., related to transportation or the human diet and meat consumption). Climate policies cannot be assessed in a static context where technologies and socioeconomic conditions are fixed. By contrast, dynamic processes such as learning-by-doing, innovation in technology and institutions, and long-term changes in norms and behaviors will play a key role. The vital importance of these issues and the uncertainty they embody must influence any assessment. They also make formal, large-scale modeling very challenging, as these aspects are difficult to capture in formulas. As a result, many attempts at formal modeling have proved misleading, in the sense that they omit many important opportunities and issues, particularly around economies of scale and changing technologies and methods.

The central role of learning, knowledge generation, and innovation, together with these uncertainties, means that policy design will have to be dynamic and adaptive (O'Brien and Selboe 2015; Kunreuther et al. 2014; Lempert and Schlesinger 2000). In particular, the impact of policies needs to be closely monitored over time and the policies have to be revised if they appear to be failing (that is, do not reduce emissions enough) or entailing unacceptable costs (e.g., threaten food security). But the criteria for revision should be clear and transparent to avoid unnecessary uncertainty, as this could inhibit investments.

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[2] Negative emissions can be achieved by removing GHG from the atmosphere through air capture (which is inherently costly), or to a limited extent through biological methods: afforestation or the use of biofuels in power plants with carbon capture and sequestration. Negative emissions could permit net reduction in the concentration of GHG in the atmosphere over time, and/or the achievement of net-zero (or net-negative) global emissions, even with positive emissions in some sectors, regions, or countries that are difficult to decarbonize.

However, climate policies, if well designed and implemented, are consistent with growth, development, and poverty reduction. To succeed, that is, to deliver efficiently and fully realize the potential benefits of carbon pricing, careful policy design is essential. Achieving the Paris objectives will require all countries to implement climate policy packages, which should include multiple policies and instruments. While the design of these packages will vary, based on national and local circumstances, a well-designed carbon-pricing system is an indispensable part of a strategy for reducing emissions in an efficient way. Many have argued that the *transition to a low-carbon economy is a powerful growth story*. In the medium term, it can be a strong driver of discovery, innovation, and investment (Stern 2015b); in the shorter term, the necessary investments in sustainable infrastructure could be a key driver of growth (Abiad, Furceri, and Topalova 2014; IMF 2014). And in the longer term, any extended attempt at high-carbon development could create an environment hostile to global growth, threatening to undermine future development gains or even reverse past ones. There are strong arguments supporting the assertion that some of the key features of low-carbon growth (such as less pollution, less congestion, greater efficiency, and more robust ecosystems) are in and of themselves very attractive (NCE 2014; World Bank 2012).

The purpose of this Commission is to explore explicit carbon-pricing options and levels that would induce the change in behaviors—particularly in those driving the investments in infrastructure, technology, plants, and equipment—needed to deliver on the temperature objectives of the Paris Agreement, in a way that fosters economic growth and development, as expressed in the Sustainable Development Goals, among others. This report does not focus on the estimation and evaluation of the climate change impacts that would be avoided by reducing carbon emissions. While the Commission, unavoidably, also covers other policies relevant and important to carbon-pricing design and delivery on the Paris Agreement, its primary focus is on pricing. As was the case of the Paris Agreement of December 2015, the analysis is set in the context of the multiple objectives of the international community, including those related to economic growth and to development and poverty reduction, particularly the Sustainable Development Goals agreed at the United Nations in September 2015.

This report's conclusions represent a judgment on the relevant evidence critically reviewed and assessed by the Commission as a whole. The analysis and conclusions are based on the Commission's assessment of the information and literature available as well as on its members' judgment, developed through their extensive international policy experience. While the commissioners are in broad agreement with the overall thrust of the arguments presented in the report, they do not necessarily support every individual element or formulation.

2 CARBON PRICING: INDISPENSABLE FOR REDUCING EMISSIONS IN AN EFFICIENT WAY

A well-designed carbon price is an indispensable part of a strategy for reducing emissions in an effective and cost-efficient way. Carbon prices incentivize low-cost abatement options and can equalize marginal abatement costs[3] across the sources and sectors to which the carbon price applies. They do so by creating incentives for markets to use all levers available to reduce emissions: the type of activity pursued, the structure and energy intensity of a particular industry or of the economy as a whole, and the type of fuel chosen.[4]

Carbon pricing can apply to all GHGs. The carbon price is generally normalized to the amount of GHG that would lead to the same equivalent warming as a ton of CO_2 over a specific period, and is specified as a price per ton of CO_2e (or CO_2 equivalent). The time period considered can alter the relative penalty on emission of different GHGs (IPCC 2013, 2014c).

Carbon prices encourage producers to decrease the carbon intensity of the energy sector and manufactured products, and consumers to choose less carbon-intensive goods. More specifically, they encourage a shift to less carbon-intensive goods (such as public transportation) and enhance the efficient use of existing systems (e.g., through carpooling and eco-driving). They also promote the adoption and diffusion of existing abatement technologies, and redirect investment toward cleaner alternatives (such as more efficient cars).

By creating opportunities to increase profitability or save money through the reduction of GHG emissions, carbon pricing also promotes innovation and incentivizes the generation of new ideas and solutions. Pricing carbon can help drive innovation in technologies and business models that can reduce carbon emissions and promote resource efficiency, and thus boost productivity improvements. As the development of green technology often requires ongoing investments, some economists consider the potential of carbon pricing to help “kick-start” cleaner energy industries (Aghion, Veugelers, and Hemous 2009).

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[3] The *marginal abatement cost* reflects the cost of one additional unit or ton of pollution that is abated, or not emitted.

[4] Under certain simple conditions, a carbon price ensures that firms equalize marginal abatement costs across different ways of reducing emissions, a necessary condition for an efficient transition (Nordhaus 1991; Pearce 1991; Pigou 1932). On the other hand, as we emphasize below, for a variety of reasons, it will generally be desirable to accompany carbon pricing with other measures. For instance, when faced with a lack of relevant knowledge and information, imperfect capital markets, and other imperfections, even a high carbon price may not lead to the most efficient long-term capital technologies being chosen. Advances in behavioral economics and theories of policy in imperfect markets have underscored the limitations of traditional economic models. In this context, efforts should be directed at developing a dynamic economics of public policy.

A carbon price can be introduced "upstream," thereby affecting the full supply chain of products without requiring tracking all emitting activities or measuring the carbon emissions embedded in goods and services. In energy-importing countries such as Morocco, where 90 percent of the energy and roughly all of the fossil fuels are imported, tax collection can be accomplished by merely monitoring the ports of entry, making a carbon tax easier to administer and enforce than other mitigation instruments or taxes.

2.1 Carbon-Pricing Options

Two main policy options are available for introducing an explicit carbon price in the economy. One option involves putting a price on carbon through a tax or fee on GHG emissions or the carbon content of fossil fuels. The second major option, known as a cap-and-trade scheme/system, limits the total allowable volume of emissions in a particular time period from a specified set of sources (the so-called cap on emissions), and allows economic actors to trade their emission rights.

If a cap-and-trade system functions well and emissions decline over time, GHG pollution will be reduced each year by a predictable amount, but the price at which the emission rights trade will be uncertain. The price of carbon in a cap-and-trade system can be hard to predict because the volume of emissions fluctuates for many reasons, such as varying economic growth rates and fossil fuel prices. Policy makers can narrow down the potential range of the price of carbon in a cap-and-trade system by allowing the banking and/or borrowing of emission rights over time; setting a floor price for auctioned emission rights; offering more emission rights to polluters if prices rise too much; or by making ex post cap adjustments (Wang, Jotzo, and Qi 2017). These mechanisms have proven their efficacy: analysts suggest that the drop in the European Union (EU) Emissions Trading System (ETS) emissions (by 2.4 percent in 2016) was primarily driven by the carbon-price floor introduced in the United Kingdom, where a £18/tCO_2 top-up on the EU ETS price resulted in the coal power plants reducing their emissions by 58 percent in 2016.[5]

A carbon tax requires economic actors to pay for every ton of GHGs released into the atmosphere, usually at a fixed price in any given year. Carbon taxes are generally easier to administer than a cap-and-trade system because they neither involve a market-based trading system nor require enforcing rules to prevent market manipulation. Moreover, they can be built on existing taxes (such as a fuel excise tax) and economic actors can predict their estimated liabilities reasonably well. Similarly, entrepreneurs who invest in low-GHG technologies can anticipate the market advantage of their products relative to their dirtier competitors. That said, in a world of uncertainties, a carbon tax does not guarantee hitting a particular emissions target in any given year. However, since the objective should be to ensure that the concentration of GHGs in the atmosphere does not exceed a specific level, what matters are the *cumulative* emissions—the year-to-year emissions are not of great concern in themselves. A carbon tax guarantees a maximum cost per unit of pollution in the sectors

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[5] European Commission data on 2016 emissions data (https://ec.europa.eu/clima/policies/ets/registry_en#tab-0-1), accessed April 2017.

covered by it. If a carbon tax underperforms environmentally, policy makers can raise the tax or design it in a way that it will rise automatically in response to emission trends (Metcalf 2008; Aldy 2017).

Carbon tax and cap-and-trade systems have at times existed side by side in one and the same country. Both options are usually combined with complementary policies. The latter may include establishing norms for recommended emission levels or technical production guidelines that encourage producers to decrease the carbon intensity of their production processes. As these policies create a constraint (and a cost) for economic actors, they are sometimes interpreted as an *implicit* price of carbon. The combination of instruments—either multiple pricing systems or a mix of prices and complementary policies—may create synergies or weaken each other, depending on the specific design. These interactions need to be considered and managed carefully, and may influence the selection of instruments.[6]

Carbon pricing can also be implemented by embedding notional prices in, for example, financial instruments that reduce the capital costs of low-carbon programs and projects (compared with other, more carbon-intensive programs and projects). Because energy-efficient power generation and renewable energy often involve higher upfront costs and larger uncertainties (than traditional energy sources), the relatively high capital costs tend to encourage the use of fossil fuels. To achieve a given degree of decarbonization, countries with relatively high capital costs need to impose a higher price on carbon emissions than countries with lower capital costs (see section 4.2.1 for examples of how capital costs influence the carbon price required). This aspect is particularly important for developing and emerging economies, where capital costs tend to be higher than in rich countries (Hirth and Steckel 2016; De Gouvello and Zelenko 2010).

Countries can use financial instruments to reduce the upfront costs of mitigation actions, using tools such as public guarantees and other risk-reducing instruments; feebates;[7] and interest rate subsidies and tax breaks for low-carbon investments. These complementary policies can be defined based on an agreed carbon value (which can include both climate and non-climate considerations, see appendix B), which can help reduce the risk of arbitrariness and ensure economic efficiency. For instance, one option is to lower the risk-weighted capital cost of low-carbon investments in proportion to the present value of the carbon value attached to a given project (Hourcade, Perrissin-Fabert, and Rozenberg 2012). While these financial instruments can be used to implement a carbon price expressed as a monetary value (US\$/tCO_2), either as a standalone policy or as a complement to explicit carbon pricing, they can only be applied to new investments and thus do not affect *existing* assets (for instance, feebates for cars can influence the fleet composition and reduce GHG emissions from new cars, but they do not create an incentive to reduce the distance traveled by old cars, as does carbon pricing). The fact that these instruments do not affect existing assets makes them less effective than carbon pricing, but potentially more acceptable politically and socially (Rozenberg, Vogt-Schilb, and

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[6] For instance, support to renewable energy reduces the price of emission rights in a cap-and-trade system. In general, the exogenous price of a carbon tax makes it easier to avoid problematic interactions with other climate policies than with the endogenous price in a cap-and-trade system (Goulder and Schein 2013).

[7] Feebate, a system of charges and rebates whereby energy-efficient or environmentally friendly practices are rewarded, while failure to adhere to such practices is penalized (see also section 6.2.)

Hallegatte 2014). As discussed in section 3.2., these instruments can also be used to foster international coordination, for instance, through the Article 6 mechanism of the Paris Agreement, which extends the experience of the Clean Development Mechanism (CDM) of the Kyoto Protocol. The presence of a multilateral or national development bank in a program can itself reduce political risk and the cost of capital. Given the right mix of instruments (including guarantees and equity), a development bank can also help manage risk, which can be acute in the early stages, and therefore help bring in private sector capital as well as act as a convener (see section 6.2).

Explicit carbon pricing can be usefully complemented by shadow pricing in public sector activities and internal pricing in firms. Governments, firms, and institutions often use shadow carbon pricing to help reorient investment decisions, anticipate future pricing or future changes in the carbon price, or account for indirect impacts on emissions (e.g., when public infrastructure investments affect emissions). The United Kingdom adopted the use of a shadow price for carbon in 2007 as the basis for incorporating carbon emissions in cost-benefit analyses and impact assessments. Institutional investors and lenders often incorporate a shadow carbon price into their environmental impact assessments and cost-benefit analyses as well. For instance, the European Investment Bank uses a shadow carbon price as a "non-financial value-added" in its cost-benefit analysis of projects. The World Bank employs a shadow price (referred to as the "social value of carbon") for use in the economic analysis of its operations and projects. Shadow pricing is increasingly becoming a common corporate practice—businesses have started setting internal shadow carbon prices to help guide decisions for a cleaner future (see section 2.4). Carbon-pricing policies can be implemented alongside these shadow carbon prices.

2.2 The Importance of Fossil Fuel Subsidies

Reducing fossil fuel subsidies is also part of carbon pricing—in effect, these subsidies act like a negative emissions price. According to the International Energy Agency (IEA), total fossil fuel subsidies in 40 (mostly developing) countries reached US$548 billion in 2013, or 5 percent of GDP and 25–30 percent of government revenues (IEA 2014). The OECD estimates that its member countries spent US$55–90 billion a year subsidizing fuels in the period 2005–11 (OECD 2013). In a more recent assessment covering most countries in the world, IMF estimates suggest that fiscal fossil fuel subsidies reached US$650 billion in 2015 (Coady et al. 2016). If unpriced pollution and other externalities associated with the use of fossil fuels are regarded as implicit subsidies, then overall post-tax subsidies can be estimated at over US$5 trillion per year (Coady et al. 2016).

Fossil fuel subsidies discourage investments in clean energy and energy efficiency, tilting the balance in favor of fossil fuels and making it difficult for renewable energy and energy-efficient equipment to compete. This is particularly obvious in the Middle East, where oil and gas subsidies reduce electricity prices to 30–45 percent of what they would be if full reference prices were paid (Fay et al. 2015). Electricity generation from oil is currently one of the lowest-cost options in the Middle East, but would be more expensive than wind, photovoltaic (PV), and even concentrated solar power, absent the subsidies. A number of countries find themselves subsidizing both fossil fuels and renewables—and sometimes even taxing carbon. An important component of achieving global temperature targets is the removal of such perverse policy incentives. Removing fossil fuel subsidies and distributing the resulting budget savings in the form of lump sum cash transfers would improve the situation of poor people (Arze del Granado, Coady, and Gillingham 2012), and the resources freed by the reform could be used for other policy goals or growth-enhancing investments (see chapter 5).

2.3 Effective Carbon Pricing through an Enabling Environment

The experience of the World Bank's Partnership for Market Readiness (PMR) shows that **developing "readiness" for carbon pricing requires both political leadership and technical/institutional readiness to advance the carbon-pricing agenda at the domestic level.** For many countries, the decision-making process surrounding the choice of an appropriate carbon-pricing approach is indeed an extensive and politically sensitive endeavor.

Carbon pricing is easier to implement if an enabling environment and an appropriate regulatory framework exist. Critical preparation steps for a carbon-pricing system include the following: setting the scope of the instruments (i.e., defining the sectors and GHGs to be priced—there may be some sectors and GHGs where direct regulation may be either an easier or more effective way of reducing emissions); collecting robust emissions data; and determining the ambition of the instruments, in line with the jurisdiction's overall climate change mitigation objectives, and how best to recycle the revenue from carbon taxes or auctioned emission rights. Once carbon-pricing instruments are in place and become effective, governments need to directly tackle implementation challenges related to the review and refinement of instruments. Some countries implementing carbon pricing will require more capacity and longer preparation than others, and the local institutional capacity and legal framework will influence the choice of instruments to price carbon. In particular, a carbon tax can rely on existing fiscal tools and institutions, and is simpler and quicker to implement than cap-and-trade systems, which require the creation of appropriate systems and institutions, and raising awareness and capacity in the private sector. Like all tax systems (see Mankiw, Weinzierl, and Yagan 2009), carbon-pricing schemes may show significant departures from the theoretically optimal setting and it is very important to apply learning and new knowledge to continuously improve these systems.

Continuous engagement with stakeholder groups—to understand and address their respective concerns—is also critical to avoiding policy misalignment (e.g., between energy market regulation and climate policy, see OECD 2015) and ensuring public and political support as well as encouraging collaboration between government and market players. While this process takes time and resources, it helps ensure the long-term credibility and sustainability of carbon pricing and reduces policy uncertainty, which is a key obstacle to investments in a low-carbon future. Carbon-pricing readiness can have benefits other than emission reductions, as improvements in technical and institutional capacity entail crosscutting benefits that can support other climate and development policy objectives beyond the implementation of a given emission-pricing instrument. This is particularly true when it comes to efforts to establish credible, compatible, and consistent standards and approaches for GHG mitigation (e.g., for data management and Monitoring, Reporting, and Verification (MRV) systems), and for economic and policy analysis that informs the selection, introduction, and future refinement of a carbon-pricing instrument.

2.4 Private Sector Gearing Up for Carbon Pricing[8]

Parts of the private sector are preparing for a future in which governments will put a price on carbon. In fact, many corporations have already introduced internal carbon prices in their decision making, but the private sector as a whole has not yet priced carbon at the rate and breadth required. Companies have three main rationales to adopt an internal carbon price. First, it incentivizes actors within a firm to reallocate resources toward low-carbon activities, and helps firms prepare for a future where carbon emissions are priced. Assigning a carbon cost to investment options creates a clear business case for innovation and for making changes toward reduced emissions. Second, it can be used to drive R&D investments, a priority for companies seeking to cut emissions from their manufacturing process and attract new business from customers interested in low-carbon, low-cost solutions. Lastly, assigning a financial value to both emitted and avoided volumes of CO_2 emissions helps reveal the hidden risks and opportunities in a company's operations and supply chain. This is particularly relevant for companies that have to navigate an array of carbon-pricing regulations because their operations span multiple countries.

In addition, investors are increasingly demanding comprehensive climate disclosure—including the assurance that companies are adequately lowering their risk exposure to policies that place a price on carbon and reallocating capital toward areas of their business that will see a higher return in a low-carbon economy. Transparency on the carbon footprint of firms and investments has been promoted by Mark Carney, as Governor of the Bank of England and Chairman of the G20's Financial Stability Board, the Carbon Disclosure Project (CDP), and the Task Force on Climate-Related Financial Disclosure. It is critical to increase awareness and help investors and consumers make decisions that account for their contribution to climate change and their exposure to climate policies.

Disclosures to the CDP in 2016 capture the corporate response: 517 companies are already using internal carbon prices as an accounting and risk management tool (which represents a 19 percent increase with respect to 2015), and an additional 732 companies have revealed plans to adopt an internal carbon price by 2018 (a 26 percent increase with respect to 2015) (CDP 2016). CDP reports that 147 companies are embedding an internal carbon price ever deeper within their business strategies and across their operations in order to take tangible action on climate change. A subset of 37 companies describe a variety of ways in which this tool has directly affected their budget allocations or investment decisions, which has resulted in tangible changes.

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[8] This section is from CDP (2016).

3 CLIMATE POLICY PACKAGES: KEY TO ACHIEVING THE PARIS TEMPERATURE OBJECTIVE

3.1 Government and Market Failures Other Than GHG Externalities

To tackle climate change efficiently, market and government failures other than the climate externality need to be considered (Fay et al. 2015; Stern 2015a). More specifically, the following aspects should be duly addressed:

- ***Knowledge spillovers.*** Decarbonization requires drastically different technologies and knowledge spillovers represent a key market failure: not realizing the *social* benefits of such spillovers can impair or slow down the development of decarbonizing technologies. Knowledge is always, to some extent, a public good, and companies that invest in R&D into low-carbon technologies are therefore unable to capture the entire return of their investment (Jaffe, Newell, and Stavins 2005). Thus, in the absence of public support, private investments in knowledge and R&D will be below their optimum levels. Economies of scale, sunk costs, and the path dependency of research also give the established technologies (Acemoglu et al. 2012) an advantage, create entry barriers (Stiglitz et al. 2014), and possibly slow down the transition toward a zero-carbon economy.

- ***Incomplete and imperfect capital markets.*** Finance is a key requirement for the kind of innovation and investments needed to achieve the objectives of the Paris Agreement (NCE 2014; Gupta et al. 2014; Kennedy and Corfee-Morlot 2013; Fay et al. 2015). Governments in both developed and developing countries already struggle to finance infrastructure projects, and firms and households in developing countries are chronically credit-constrained. Plagued by incomplete financial and risk markets, innovative or large-infrastructure projects often struggle to secure the necessary funding, even when they are competitive. And the capital required to transition to low-carbon futures often faces large uncertainties, political risks, illiquid assets, and solid returns in the long term only. Aside from the standard credit constraints, investors lack the knowledge and information necessary to assess the quality of innovative, low-carbon projects.

- ***Network effects and coordination failures.*** Technologies that are components of interlocked networks—as in the case of electric or plug-in vehicles and specific charging infrastructure—can be difficult to establish through market forces alone due to the high upfront costs and long-term risky returns, but also due to coordination failures (Grübler, Nakićenović, and Victor 1999). Increasing the share of renewable energy in the energy mix requires investments in robust power grids and large-scale (often international) coordination. The challenge when trying to support low-carbon technologies and systems such as electricity grids, public transportation, recycling, or broadband networks, lies in offering the appropriate combination of economic, fiscal, and financial incentives.

- ***Lack of information.*** Information about the energy efficiency or carbon content of a product or production process may not be available, making it difficult for economic agents to make informed decisions. Individuals may also just prefer to rely on simple rules of thumb rather than carefully process the available information, or they exhibit systematic cognitive or behavioral biases (Weber and Johnson 2011). For these reasons, information disclosure efforts are often seen as a key step toward getting individuals to adopt more socially desirable behaviors.

- ***Unpriced co-benefits.*** Various co-benefits—for instance, lower air pollution, improved health, higher energy security, and lower expenditures—increase the value of reducing GHG emissions for the society. Some of these co-benefits have a direct *financial translation* (such as savings from reduced fuel use) while others (such as better health or the preservation of biodiversity) cannot be directly and consensually assigned a monetary value. Moreover, there are second-order impacts, including the freeing of public resources for alternative uses, and positive macroeconomic impacts (such as growth and higher employment) associated with climate-related investments. The co-benefits of mitigation can be substantial and are therefore often an important element in analyses by policy makers. Observational and modeling studies indicate that 3 million premature deaths are attributable to ambient air pollution and 4.3 million premature deaths to household pollution (WHO 2016). The global average marginal co-benefits of avoided mortality are estimated at US\$50–380/tCO_2 (West et al. 2013). In 2011, the United Nations Environment Programme (UNEP) estimated that fast action to reduce emissions could avoid 52 million tons (or 1 to 4 percent) of crop losses per year (UNEP 2011). In a 2014 World Bank study, the annual co-benefits of sector policies aimed at stimulating a shift to clean technologies in six regions (the United States, China, the EU, India, Mexico, and Brazil) were estimated at US\$1.8–2.6 trillion in GDP growth (World Bank 2014). Bollen (2015) estimates that the economic value of co-benefits could be as high as 75 percent of total climate policy costs in the developing world. However, in many cases, the co-benefits are not monetized, quantified, or even identified by decision makers and businesses.

- ***Inability to commit and other government failures.*** The transition toward zero net emissions is a long-term process that will span decades and involve infrastructure and urban planning decisions whose impact will still be felt in decades to come. Providing the right incentive for these decisions is made more difficult by the fact that governments have very limited ability to make commitments spanning such long periods (Brunner, Flachsland, and Marschinski 2012; Helm, Hepburn, and Mash 2003)—as Australia's recent reversal on carbon taxes illustrates. Other government failures that may reduce the efficiency of climate policies are the lack of enforcement of regulations (see Nepstad et al. 2014, for an example in Brazil) and allowing the capture by interest groups (Chang 2006; Hallegatte, Fay, and Vogt-Schilb 2013; Rodrik 2014).

- ***Distributional and ethical considerations.*** Distributional and ethical aspects may also influence the design of climate policies (Jenkins 2014; Nemet et al. 2017; Harrison 2013; Fay et al. 2015; Stern 2015, 2014). The transition toward carbon neutrality implies that some sectors, activities, and technologies will be replaced by new ones that are more efficient or based on zero-carbon energy sources. This transformation cannot be realized without some negative impact on the owners and employees of energy-intensive sectors (e.g., the coal industry), and on specific groups such as fishermen (who depend on diesel fuel), farmers (who use diesel pumps for irrigation), and small and medium-sized enterprises. Carbon pricing will no doubt lead to higher energy prices, at least in the short term, which may affect consumers—especially by undermining universal access to modern energy, with potentially dire health effects (e.g., because of the use of biomass for cooking). In some countries, pressures from those who may lose because of decarbonization have succeeded in raising impediments to the use of more efficient, low-emission technologies.

  Norms regarding what would be a "fair" distribution of the negative effects of carbon pricing touch on difficult ethical issues and, in the context of climate change, these effects are particularly severe and can lead to catastrophic outcomes and loss of life on a major scale. Given the uncertainties around future climate trajectories, it is also important to incorporate considerations regarding temporal (intergenerational) ethics in social decision making.

  The higher the carbon price, the larger its distributional impacts will be. Opposition may be partially overcome by using some of the revenues from carbon pricing to provide grants or other benefits to those groups adversely affected by the policy (see chapter 5); unfortunately, perfect targeting of specific population groups is rarely possible. In some cases, the carbon price required to achieve the desired reduction in emissions may be very high and the ability to undertake offsetting measures relatively low. And offsetting distributional effects with *imperfect* targeting may introduce new distortions and inefficiencies. As we noted earlier, complementary measures (such as the requirement that all new, coal-fired electricity generating plants have a minimum of carbon storage capacity) may significantly reduce the carbon price required to reach the Paris goals and mitigate the distributional impacts.

These issues not only interact with each other, but also with the climate change externality (Lipsey and Lancaster 1956; Meade 1955; Atkinson and Stiglitz 2015; Diamond and Mirrlees 1971; Drèze and Stern 1990). **As a result, efficiency and equity considerations may demand that governments complement carbon pricing with other policies.** In fact, a climate policy package can target these multiple issues and account for the political economy of reforms. More specifically, climate policy packages may include:[9]

- ***Carbon pricing.*** As discussed above, a well-designed policy to price carbon and other GHGs is an indispensable part of a strategy for reducing emissions in an efficient way.

- ***Complementary policies.*** In general, other policies can be useful to complement the carbon-pricing

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[9] Other categories have been proposed, for instance, the *State and Trends or Carbon Pricing* Report (World Bank, Ecofys, and Vivid Economics 2016) uses the categories complementary, overlapping, and countervailing policies.

policy, especially in the context of other market failures and significant distributional impacts that are not easily compensated.

- ***Facilitating policies.*** To make climate action sustainable, action is needed to manage the distributional impacts and make the required climate policies socially and politically acceptable.

3.2 Country Policy Design: A Reflection of National and Local Circumstances

In a simple *theoretical* setting, assuming the possibility of unlimited and lump sum international transfers (i.e., transfers that would not affect the incentives of consumers, producers, and other economic agents) and in the absence of other relevant market failures, it is possible to separate the question of where emission reductions should take place and who should pay for them, and therefore to separate global efficiency from distributional considerations. Considering global climate objectives in such a setting, it would be optimal to seize the lowest-cost opportunities to reduce emissions first, regardless of their geographic location, through a carbon price that is uniform across countries. The resulting unequal distribution of mitigation efforts could then be corrected through transfers. (These transfers could also be achieved through the appropriate distribution of emission rights in a global carbon market.) In this case, the high elasticity of emissions typical of low-income countries (i.e., the existence of cheap emission reduction potentials) would lead to large reductions in these countries, compensated by large financial transfers from the rich to the poorer countries to pay for these reductions.

In a more realistic setting, such unlimited lump sum transfers are impossible and, as a result, efficiency and equity cannot be separated, nor can distributional and ethical considerations as well as other market failures be ignored when deciding where emission reductions should be implemented first. In such a situation (as shown in Chichilnisky and Heal 1994; Chichilnisky, Heal, and Starrett 2000), it is optimal for carbon prices to differ across countries.

With constrained transfers, there are two (interlinked) reasons why lower-income countries may choose lower carbon prices than high-income countries: (1) low-income countries tend to have less ambitious objectives for emission reductions; and (2) low-income countries tend to require a lower carbon price to achieve a given level of emission reductions.

First, climate policies need to be designed in a way that supports continued development and poverty reduction. Well-designed climate policies are compatible with development and poverty reduction. And recent technology development and policy instruments create some opportunities for low-income countries to benefit from low- or zero-carbon technologies and leapfrog fossil fuel technologies. For instance, small-scale solar energy and mini grids offer new opportunities to provide modern energy to low-density, remote rural areas, at a much lower price than gridded electricity or small-scale diesel generators. And since developing countries are building their energy infrastructure at present, they have the opportunity to build it in an efficient and low-carbon way at a moderately higher cost, rather than having to pay for costly retrofitting (Fay et al. 2015; NCE 2014; Stern 2015a).

Building low-carbon energy infrastructure also allows avoiding some of the negative side effects of fossil-based development, such as the local air pollution that is observed in many cities of emerging economies and kills millions each year.

When and where trade-offs between development and emission reductions exist, the imperative of development and poverty reduction may justify slower and more moderate emission reductions over the short term (Fleurbaey et al. 2014; Kolstad et al. 2014; Knopf et al. 2012; Stern 2014; and Agrawal and Narain 1991). In other words, these countries could do less to reduce their emissions in the short term to ensure rapid poverty reduction (which does not mean that they should do nothing; in particular, they have an interest in avoiding a costly lock-in in carbon dependency; see Avner, Hallegatte, and Rentschler 2014; Vogt-Schilb, Meunier, and Hallegatte 2014). Indeed, even if poor countries have cheaper emission reduction options, a similar amount of emission reductions in a low-income country may have a higher economic and welfare cost than in a higher-income country for the following reasons:

- The opportunity cost of consumption is higher in poor countries. Poor people have a higher marginal utility of consumption and losing a given amount of consumption means more to them than to wealthier individuals (Harberger 1984; Fleurbaey and Hammond 2004).
- Developing countries are at a development stage in which they are building their infrastructures and are still very dependent on energy-intensive industries like cement, steel, aluminum, and nonferrous and basic chemicals. Higher production costs in these sectors propagate throughout the economic system and generate higher costs in the manufacturing and services sectors, which may have negative repercussions for the overall social welfare of these countries (Crassous, Hourcade, and Sassi 2006; Luderer et al. 2012)
- Some substitution options may be unavailable in poor countries due to incomplete markets and market and government failures. For instance, a low-income country closing a coal power plant or not investing in it to reduce emissions may have more trouble replacing the power generation gap with renewables if the policy and political environment makes investment in renewable energy more expensive or less attractive to investors than in a richer country.

Lifting the poor out of poverty need not increase emissions significantly and poverty reduction can benefit from low-carbon investments and renewable energy (Tait and Winkler 2012; Hallegatte et al. 2015; IPCC 2014c). Since the Industrial Revolution, the largest share of GHG emissions has been derived from the industrialization of developed countries. Over the last few decades, total cumulative CO_2 emissions have increased by a factor of two—from about 910 $GtCO_2$ in the period 1750–1970 to about 2,000 $GtCO_2$ in the period 1750–2010 (IPCC 2014c). Regional patterns of GHG emissions are shifting along with changes in the world economy (ibid). Emissions associated with the activities of poor people account for a small share of global emissions (Chakravarty et al. 2009). Many recent studies support the idea that providing the extremely poor people with access to basic services would not jeopardize climate mitigation:

- Above a Human Development Index (HDI) of 0.8 (the threshold to be considered a developed country), carbon emissions and the HDI are decoupled (Steinberger and Roberts 2010).

- The IEA estimates that universal access to basic energy services by 2030 could be achieved by increasing electricity consumption by 2.5 percent, and fossil fuel consumption by 0.8 percent only (IEA 2011).
- The World Development Report 2010 estimates that the additional emissions that would be generated to provide universal access to electricity in 2010 could be offset by switching the standards of the United States vehicle fleet to European standards (World Bank 2010).

Energy poverty is a major development and poverty issue—lack of access to energy has a significant impact on economic and social development and on poverty, among others, through indoor pollution and its impacts, especially on women and children. Investments in renewable energy and energy efficiency can tackle this challenge, reduce the energy expenditures of the poor, and simultaneously reduce GHG emissions, which further contribute to the particularly high health costs in these countries (World Bank 2012a).

Second, even if low-income and higher-income countries aim for similar emission reductions (in relative terms), such reductions may be achieved with lower carbon prices in low-income countries. This is in part linked to the availability of cheaper emission reduction options and the higher price elasticity of emissions in low-income countries. A given carbon price (translated to local currency based on market exchange rates) will also be equivalent to a higher local price in poorer countries, since the Purchasing Power Parity (PPP)[10] exchange rates are usually higher than the market exchange rates (for instance, by a factor of 1.8 in China and Brazil, 3.8 in India, and 2.3 in South Africa).[11] The Deep Decarbonization Pathways Project (DDPP)[12] shows that pathways compatible with the objectives of the Paris Agreement usually show lower carbon prices for lower-income countries, partly because of a stronger behavioral response of poor economic agents to a given carbon-price level. However, higher capital costs in developing countries act in the opposite direction.

And, even if low-income countries and higher-income countries impose the same effective carbon price on their economies, the balance between explicit pricing and implicit pricing may be different in these two country categories. Given the concerns over distributional impacts and market failures (see section 3.1), countries may conclude that rapid and equitable changes can be achieved more efficiently and effectively with instruments other than an explicit carbon price. In particular, some policies—such as notional carbon prices embedded in subsidies, public guarantees and other forms of financial devices for renewables or energy efficiency, and performance standards for cars and buildings—do not make carbon emitters pay a fee for their emissions, but they still impose a cost on them, which can be interpreted as an implicit carbon price. The much larger market failures and constraints found in low-income countries can push their policy makers toward a stronger use of policies that put implicit prices on carbon, which makes it possible to achieve a similar emission reduction with a lower explicit carbon price.

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[10] The *Purchasing power parity* (PPP) exchange rates are those that equalize the currency purchasing power in each of two countries compared. This means that the exchange rate between two countries should equal the ratio of the two countries' price level of a fixed basket of goods and services.

[11] World Development Indicators (http://data.worldbank.org/data-catalog/world-development-indicators), World Bank. Accessed: April 2017

[12] The Deep Decarbonization Pathways Project (DDPP) is a global collaboration of energy research teams charting practical pathways to deeply reduce GHG emissions in their own countries; see the background paper prepared by the DDPP for this report (DDPP 2017).

Furthermore, in developing countries, a climate-centric perspective focused on the carbon price as the only driver of transformation fails to capture the broad set of potential complementarities between the climate and other sustainable development objectives. The Indian DDPP team (Shukla et al. 2015) considered the role of carbon prices from the broader perspective of the integrated social, economic, and environmental value of mitigation. It shows the extent to which well-designed land use policies, transport infrastructure, urban planning legislation and development, building codes, education, technology substitution, and investment flows can deliver the same level of cumulative carbon emission reductions with a much lower carbon price.[13]

Finally, the decision on the appropriate value needs to take into account the benefits that can be generated by carbon pricing, aside from the reduction in carbon emissions. For instance, as discussed in chapter 5, the appropriate value for an explicit carbon price may be higher where it promotes efficiency and growth, for instance, because carbon-pricing revenues can be used to reduce other distortive taxes (Goulder 2013), improve the efficiency and fairness of the fiscal system (Liu 2013; Bento, Jacobsen, and Liu 2013), and finance public goods such as infrastructure, education, or health (Edenhofer et al. 2015; Franks, Edenhofer, and Lessmann 2015; Hallegatte et al. 2015).

Emission reductions may seem more profitable when considering their co-benefits, such as reduced air pollution and improved human health (West et al. 2013; Dubash and Joseph 2015). These considerations will affect both the ambitions of emission reductions in a given country (e.g., a country may decide to further reduce emissions to reduce local air pollution) and the appropriate balance between explicit and implicit pricing (e.g., a country may decide to increase the explicit price because the latter helps close its infrastructure financing gap). The benefits and co-benefits of climate action may be aggregated into a Social Value of Mitigation Action (or SVMA, see appendix B).

And many other characteristics will influence a country's decisions regarding explicit carbon pricing and the design of climate policies: resource endowments (e.g., geothermal energy), climate conditions (e.g., solar and wind potential), and the ability to innovate are important additional factors that need to be considered.

3.3 Dynamic and Adaptive Climate Policy Designs

Carbon prices are intended to incentivize the kind of changes needed in investment, production, and consumption patterns, and induce the pace and scale of technological progress that will bring down future abatement costs (NCE 2014). Higher prices today may be more effective in driving the needed changes and may not require large future increases, but they may also impose higher short-term adjustments costs. In the medium to longer term, explicit price trajectories may need to be adjusted, based on the experience of technology development and economic actors' responsiveness to policy. The policy dynamics should be designed to induce learning and should respond to new knowledge.

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[13] The study does not make any conclusions regarding the aggregate efficiency of these different policy options.

The uncertainties around the carbon-price trajectories that are consistent with a 2°C target imply that policies will have to involve experimentation, be closely monitored over time, and revised when they seem to fail (that is, do not reduce emissions enough) or impose unacceptable costs (e.g., threaten food security). Carbon prices will have to be designed accordingly—based on predefined targets—and be revised over time as new information becomes available on the speed with which different targets can be reached (Metcalf 2009; Aldy 2017) or the appropriateness of different targets. For instance, if new, low-carbon technologies become available at a competitive price in the electricity sector, the price of carbon could be reduced; on the other hand, the price may have to be increased if some technologies are found to be impractical. Similarly, if climate change impacts are larger than expected, or if our ability to adapt is lower than expected, policy ambition may have to increase.

The efficiency of carbon-price signals in changing behaviors and driving investments depends on the long-term credibility and predictability of those signals. Policy frameworks that deliver carbon prices to match environment goals need to encourage the business and financial sector to explore lower-carbon strategies. In this context, confidence in the basic direction of energy and climate policy is crucial. Redirecting major investments toward low-carbon options requires credible carbon-price pathways spanning several decades. For example, France revised its policies in November 2015 to introduce a carbon-price component that will reach 56€/tCO_2 by 2020 and 100€/tCO_2 by 2030. Creating confidence in future policies is difficult because it requires credible commitment from policy makers over the medium and long term (Helm, Hepburn, and Mash 2003; Brunner, Flachsland, and Marschinski 2012). However, it is possible to improve credibility through institutional change (for example, by creating an independent commission on climate change) or legal tools (such as climate legislation).

At the same time, some degree of flexibility and the ability to adjust carbon prices in line with new information on technologies or the impact of policies remain necessary. The announcement of price “corridors”—that is, price ranges that will prevail in the future—provides a way to balance commitments, high prices, and flexibility in policy making. Still, policy revisions will have to be based on transparent criteria (Canfin and Grandjean 2015; Canfin, Grandjean, and Mestrallet 2016). To bolster the long-term credibility of the price signal, it is critical to build strong political support across political lines, engage economic decision makers, and manage the pressure from interest groups and distributional issues. But most important of all may well be to choose a carbon-price trajectory that people believe will be politically durable.

3.4 International Cooperation to Promote Consistency of Actions across Countries

Climate change is a global externality, and thus can be best tackled globally. However, there is an increasing recognition that the transition to a low-carbon economy is not only appealing because of the climate change impacts that can be avoided, but also because of the benefits and co-benefits it generates locally (in the country, region, or cities that are taking abatement action), in the short term. This widespread recognition contributed to the success of COP21 in Paris and facilitates international cooperation.

Nevertheless, there is a risk that if any country fails to take active measures, or if carbon prices vary widely across countries, sectors with high levels of carbon emissions may relocate to countries with laxer policies. This phenomenon is referred to as "(carbon) leakage." At present, however, leakage cannot be observed, probably because the differences in energy prices and environmental regulations across countries are dominated by other factors such as labor and transport costs or other regulatory elements (Branger and Quirion 2013; Demailly and Quirion 2008; Sartor 2013). Yet leakage may become an issue as climate policies become stricter in some countries. Moreover, even if the quantitative effects are limited, the political consequences of plants and jobs moving to another jurisdiction because of its lower carbon price can be significant, and undermine support for strong carbon policies.

Carbon-pricing strategies both benefit from international cooperation and in turn reinforce that cooperation. International coordination and convergence of carbon prices over time can prevent leakage and ensure efficiency across regions. Cooperation—among others, through international transfers—can help lower the overall cost of reducing emissions, prevent distortions in trade and capital flows, and facilitate the efficient reduction of emissions (as well as the achievement of other Paris Agreement objectives, such as those related to the "financial flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development").

International cooperation requires credible mutual commitments and stable incentive structures. If countries perceive that their own efforts are not being matched by corresponding climate policies in other countries, the willingness to "ratchet up" the NDCs could diminish (Ostrom and Walker 2005). Carbon prices are easy to compare and provide an approximate indicator of one aspect of countries' climate policy ambitions and abatement costs.

Eventually, global coordination needs to be set in the context of a burden-sharing mechanism involving rich and poor countries to enhance this reciprocity and enable countries to increase their domestic carbon prices. Some have proposed the *allocation of transfer payments* to poorer countries on condition that the latter accept a minimum price for emissions (MacKay et al. 2015), possibly with different minimum prices according to country groups. *Conditional* transfers would mitigate the incentive problem inherent in a voluntary commitment scheme, since a reduction in the level of ambition would lead to the loss of international support. Each country would benefit from the conditionality of the transfers, as faith that other countries will likewise pursue ambitious climate protection is increased and as contributions are part of an established, solid system for coordinating ambitious climate policies.

The *redirection of financial flows* recommended in Article 2 of the Paris Agreement opens another avenue for creating confidence with immediate tangible gains of cooperation—through financial devices that mobilize state and nonstate actors, and that could be based on public guarantees provided by donor countries to support low-carbon investments in developing countries. Public guarantees impose a limited burden on the richer countries because they are only paid if a particular project fails. On the other hand, they would definitely raise the number of economically viable, low-carbon investments (Sirkis et al. 2015; and Hourcade, Shukla, and Cassen 2015).

A more comprehensive and effective system would involve a much larger role for the multilateral development banks (MDBs) in fostering and financing sustainable investments, particularly in sustainable infrastructure. The presence of an MDB in a project or program in itself reduces political and other types of risks, and an MDB can provide a broad range of instruments to handle risk in the particularly difficult early stages of a project or program. MDBs can thus drastically reduce the cost of capital and help leverage substantial quantities of private sector capital. And a lower cost of capital can in turn have a profound effect on the relative profitability of cleaner technologies (see section 4.1).

While carbon prices will differ across countries, the range of carbon prices across countries can be expected to narrow over time, at least under an optimistic scenario. Such (partial) convergence may result from (i) convergence in countries' development and income levels, which would reduce the range of opportunity costs of consumption; (ii) convergence in the price elasticity of emissions, as the lowest-cost opportunities to reduce emissions are captured in low-income countries; (iii) a reduction in the number of market failures and implementation constraints in low-income countries that will shift the balance between implicit and explicit pricing toward explicit pricing; and (iv) an increase in the international transfers supporting lower-income countries.

4 EVIDENCE ON CARBON-PRICE TRAJECTORIES CONSISTENT WITH PARIS AGREEMENT TEMPERATURE OBJECTIVE

Analyses of least-cost stabilization pathways typically show global emissions peaking around 2020 and declining to net zero before the end of the century; the pace of transition is shaped in part by the slow turnover of long-lived energy infrastructure and the related capital stock. In those pathways, the earliest technological changes are occurring in the electricity sector, where conventional power generation is replaced by any of several near carbon-free alternatives: renewable energy, nuclear power, or fossil fuel-burning power with sequestration. These changes are paralleled by the electrification of much of industry, road transport, and household heating. A major transformation of the oil-reliant transport sector occurs—with different components (road, sea, air) facing different challenges. Public transportation and rail along with electrification play important roles in reducing emissions. And enhancing energy efficiency is a major component of cost-effective action throughout the economy.

In these stabilization pathways, carbon pricing begins immediately, with prices that drive technological change in the electricity sector and continue rising until mid-century to trigger the electrification of industry, household heating, and transport. How high such analyses expect prices to be toward the end of the century depends heavily on the availability of backstop technologies, for instance, systems that remove CO_2 directly from the air (so-called “negative emission technologies”).

4.1 Evidence on Carbon Price That Would Be Consistent with the Paris Agreement

Three lines of evidence can be used to provide information about the carbon price that would be necessary to deliver the changes needed to achieve the objectives of the Paris Agreement: technological roadmaps, national modeling exercises, and global energy-economy models.

4.1.1. Technological roadmaps

Decarbonization strategies can be informed by technological roadmaps—that is, sectoral targets and milestones at different points in time, expressed using various sector-specific indicators (Fay et al. 2015; Rockström et al. 2017; IEA 2016; Williams et al. 2012; IDDRI and UNSDSN 2014; IPCC 2014c). Examples include renewable energy targets (produce at least 30 percent of electricity from renewable energy sources by 2025), efficiency targets (reach 90g of CO_2/km for vehicles sold in 2030), fuel-shifting targets (use 20 percent of wood for structure in new buildings in a city by 2025) and land use targets (increase forest cover by 2 percent per year). These sectoral pathways provide implementation guidance for sector plans, and make it possible to use existing regulatory standards and institutions to design and implement the necessary measures. In basic theories of cost-effective planning involving major changes, there is an iteration between overall strategies to achieve targets and the associated shadow prices that can incentivize the required change. This approach is particularly complex in the climate-change context because of the role of learning-by-doing and the pace and scale of the required changes.

These roadmaps can provide guidance on the carbon price that is required to achieve the temperature objective of the Paris Agreement, looking at the "switching prices" for various technologies in different countries. For instance, the carbon price that will make coal noncompetitive in Africa—in other words, that will stop all new investment in coal and lead to the retirement of old plants—is likely to be different than in Europe. The carbon price that will make CCS competitive is also different from the one that will make concentrated solar competitive or the one that will accelerate the move toward low-carbon transportation modes.

Available estimates reflect current uncertainties. The recent IEA publication *Energy, Climate Change and Environment: 2016 Insights* (IEA 2016) for coal/gas/wind[14] finds that switching carbon prices vary widely between regions, given different climate conditions, fossil fuel prices, plant technologies, capital costs, tax structures, and whether competition is between existing plants or for new build (table 1). The rapid pace of change in some technologies means that there is considerable uncertainty about switching prices. Moreover, a higher carbon price is obviously needed to displace existing assets where capital is sunk, compared to the case where competition is between two options for investment in new power generation facilities.

Table 1: Switching Prices for Onshore Wind in Three Countries

	New Onshore Wind vs. Existing Unabated Coal	New Onshore Wind vs. New Unabated Coal
United States	10	0
Germany	80	60
China	30	20

Source: Energy, Climate Change and Environment: 2016 Insights (IEA 2016).

Note: Unabated coal plants are plants that are not fitted with CCS technology, which captures the harmful emissions that cause global warming for permanent burial. All figures are expressed in US$/t$CO_2$ (United States dollars per ton of carbon dioxide emissions). Germany has less favorable wind conditions than China and the United States.

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[14] This analysis uses 2015 information on fossil fuel prices and the cost of renewable energy. It is intended to illustrate the policy implications of varying circumstances rather than provide up-to-date information on the cost of switching to a different energy generation technology.

Many estimates have been proposed for some specific technologies. According to the Global CCS Institute, coal-fired generators in the United States with CCS capability would be on par with traditional (unabated) coal and gas generation if carbon were priced between US$48 and US$109 per ton of CO_2 (Global CCS Institute 2015). Estimates from the U.S. Clean Air Task Force (2013) suggest a similar range: assessed against the displacement of non-CCS coal-fired power supply, CCS appears to provide abatement at between US$65/$tCO_2$ (for a gas-fired power station with CCS) to US$115/$tCO_2$ (for a coal-fired power station with CCS). Rubin, Davison, and Herzog (2015) calculated the cost of CO_2 captured from supercritical pulverized coal plants and geologically stored as between US$46 and US$99/tCO_2 abated, whereas the cost of CO_2 captured from natural gas combined cycle plants and geologically stored are between US$59 and US$143/tCO_2 abated. Calculations for the future would depend on assumptions concerning economics of scale—CCS has not yet been implemented on a major scale although a number of project-based examples exist—and on learning and technological progress.

The Carbon Pricing Corridor Initiative led by We Mean Business and the Carbon Disclosure Project provide consistent estimates for the carbon price able to lead to the decarbonization of the power sector, but using a very different approach (see box 1).

Box 1: The Investment-Grade Carbon Pricing Corridors

The Investment-Grade Carbon Pricing Corridors Initiative, facilitated by We Mean Business and CDP, brings together leaders from across industry and the investment community to explore the carbon-related price signals that will decarbonize electricity generation and heavy industry through the short to medium-term (2020, 2025 and 2030) and help deliver a sub-2°C world as defined by the Paris Agreement.

While the Commission and this report cover all economic sectors, the first Corridors report focuses solely on the power sector, with plans to expand to other high-emitting sectors by mid-2017. Initial findings reveal that the industry-forecast aligns with most techno-economic models in the short run. Interestingly, the bottom range of the corridor remains at US$30 per ton of CO_2 from 2025 onward—this is partially explained by the expectation that the levelized-cost of renewable energy sources will continue to decrease. The report explores the variety of factors that influenced the carbon-price levels indicated by the panel members.

Year	Carbon-Price Corridor (US$/$tCO_2$)
2020	24-39
2025	30-60
2030	30-100

Source: The Investment-grade Carbon Pricing Corridors Initiative.

The carbon price needed to make low-carbon technology competitive depends on the cost difference with traditional, fossil fuel-based technologies. Therefore, the required price of carbon is lower if:

- R&D and pilot projects on low-carbon technologies are supported by innovation policies, and if support for R&D on fossil fuels is reduced or eliminated altogether.
- Exploration and investment in fossil fuel extraction is limited or stopped (or if fossil fuel subsidies are eliminated), so that fossil fuels become more expensive.

Switching prices also depend on the current and future costs of capital. As low-carbon technologies are often more capital-intensive but benefit from lower operational costs, they are at a disadvantage when upfront capital is expensive or limited. Switching prices also vary with political risk and risk perception. Low-carbon technologies are sometimes profitable precisely because climate policies are present. However, the risk of policy reversal leads to a risk premium being charged, which makes these technologies more expensive again; the size of this premium depends on the credibility of the policy over time. The required carbon price is lower if the long-term credibility of climate policies is higher.

The cost of capital can be reduced by classical fiscal and monetary policies, better investment climates and rule of law, or specific de-risking instruments such as guarantees, thereby reducing the carbon price needed to make some technology competitive. Finon (2017)[15] calculates switching prices for nuclear and CCS in the power sector (compared to reference emitting plants like gas-CCGT[16] and coal power plants) under three scenarios: (i) a common regime of investment with an identical capital cost of 8 percent for reference power plants and low-carbon technologies; (ii) differentiated capital costs with a government guarantee on investment in low-carbon technologies, which results in a capital cost of 5 percent while the capital cost for emitting plants is still 8 percent; and (iii) a scenario where the perceived risk of investors implies a capital cost of 12.5 percent in low-carbon technologies plants, while the capital cost is still 8 percent for gas CCGT and coal power plants. The results show that depending on the reference plant and the cost of capital, switching prices vary between 20€/tCO_2 and 120€/tCO_2 for CCS and between 12.5€/tCO_2 and 132€/tCO_2 for nuclear (table 2). Additional calculations in Hourcade et al. (2017) for Brazil, France, and India, show how switching prices can be lowered by public guarantees that decrease the projects' upfront cost by valuing avoided emissions with a shadow carbon price.

The required carbon price is likely to be lower if resources can be reallocated rapidly thanks, for example, to efficient capital markets, a highly skilled workforce with lifelong training, and strong social systems able to support the people and regions negatively affected. But, as discussed further in chapters 5 and 6, this requires the ability to deal with stranded assets (like coal power plants too expensive to be operated), skill mismatch of workers (such as people with a career in the mining industry), and industrial/economic redevelopment (in areas that are today specialized in fossil fuel-dependent industries).

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[15] Input from Finon (2017), The Carbon Prices Making Low Carbon Plants Competitive, received for this report.

[16] A Combined Cycle Gas Turbine (CCGT) is a form of highly efficient energy generation technology that combines a gas-fired turbine with a steam turbine.

Table 2: Three Investment Scenarios for Switching from Fossil Fuel to Low-Carbon Technology Plants

8% (baseline) | 5% (guarantee on low-carbon technology investment) | 12.5% (risk aversion toward low-carbon technology investment)

COAL WITH CCS

Capital Cost Scenario	8%	5%	12.5%
Ref: Gas CCGT 8% capital cost	€85/tCO$_2$	€50/tCO$_2$	€120/tCO$_2$
Ref: Coal plant 8% capital cost	€35/t	€20/t	€54/t

NUCLEAR

Capital Cost Scenario	8%	5%	12.5%
Ref: Gas CCGT 8% capital cost	€60/tCO$_2$	€20/tCO$_2$	€132/tCO$_2$
Ref: Coal plant 8% capital cost	€30/t	€12.5/t	€60/t

Source: Finon (2017).

Note: CCS = Carbon Capture and Sequestering; CCGT = Combined Cycle Gas Turbine. The calculations are calibrated under 3 scenarios—with capital costs of 8%, 5%, and 12.5% respectively for low-carbon options, while the cost of capital remains at 8% for coal and gas. In the baseline scenario (capital cost of 8%), coal plants with CCS become competitive with simple coal plants at a carbon price of €35/tCO$_2$ and with CCGT at a carbon price of €85/tCO$_2$.

The switching price approach is used by the IEA to develop 2°C scenarios. Rather than assuming explicit carbon prices, the Energy Technology Perspectives scenarios use the marginal abatement cost of various technology options to construct least-cost scenarios. In some cases, standards, mandates, or subsidies rather than explicit carbon prices lead to deployment of these technologies. Under the 2°C scenario, carbon prices in 2030 rise to US$100/tCO$_2$ in the OECD regions and to US$75/tCO$_2$ in China, Russia, Brazil, and South Africa in the power and industrial sectors, accompanied by a phasedown of fossil fuel subsidies. Table 3 indicates the most expensive (marginal) technologies that are deployed in various time periods. According to recent estimates from the IEA and the IRENA in *Perspectives for the Energy Transition*, under a scenario with a 66 percent chance of maintaining temperature change below 2°C, carbon prices in 2030 will rise to US$120/tCO$_2$ in OECD countries and to US$90/tCO$_2$ in emerging economies for energy-related CO$_2$ emissions.

The pathways followed in technological roadmaps are not based solely on current marginal costs, but also on the timing of various investments (Vogt-Schilb and Hallegatte 2014; del Rio Gonzalez 2008). For example, a study on Brazil found that developing clean transport infrastructure is necessary over the short term, in spite of its relatively high cost, because clean transport is required to achieve deep decarbonization over the long term, and transport systems and infrastructure cannot be transformed quickly (Vogt-Schilb, Hallegatte, and de Gouvello 2014).[17] Similarly, while some of the technologies used to reduce emissions are relatively mature (e.g., wind turbines) and some are currently experiencing rapid reductions in cost (e.g., solar photovoltaics), others (such as electric cars) are still in earlier stages of development. Since the costs of these technologies will decrease as their deployment continues—through learning-by-doing effects, R&D, and economies of scale—it may make sense to use some of these options in the short term to bring down their cost (Azar and Sandén 2011; del Rio Gonzalez 2008; Gerlagh, Kverndokk, and Rosendahl 2008; Kalkuhl, Edenhofer, and Lessmann 2012).

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[17] See Vogt-Schilb, Meunier and Hallegatte (2014) on the impact of capital accumulation pathways on the definition of marginal abatement costs.

Table 3: Global Marginal Abatement Costs and Example Marginal Abatement Options under the IEA 2°C Scenario

	2020	2030	2040	2050
Marginal cost (USD/tCO$_2$)	30-50	80-100	110-130	130-160
Energy conversion	• Onshore wind • Rooftop POV • Coal with CCS	• Utility scale PV • Offshore wind • Solar CSP • Natural gas with CSS • Enhanced geothermal systems	• Same as for 2030, but scaled up deployment in broader markets	• Biomass with CCS • Ocean energy
Industry	• Application of BAT in all sectors • Top-gas recycling blast furance • Improve catalytic process performance • CCS in ammonia and HVC	• Bio-based chemicals and plastics • Black liquor gasification	• Novel membrane separation technologies • Inert anodes and carbothermic reduction CCS in cement	• Hydrogen smelting and molten oxide electrolysis in iron and steel • New cement types • CCS in aluminium
Transport	• Diesel ICE • HEV • PHEV	• HEV • PHEV • BEV • Advanced biofuels	• Same as for 2030, but wider deployment and to all models	• FCEV • New aircraft concepts
Buildings	• Solar thermal space and water heating • Improved building shells	• Stability of organic LED • System integration and optimization with geothermal heat-pumps	• Solar thermal space cooling	• Novel buildings material; development of ”smart buildings” • Fuel cells co-generation

Source: Energy Technology Perspectives 2012 (IEA 2012), as cited by Hood (2017).[18]

Note: BAT = Best Available Technology; BEV = Battery Electric Vehicle; CCS = Carbon Capture and Sequestration; CSP = Concentrating Solar Power; FCEV = Fuel-Cell Electric Vehicle; HEV = Hybrid Electric Vehicle; HVC = High-Value Chemical; ICE = Internal Combustion Engine; IEA = International Energy Agency; LED = Light-Emitting Diode; PHEV = Plug-in Hybrid Electric Vehicle; PV = Photovoltaic energy; USD = United States dollar.

4.1.2 Analysis of National Mitigation and Development Pathways

National-scale studies and modeling exercises sometimes provide estimates of the shadow price of carbon (or, in some cases, of the explicit price of carbon) that is required to deliver decarbonization in a given economy, and deal with some of the limitations of technological roadmaps (for instance, by considering interactions between sectors). Studies such as those conducted by the DDPP provide national policy makers with relevant information.[19] The DDPP accommodates different modeling paradigms supporting national decarbonization studies in different countries—ranging from sophisticated combinations of macroeconomic, technology stock turnover, and land use models to simple spreadsheet models (Pye and Bataille 2016).

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[18] Input received, in personal capacity, for this report (Hood 2017).

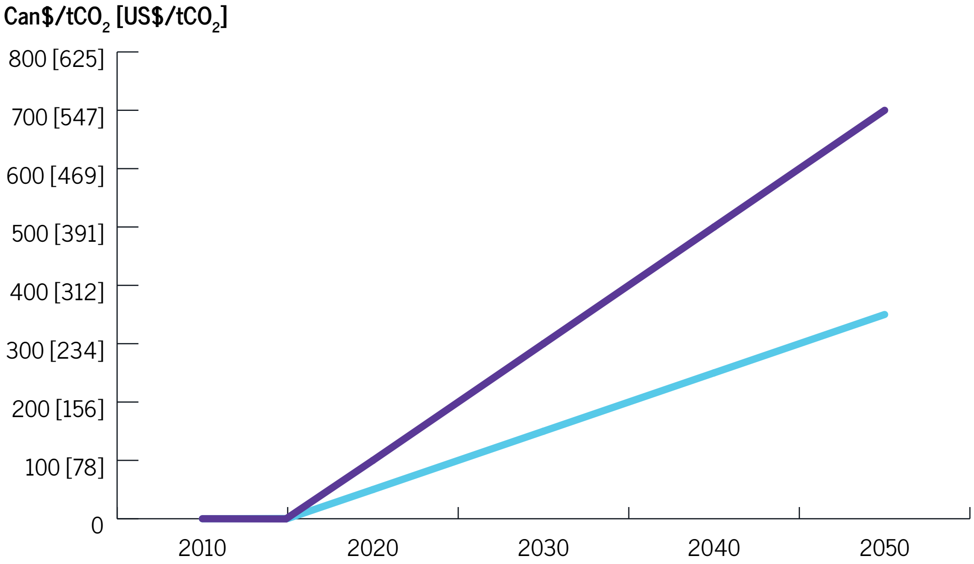
[19] See the background paper provided by the DDPP for this report (DDPP 2017).

In all national scenarios, the deep decarbonization of energy systems involves strong action on three pillars of decarbonization: (i) energy efficiency and conservation; (ii) decarbonization of energy carriers (electricity and fuels); and (iii) fuel switching toward low-carbon energy carriers in end-use sectors. In some countries, land use, natural sinks, and changes in agricultural practices represent a fourth pillar.

A key insight from DDPP on carbon prices is that, to make long-term decarbonization happen, a rapid increase in the signal on the shadow cost of carbon to emitting firms and households is needed in the short term. The need for high carbon prices is also valid in national modeling for developing countries, but the value appears lower in absolute terms in these countries than in the analysis for developed countries.

Simulations suggest that the carbon prices needed to achieve deep decarbonization depend on the presence of other policies—lower prices are needed if the price policies are complemented by additional measures. For instance, Bataille et al. (2015) developed scenarios for Canada that include either a single carbon price or a combination of: (i) economy-wide carbon pricing starting at Can$10/ tCO_2e (in 2015 Canadian dollars) and rising by Can$10 per year steadily through time, recycled equally to corporate and income taxes; (ii) sector-specific performance standards for new and retrofit transport and buildings falling to net-zero emissions by 2025–40; (iii) an intensity-based, tradable performance standard falling to –90 percent by 2050 for large emitters, using output-based allocations; and (iv) methane and land use regulations to achieve its DDPP target at the lowest possible carbon "sticker price." While this study does not provide an aggregate estimate for the cost of climate policies, figure 1 shows the carbon-price level needed to reach a level lower than $2tCO_2$ per capita in 2050 under the policy package described above, and the carbon price needed to reach the same emission levels if pricing is the only policy.[20] Involving other instruments is found to halve the requisite explicit carbon price.

Figure 1: Use of Carbon Price to Trigger Transition Toward Deep Decarbonization in Canada



Note: tCO_2 = tons of carbon dioxide. Prices are given in Canadian dollars (Can$) and United States dollars (US$), based on the average exchange rate for 2015. The blue line depicts the scenario with complementary polices, while the purple line depicts the scenario without complementary policies.

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[20] Here the $2tCO_2$ per capita is used as a milestone in 2050 in the pathway toward zero-net emissions.

4.1.3. Global Integrated Assessment Models

Integrated Assessment Models (IAMs) produce global scenarios of future socioeconomic and technological development that are consistent with different global temperature targets, including the 2°C and 1.5°C target.[21] As global models, IAMs cannot have the same level of detail as national-level exercises. They also remain limited in their ability to capture some fundamental aspects of technological change, learning, and economies of scale that we know from experience are of vital importance—not only based on climate and sustainable innovations and investment that we have seen in recent years but also on past waves of technological change in economic history. Some also involve imperfect treatment of capital stock. However, they can account for some interactions between sectors (for instance, the link between power generation and transportation) and between countries (oil revenues and oil imports, impacts on trade). They can also investigate the timing of actions and emission reductions, and provide global emission scenarios and global cost estimates.

In some models, the carbon value is the shadow value of the carbon constraint, which is equal to the cost of reducing the last ton of GHG emissions needed to achieve the climate stabilization targets at the lowest cost (therefore, it is equal to the additional cost of using the most expensive technology needed for the transition). In other models, a carbon price is imposed exogenously so that emissions (or the carbon budget) meet some predetermined constraint. The difficulty with this exercise is that deep decarbonization involves nonmarginal and unprecedented changes in energy systems and other emitting activities, thus posing special analytical challenges to estimating the price that is consistent with a given carbon constraint.

While there is a consensus across models on the technical changes that are needed to maintain climate change below 2°C, models fail to agree on the carbon price required to trigger those changes. Based on the assessment provided in IPCC (2014c), scenarios that limit warming to below 2°C with a greater than 66 percent probability imply carbon prices increasing throughout the 21st century, but with prices ranging from US$15 to US$360 (in 2005 United States dollars) per tCO_2e in 2030, and from US$45 to US$1,000 (in 2005 United States dollars) per tCO_2e in 2050 (figure 2).[22]

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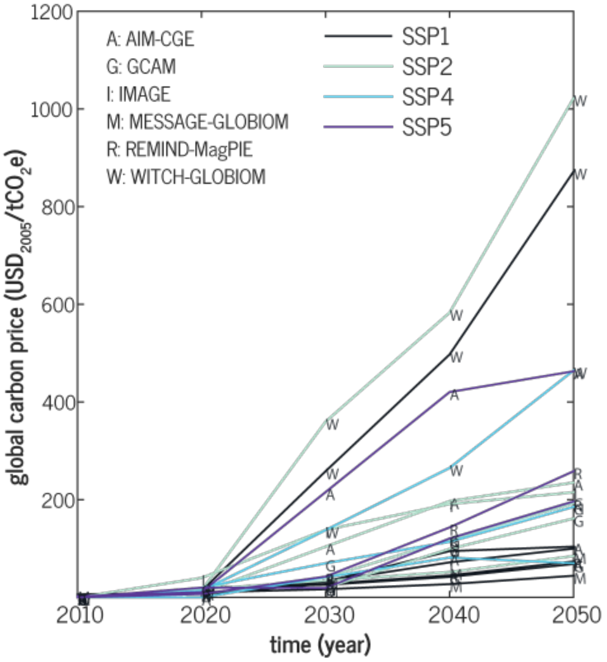
[21] Few scenarios are currently available that achieve the 1.5°C target, but work is under way to produce more of these scenarios, in view of the Special Report of the IPCC on the 1.5°C target.

[22] In the models used to make these estimations, these “carbon” prices are applied to all anthropogenic GHG emissions, which are therefore expressed in US$ per metric ton of carbon dioxide equivalent emissions (US$/$tCO_2e$).

Figure 2: Carbon-Price Trajectories Limiting Warming in 21st Century below 2°C



Source: Riahi, van Vuuren, et al. 2017, as cited by Guivarch and Rogelj 2017.[23]

Note: Carbon-price trajectories that have a probability >66 percent of keeping global temperature change below 2°C, based on a review of six different Integrated Assessment Models (IAMs), and considering four different baselines (Shared Socioeconomic Pathways, SSPs).

This wide range reflects differences in baseline scenarios (what would be the world evolution in the absence of climate policies?), policy assumptions (what are the complementary policies implemented in parallel with pricing policies?), and modeling framework/structure and assumptions (how do the models assume that economic agents respond to price signals? how much learning-by-doing and technological change can be expected in response to climate policies?). The effects of these uncertainties are well understood:

- ***The price of carbon required to meet the 2°C target is lower in baseline scenarios*** with faster per capita growth, more expensive fossil fuels, or preferences for low-energy consumption patterns (e.g., regarding diets). Figure 3 shows the carbon price in 2050 consistent with a 2°C scenario, for three baseline scenarios involving increasing challenges for mitigation. Scenarios that limit warming to below 2°C with a greater than 66 percent probability imply carbon prices varying from US$50 to US$100 per tCO$_2$e with SSP1 assumptions, and US$200-US$450/tCO$_2$e with SSP5 in 2050.

- ***The price of carbon required to meet the 2°C target is lower the higher the credibility of the price signal.*** Models in which agents have perfect foresight of future technological and socioeconomic developments tend to have lower carbon prices in the short term because decisions that involve long-lived capital take into account the knowledge of (usually increasing) future prices. In models where emission reductions in the short term are only based on knowledge of current prices and costs, higher prices are required over the short term. Near-term carbon prices thus have to be assessed in the context of the credibility of their implied, long-term carbon-price signal.

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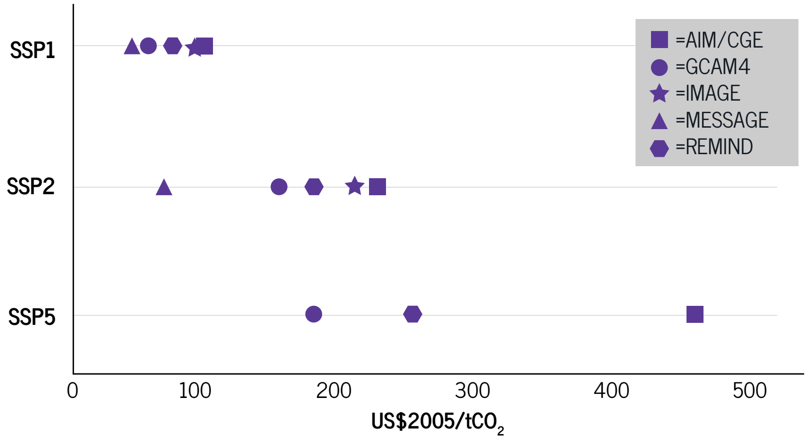
[23] Guivarch, C., and J. Rogelj. 2017. "Carbon Price Variations in 2°C Scenarios Explored." Paper commissioned for this report.

- ***The price of carbon required to meet the 2ºC target is lower the better the potential for low-carbon technologies.*** The difference between price trajectories is strongly influenced by the models' structures and parameterization, in particular regarding the cost of new technologies and constraints on their penetration. Both aspects are difficult to model and forecast because they are driven by many factors such as innovation and learning, and institutional and financial constraints (Acemoglu et al, 2012; Wilson et al. 2013; van Sluisveld et al. 2015; Vogt-Schilb, Meunier, and Hallegatte 2014; WRI 2016).
- ***The price of carbon required to meet the 2ºC target is lower the higher the ability to reallocate resources across the economy.*** In IAMs, constraints on technology penetration can be structural, meaning that the model by design cannot accommodate specific transformations—for instance, it does not allow installed capital to be early-scrapped or it limits the reallocation of workers across sectors.

The highest and lowest estimates of the carbon price needed to achieve the temperature objective of the Paris Agreement are explained by a combination of pessimistic or optimistic assumptions. The highest price is derived from the WITCH model, which incorporates pessimistic modeling assumptions—for example, very limited substitution between technologies—which explain why this model generates much higher shadow costs of carbon than other models. Similarly, the AIM model, assuming no induced technological change except in CCS, results in a relatively high shadow cost of carbon. At the other extreme, the MESSAGE model assumes perfect foresight and perfectly optimized responses to carbon prices, and therefore yields a very low shadow cost of carbon, especially when combined with the most optimistic baseline scenario—the SSP1 that assumes very low energy consumption and emissions, even in the absence of climate policies.

Figure 3: Carbon Prices in 2050 Consistent with a 2ºC Scenario Depend on the Baseline Scenario



Note: The plot shows the 2050 CO_2 prices in the RCP2.6 scenarios for all SSP marker models (AIM/CGE, GCAM4, MESSAGE-GLOBIOM, REMIND-MAgPIE, IMAGE) and all scenarios with low to medium challenges for adaptation (SSP1, SSP2 and SSP5). From SSP1 to SSP5, socioeconomic challenges for mitigation increase from low (SSP1), and medium (SPS2) to high (SSP5) by varying assumptions on population and GDP growth, consumption patterns, development of technology costs and performances, resource availability, efficiency policies and environmental regulation, etc.

4.2 Current Level and Breadth of Carbon Pricing Inconsistent with Paris Agreement

The current levels of carbon prices are insufficient to induce the abatement levels consistent with the temperature objective of the Paris Agreement, and future prices will definitely have to be higher. The vast majority of governments around the globe—189 countries representing 96 percent of global GHG emissions and 98 percent of the world's population—have committed to reducing their GHG emissions and adapting to the changing climate through their Intended NDCs.

However, most emissions are currently not priced, and the range of carbon prices across existing initiatives remains substantially smaller than those necessary for achieving the Paris temperature target. The carbon prices observed span from less than US\$1/tCO$_2$e to US\$126/tCO$_2$e, 85 percent of global emissions are not priced today, and about three quarters of the emissions that are covered by a carbon price are priced below US\$10/tCO$_2$e (World Bank, Ecofys, and Vivid Economics 2016, PMR 2017; World Bank and Ecofys 2017).[24] Many countries have not put a price on carbon, or (as in the case of Australia) have removed carbon-pricing mechanisms. However, emissions covered by carbon pricing have increased threefold over the past decade. In addition, the number of initiatives implemented or scheduled for implementation has jumped from 9 to 42 in the same period (figure 4).

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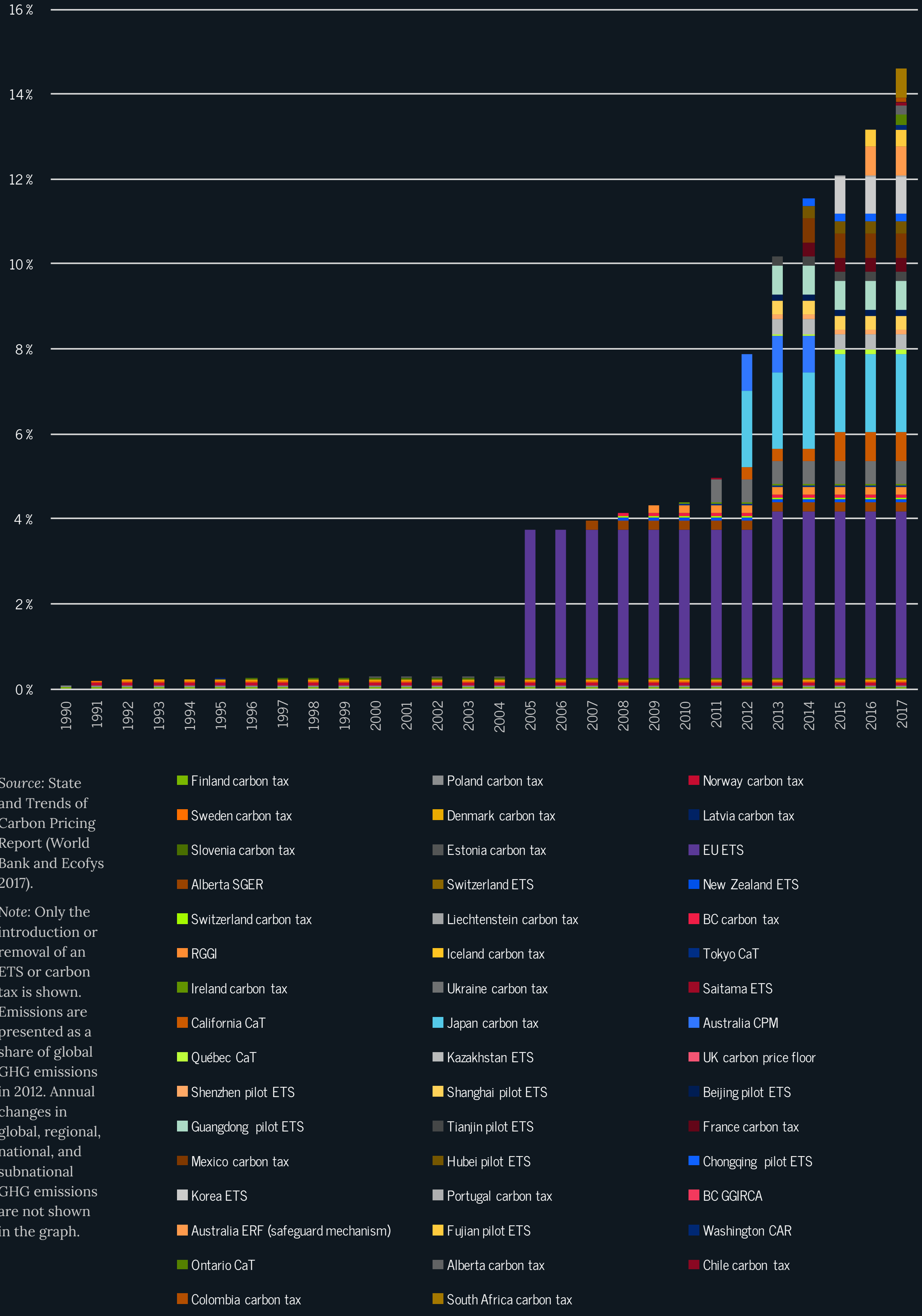
[24] Even including excise taxes, currently 80 percent of emissions from energy use are priced at less than US\$40/tCO$_2$ and 89 percent at less than US\$50/tCO$_2$.

Figure 4: Regional, National, and Subnational Carbon-Pricing Initiatives—Share of Global GHG Emissions Covered



Source: State and Trends of Carbon Pricing Report (World Bank and Ecofys 2017).

Note: Only the introduction or removal of an ETS or carbon tax is shown. Emissions are presented as a share of global GHG emissions in 2012. Annual changes in global, regional, national, and subnational GHG emissions are not shown in the graph.

5 TAPPING CARBON-PRICING REVENUES

The revenues derived from carbon pricing can be used in many different ways. The decision on how to spend the revenues from carbon pricing should be based on the objectives and circumstances of a particular country, bearing in mind the commitments made in regard to the Paris objectives. Since tax revenues are fungible, standard principles of public finance indicate that the decision on how to use carbon-pricing revenues should be no different than the decision on the use of any other tax revenue: revenues should be spent in the way that produces the highest value for the population. However, political economy considerations may affect this choice. Experience from fossil fuel subsidy reforms and carbon pricing show that policy packages that include both a revenue component (lower subsidy costs or higher revenues through a tax or other pricing instrument) and a spending component (e.g., a reduction in other taxes; increased spending on social protection, cash transfers, or public services; or increased investments) have a much higher probability of success than in the case of the revenue component alone (Fay et al. 2015; Ruggeri Laderchi 2014). For instance, after reviewing subsidy reform projects in the Middle East and North Africa, the IMF concludes that "*of the cases where cash and in-kind transfers were introduced* [as compensatory measures for energy price hikes], 100 *percent were associated with a successful outcome, while only* 17 *percent of the cases where these transfers were not introduced resulted in a successful reform*" (Sdralevich, Sab, and Zouhar 2014). In British Columbia, the introduction of the carbon tax was also facilitated by the parallel reduction in other taxes (Harrison 2013).

5.1 Carbon Pricing as a Source of Government Revenue

Explicit carbon-pricing instruments can raise significant revenue. Based on current CO_2 emissions and in the absence of any international transfers, a US$30/t$CO_2$ domestic carbon tax would raise resources representing more than 1.5 percent of local GDP in half of the 87 countries (both developed and developing) analyzed in a recent study (Hallegatte et al. 2015). In British Columbia, the carbon tax currently provides 3 percent of the province's budget (Harrison 2013), and in Sweden, it contributes 1 to 2 percent of the national government budget.

Carbon prices raise revenues in an efficient way, in the sense that they tackle a key market failure, the climate externality. They can also provide a good tax base and limit tax evasion and collection costs.[25] However, the relative efficiency of carbon-pricing revenues depends on the way these revenues are spent and the policies they replace. Recycling revenue to reduce distortionary taxes may, under certain conditions, offer a "double dividend"—by providing both environmental benefits and an aggregate economic gain: taxing "bads" (pollutants) rather than "goods" (labor, capital) can allow

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[25] Revenue accrues directly from carbon taxes while, in the case of a cap-and-trade system, revenue depends on the volume of allowances being auctioned (rather than allocated for free).

for a less costly tax system (Goulder 2013; de Mooij 2000). Still, under certain conditions, the fact that carbon taxes can be used to reduce other distortionary taxes has been shown to increase the desirable (or optimal) level of carbon tax.[26]

Carbon pricing offers a good tax base because a carbon price, if well structured, is difficult to evade. Carbon sources are concentrated, especially in countries that import their fossil fuels, making it easy to measure and monitor physical units of energy at the supplier level. Monitoring a carbon-pricing scheme is generally easier than monitoring other tax bases, such as hours worked, profits earned, or personal income. In Sweden, where a carbon tax has been in place since 1991, carbon tax evasion is less than 1 percent, substantially less than value added tax (VAT) evasion. In the United Kingdom, evasion is estimated at about 2 percent for the excise tax on diesel, as opposed to 9 percent for the corporate tax, 11 percent for the VAT, and 17 percent for income taxes (HM Revenue & Customs 2014).

In addition, for developing countries especially, carbon taxes offer a way to reduce incentives for firms and individuals to stay in the informal sector—while conventional taxes (like the ones levied on wages, sales, or profits) apply only to the formal sector, a fuel tax applies equally to the formal and informal sector. When carbon tax revenues are used to reduce other conventional taxes, the gap between the tax burden in the formal and informal sector decreases, which in turns reduces the incentive to join the informal sector (Bovenberg 1999; Goulder 2013). (Jobs in the formal sector typically provide more financial security and social protection.)

In cost-efficient decarbonization scenarios, revenues from carbon pricing remain significant for decades. While the ultimate objective is to reduce emissions over time (until they reach net zero), in many models, dynamic efficiency requires that carbon prices increase in real terms over time. In modeling exercises, such an increase keeps revenue streams relatively stable for an extended period of time, even as emissions decrease (e.g., Rausch and Reilly 2015). In any climate stabilization scenario, revenues do eventually drop essentially to zero, or even become negative in the presence of negative emissions, but only over the long term.

Recycling revenue from carbon pricing into broad cuts in other taxes—including through "revenue neutrality" of the reform—can help offset the economic burden of the carbon tax and, if used well, facilitate pro-growth tax reforms. The revenue can be used to foster growth in an equitable way, as revenue can be returned to consumers in the form of household rebates, thereby reducing the burden of other taxes, supporting poorer groups, managing transitional changes, investing in infrastructure, and fostering technological change. Numerous studies, synthesized in the IPCC reports, highlight the potential for benefits to be derived from such reforms (IPCC 2007, 2001).

Revenues can also be used to reduce the social charges imposed on labor costs. This may reduce unemployment rates and help increase real wages. This would also serve to counteract the

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[26] See Stiglitz (2013), using a Ramsey (1927) optimal tax framework, extended to the context of corrective (environmental) taxation by Sandmo (1976). For a particular application using the DICE model, see Nordhaus (1993). For a broader discussion, see Stiglitz (2015) and also Goulder (1995a, 2013, 1995b), Bovenberg (1999), and de Mooij (2000).

potentially regressive effects of higher carbon prices and help poor people deal with the higher price levels caused by carbon pricing. It also has positive distributional impacts because of the larger share of wages in the total income of poor households (higher-income households may have other sources of income—capital, interest, and rents). Moreover, mitigation options (e.g., energy efficiency, renewables, and agricultural and forestry low-carbon practices) are generally more labor-intensive than economic activities based on fossil fuels. Therefore, recycling carbon tax revenues may generate a double dividend: fostering the transition toward decarbonization while simultaneously promoting economic growth and social development (Combet 2013; Grottera, William, and La Rovere 2016; La Rovere et al. 2017; Goulder 1995a).

5.2 Redistributing Carbon-Pricing Revenues to Protect the Poor and Vulnerable

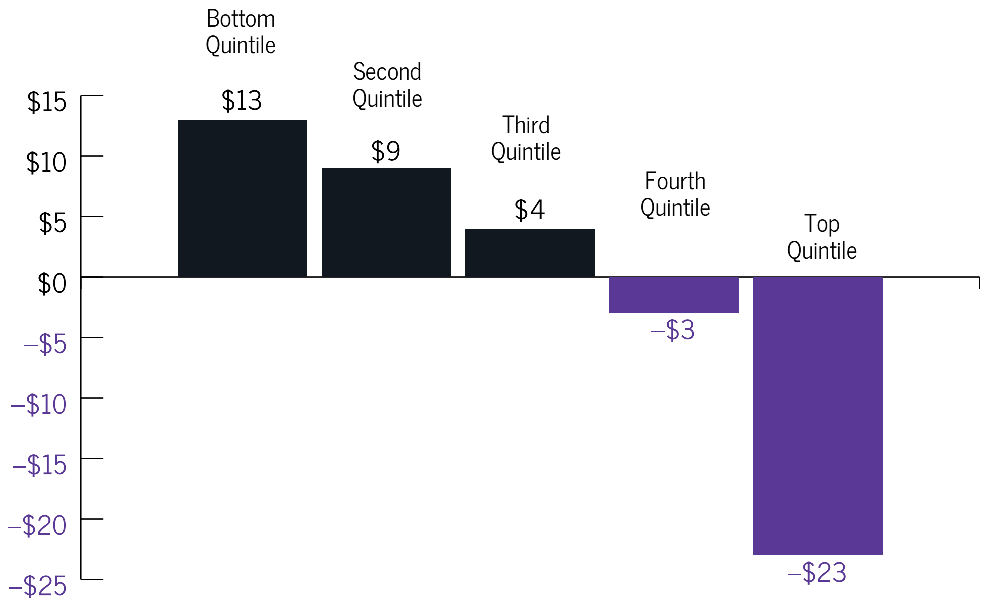
Revenues from carbon pricing can be redistributed to protect poor and vulnerable people. This is all the more important because carbon pricing can have significant impacts on the income and budgets of the poor, depending on their consumption patterns. On the consumption side, energy price increases may be progressive, as energy's share of household budgets usually rises with income in developing countries, contrary to the case of developed countries.[27] But the final impact will depend on the fuel mix used by poor people. Moreover, in a dynamic setting, higher prices for modern energy could slow down poor households' transition away from biomass to modern fuels for cooking, entailing significant adverse health impacts.

The distributional impact of carbon pricing will depend on the way revenues are used, but equal distribution per capita would benefit the poorest, and recycling only part of the revenues would suffice to make the overall scheme progressive. If rebates financed by a carbon-pricing instrument are divided equally (that is, adjusted for household size), then poor households would be better off than before the carbon tax. This is because, even though their carbon-related burden may represent a relatively small share of their overall income, higher-income people pay more in absolute terms and the revenue would be redistributed across all households. In Indonesia, for instance, the recycling of carbon revenue through uniform, lump-sum transfers would make a carbon tax progressive[28] (Yusuf and Resosudarmo 2015). Data from developing countries also suggest that taking US$100 away from fossil fuel subsidies and redistributing that money equally among the population would on average transfer US$13 to the bottom quintile and take US$23 away from the top quintile (figure 5). Poverty can be further reduced by using revenues to fund more targeted instruments that help poor people (such as targeted cash transfers), or existing social safety nets (such as school feeding). Reforms of fossil fuel subsidies provide useful lessons on how the freed-up resources can help poor households adjust to the change in energy prices, through in kind or in cash transfers (Ruggeri Laderchi 2014).

[27] Bacon, Bhattacharya, and Kojima (2010) used household survey data from nine developing countries in Africa and Asia, and found that in four countries, people in the lower quintiles spend more money on energy than people in the higher quintiles, while the shares were similar in five other countries. However, what matters is the share of income people spend on modern energy, which in the nine countries surveyed increased from the lower to the higher quintiles.

[28] A *progressive tax* collects a larger share of wealth, income, or consumption from richer people than from poorer people.

Figure 5: Benefit to the Poorest of Recycling US$100 from Fossil Fuel Subsidy Budget as a Universal Cash Transfer



Source: Based on Arze del Granado, Coady, and Gillingham 2012.

Note: All prices are expressed in United States dollars. Average over twenty developing countries from Africa, Asia, the Middle East, and Latin America.

Cash transfers to households (or "rebates" or "dividends") may improve the attractiveness and durability of carbon pricing as people receive immediate and tangible benefits, even as they face higher energy prices. Revenues can also be used directly to lower the energy bills of poor households. While this would have the advantage of directly offsetting the tax incorporated into energy prices, careful design would in this case be necessary to maintain the incentives to reduce energy consumption, as this is an important channel of emission reductions.

5.3 Carbon-Pricing Revenues to Smoothen the Transition toward Decarbonization

The transition to a deep decarbonization pathway can be disruptive in the short term, and a major advantage of explicit carbon pricing is that it raises revenue that can be redistributed to manage the negative side effects of the transition.

The introduction of a carbon price will cause losses concentrated in the carbon-intensive sectors, especially in the form of stranded assets—whose owners may therefore oppose the carbon tax. Climate stabilization will require that much of the known fossil fuel reserves be kept in the ground, leading to a loss of wealth for some countries and regions (McGlade and Ekins 2015). Where vulnerable sectors, such as steel or coal mining, dominate the local economy, regional impacts could be severe, with significant social, cultural, and political implications.

Many other groups have been found to be particularly vulnerable to climate policies, including fishermen (who depend on diesel fuel) and farmers (who use diesel pumps for irrigation), as well as small and medium-sized enterprises. Agricultural households are also affected—by higher fertilizer costs and higher transportation costs (raising the cost of getting their produce to markets).

Revenues from carbon pricing can be used to help those who may be burdened by emissions abatement policies. For instance, revenues may be used to reduce carbon leakage and unfair international competition if some countries fail to impose significant carbon constraints on their economic system. In that case, a share of carbon-pricing revenues could be rebated to firms that are both carbon-intensive and exposed to international competition. If the rebate is output-based, that is, based on the *value* of a firm's production rather than the production's carbon content, then it does not reduce the incentive to reduce emissions, but it does protect these firms against unfair competition (Monjon and Quirion 2011; Branger and Quirion 2013). Concerns over carbon leakage and unfair competition can also be tackled by improving policy coordination across countries and introducing so-called border carbon adjustments.[29]

Revenues can also be used to smooth the transition of declining sectors to mitigate social impacts. Studies show that accompanying measures can mitigate part of the losses from structural change at a very small aggregate cost (Porto and Lederman 2014; Trebilcock 2014). When Japan modernized its economy in the 1960s and early 1970s, more public support went to traditional industries (such as textiles) than to modern, growing sectors (such as electronics and manufacturing) (Beason and Weinstein 1996). Later, the 1978 Law for Temporary Measures for the Stabilization of Specific Depressed Industries helped smooth the decline of 14 "structurally depressed" industries—including textiles and ship building. It did this by planning capacity reduction, reallocating resources within and outside the depressed industries, providing financial assistance to troubled firms, and mitigating the negative impacts on labor (Krauss 1992; Peck, Levin, and Goto 1987). The compensatory approach has also been used by the United States in the context of trade liberalization—typically through wage subsidies in the sectors that benefit from liberalization (to help them absorb workers from declining sectors) and unemployment insurance for the workers who remain trapped in declining sectors. In the mid-1970s, U.S. Trade Adjustment Assistance (TAA) was used to provide re-employment services to displaced workers and financial assistance to manufacturers and service firms hurt by import competition.

Support for innovation can help affected sectors benefit from the transition. Some automakers already positioned themselves as leaders in green and electric or hybrid cars, and thus as potential winners from more ambitious climate mitigation. Oil and gas companies can reinvent themselves if they develop technologies to capture and store carbon from the atmosphere. Supporting R&D and innovation also facilitates this transition, provided it targets potential losers to transform them into potential winners. Furthermore, when pilot projects for green technologies are created, they can be located in the areas that are most likely to lose from climate policies, thereby ensuring that all regions derive some benefits from the reform. Innovative concentrated solar power generation or CCS plants could, for instance, be located in a

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[29] *Border tax adjustments*, import fees levied by carbon-taxing countries on goods manufactured in countries that do not price carbon.

place where fossil fuels are extracted, thereby creating green jobs and activities in these locations, mitigating negative social impacts of (and building support for) climate policies. The above examples illustrate how well-designed policies could even turn some traditional opponents into supporters of the reforms.

5.4 Boosting Investment and Economic Growth with Carbon-Pricing Revenues

Infrastructure investments are hampered by financing challenges, especially in developing countries. Many countries are simply too poor to generate the required savings domestically, while others lack local capital markets that are sufficiently developed to transform local liquidity into the patient capital that is needed for longer-term investments. Further, public spending is often limited by a small tax base (10 to 20 percent of GDP).

Revenues from carbon pricing could help close the gap in infrastructure investments in developing countries (i.e., provide funds for building the infrastructure required to provide universal access to basic services such as modern energy and promote growth and prosperity). One option would be to invest the tax proceeds directly into infrastructure development. In fact, research suggests that the amount raised through carbon pricing (at a level consistent with the 2°C target in seven models used in the EMF27 study[30]) would be sufficient to close the infrastructure gap, as shown in figure 6 (Jakob et al. 2016). These infrastructure developments could support and accelerate economic growth by making economies more productive and efficient (Abiad, Furceri, and Topalova 2014; IMF 2014). What is more, in contexts of depressed demand or high unemployment, these investments could stimulate the economy and reduce unemployment.

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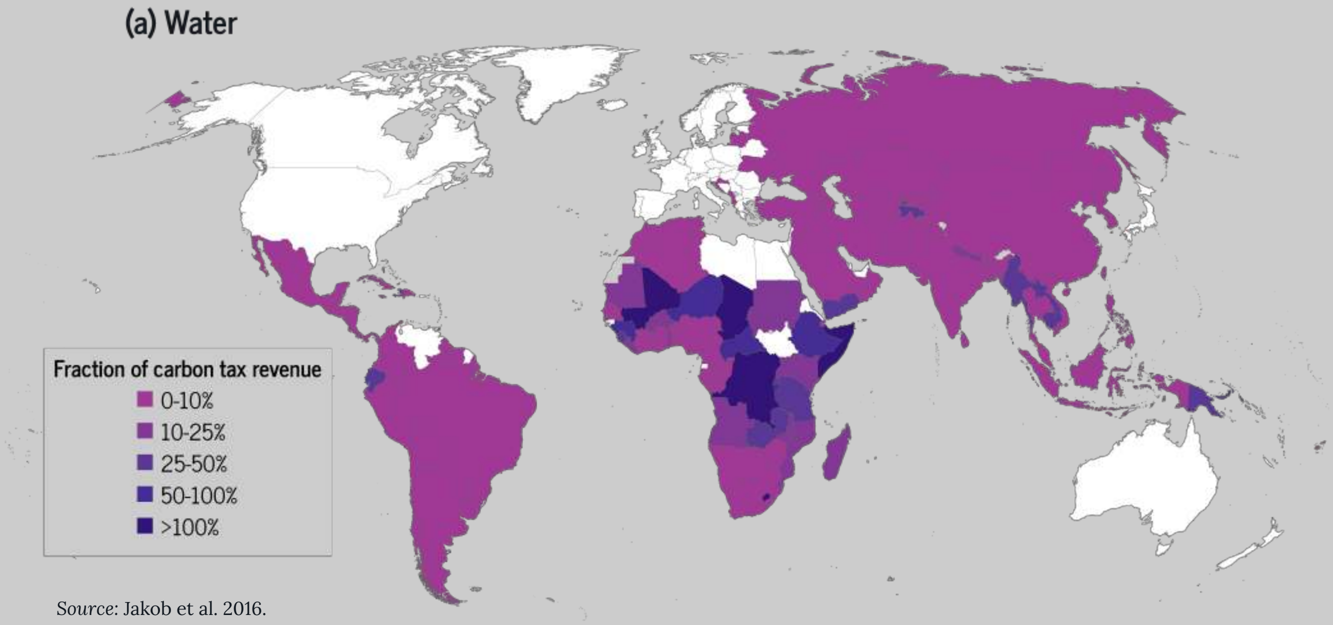
[30] The Stanford Energy Modeling Forum Study 27 (EMF27) investigated the importance of individual mitigation options such as energy intensity improvements, CCS, nuclear power, solar and wind power, and bioenergy for climate mitigation. It was driven by a model inter-comparison of 18 energy-economy and integrated assessment models.

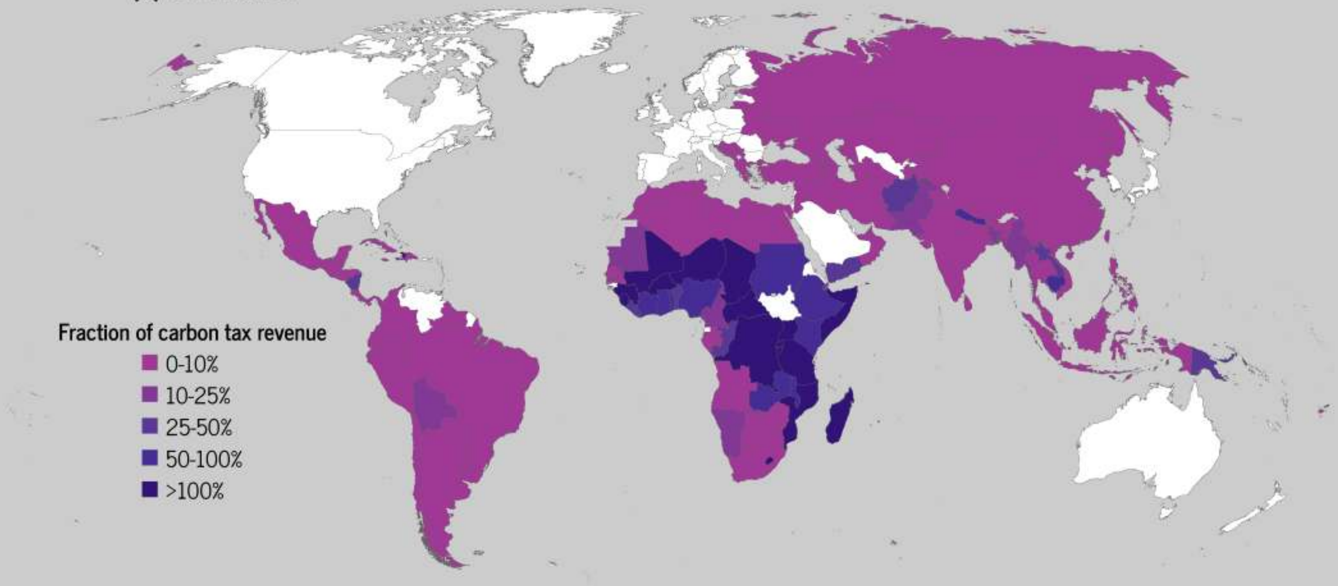
Figure 6: Share of Carbon-Price Revenues Required to Finance Universal Access to Infrastructure



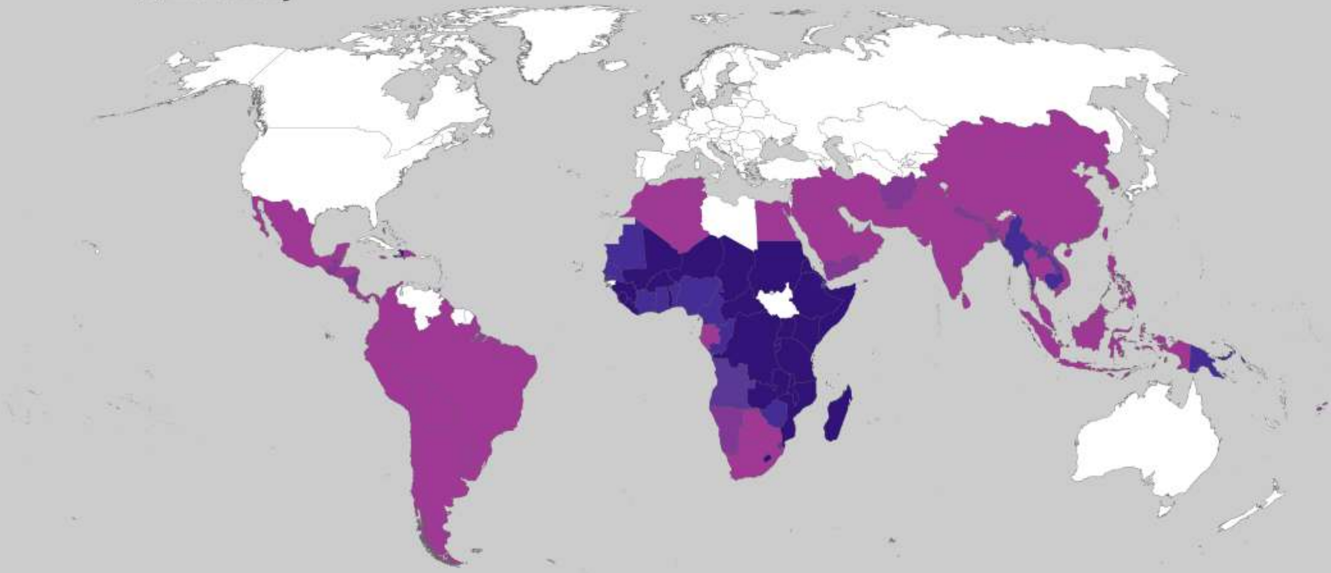
Source: Jakob et al. 2016.

Note: Share of carbon-pricing revenues required to finance universal access to infrastructure under domestic carbon pricing (i.e., without transfers between countries) for the 450 ppm scenario with full technological availability. (a) water, (b) sanitation, (c) electricity, and (d) costs of paving all unpaved roads. Countries in white are developed countries or countries where data are not available. The boundaries, colors, denominations, and other information shown on any map in this work do not imply any judgment concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

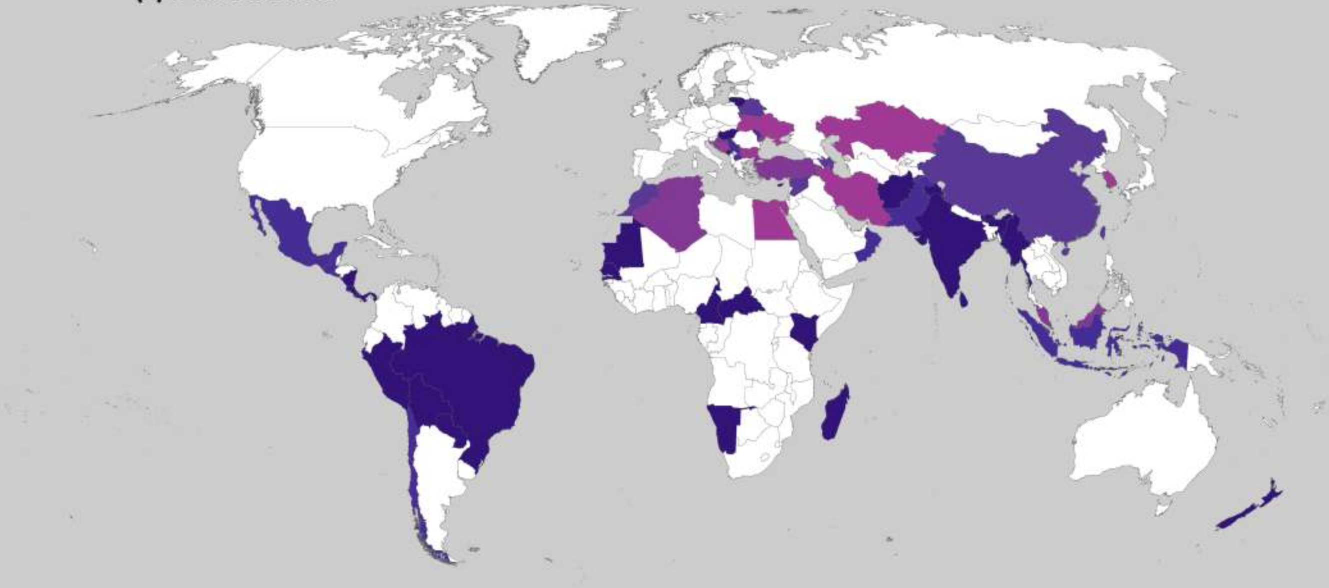
(b) Sanitation



(c) Electricity



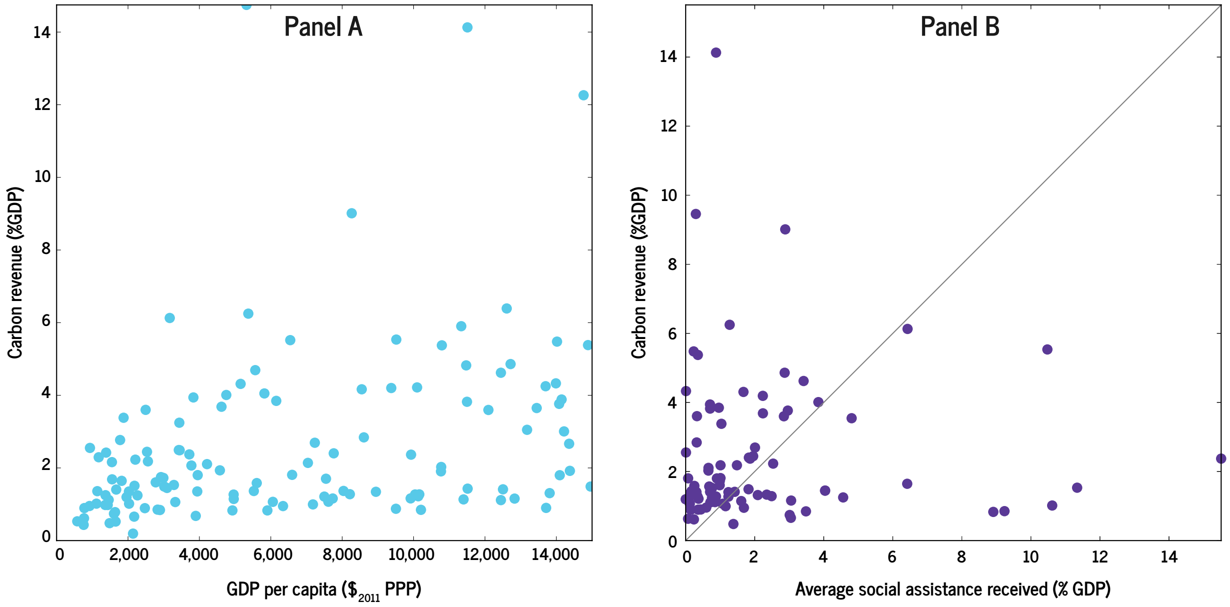
(d) Paved Roads



Revenues can also help finance public goods such as education and health, and social safety nets.

Without any international transfers, a US\$30/tCO$_2$ domestic carbon tax would raise resources amounting to more than 1.5 percent of local GDP in most countries (figure 7, panel A). In the Sahel countries, 1.5 percent of GDP represents more than the amount needed to protect households affected by severe droughts, which have long-term negative repercussions for these countries' development prospects (Hallegatte et al. 2017). And in 60 of the 87 countries studied, a US\$30/tCO$_2$ domestic tax would provide the resources to more than double current levels of social assistance in the country (figure 7, panel B).

Figure 7: Using Carbon-Pricing Revenues to Boost Social Assistance



Source: Shock Waves Report, by Hallegatte et al. 2015.

Note: Panel A shows the revenue derived from a carbon price of US\$30/tCO$_2$, expressed as a fraction of Gross Domestic Product (GDP). Each dot represents a different country. PPP = Purchasing Power Parity. Panel B shows how this revenue compares to current social assistance benefits provided in those countries (based on the ASPIRE database). In 60 of the 87 countries for which data are available, a US\$30/tCO$_2$ tax would provide sufficient resources to more than double current social assistance transfers (represented by the dots above the diagonal line in panel B). These calculations assume the energy consumption remains unchanged.

5.5 Carbon-Pricing Revenues to Foster Technological Change and Transition toward Decarbonization

Revenues could also pay directly for emission reductions or finance R&D in low-carbon technologies.

One option would be to earmark revenues to strengthen environment policy and invest in green projects or technologies. As discussed in chapter 3, without government support, private sector agents underinvest in R&D into low-carbon technologies. To resolve this issue, revenues can be used to fund investment tax credits, R&D tax credits, or support energy efficiency investments and innovation to help companies transition to a low-carbon future. Targeted R&D and investment credits can help improve the economic performance of supported industries and boost technological change. While these arguments apply generally to R&D underinvestment, they are particularly important in this context because of the scale of climate risk, the urgency of acting now, and because the use of any new technology benefits everyone (not just its user) through reduced emissions (Aghion, Veugelers, and Hemous 2012; Acemoglu et al. 2012).

Earmarking should be considered carefully, however, as it entails significant risks. While technological change could potentially be accelerated, a modest carbon-price path is likely to bring in more money than could be spent wisely on emissions abatement or low-carbon technologies. Since there is no particular connection between the amount of revenue a carbon-price policy raises and the appropriate level of spending on R&D, adaptation, or other climate goals, earmarking—for instance, a certain percentage of the revenue—for such purposes would not necessarily make fiscal sense. And there is a significant risk of capture of this revenue by well-connected interest groups (Rodrick 2014; Hallegatte, Fay, and Vogt-Schilb 2013). Moreover, from a fiscal policy standpoint, it would be wise to ensure that the benefits of climate-related spending are at least comparable to what they would be if the revenue were used for other purposes.

6 COMPLEMENTING CARBON PRICING WITH OTHER, WELL-DESIGNED POLICIES

Carbon pricing by itself may not be able to induce a transition at the pace and on the scale required for the Paris target of "well below 2°C" without unacceptable costs and distributional impacts. It is theoretically both unsound and impracticable to rely on carbon pricing only (Stern 2015a; Stiglitz 2013)—carbon pricing should be complemented by other well-designed policies. As explained in chapter 3, issues related to relevant market and government failures as well as distributional considerations should influence policy. If these aspects are properly addressed, the carbon price to be set may actually end up being lower than initially foreseen.

Such complementary policies could include the introduction of performance standards; new rules for city design, land and forest management, and investments in infrastructure; the development of new methods and technologies; and the use of financial instruments that foster private sector participation and reduce the risk-weighted capital costs of low-carbon technologies and projects (Fay et al. 2015; Bhattacharya et al. 2016). These policies would work alongside carbon prices and generally reduce the carbon price required to bring about the necessary emission reductions.

This chapter explores the important relationships between carbon pricing and some of these policies, with an eye to identifying those that can be efficient or equitable complements to carbon pricing. This applies especially when political economy issues result in carbon prices that are too low to induce change at the required pace and scale.

6.1 Using Complementary Infrastructure and Planning Approaches to Facilitate the Transition

The scale and pace of the required change may be supported by complementary infrastructure and planning approaches alongside carbon pricing. City design, transport infrastructure, and land use plans shape the options available to individuals and communities, how networks function and the way in which individuals interact, and the externalities they may inflict on each other. Priority policies in this context include the following:

- ***Investments in public transportation infrastructure and urban planning:*** Investments in transportation systems include large-scale provision of road and railway infrastructure support for carbon-free vehicles (via carbon-free, electricity-charging infrastructure), urban planning and housing investments to make public transit viable—by duly managing congestion and pollution, and offering broad access for all to jobs, services, and opportunities (Cervero 2014). A key aspect of transportation infrastructure is that it takes time to develop and has long-term implications for emissions and the ability to reduce them (Avner, Hallegatte, and Rentschler 2014). Moreover, transportation infrastructure projects do not respond strongly to the price signal, partly because most of these investments are publicly financed and driven by a variety of monetary and nonmonetary considerations (and not only by profit maximization).

- ***Efforts to improve the transmission and governance of the energy system to allow the development of renewable-based power generation*** are essential to incentivize private sector investment in renewable energy (Jorge and Hertwich 2014). Electricity transmission grids and the regulations governing them are critical for countries weighing major expansions of their renewable generation capacity (Haller, Ludig, and Bauer 2012).

A carbon price—whether or not it is used in an explicit pricing mechanism—can be used for project appraisal or public procurement, thereby promoting a shift toward low-carbon infrastructure investments. And, as described in section 2.4, it can be used by financial institutions and private firms to inform decision making regarding technologies, investment, and R&D.

6.2 Using Complementary Policies to Tackle Other Market Failures and Distributional Impacts

Well-designed complementary policies may be needed to tackle other market failures or manage distributional outcomes. More specifically, efficiency standards and investment incentives can be introduced where carbon pricing would be difficult to implement or just inefficient. Allocative inefficiencies can be resolved by the introduction of standards and incentives to encourage “sunrise” sectors or technologies. In situations marked by learning, economies of scale, and uncertainty, regulations can be more effective than prices, as illustrated by two successful government interventions—the banning of incandescent lights bulbs, which promoted the development of cheap and highly efficient LED, and the banning of lead in gasoline (with appropriate adjustment delays), which effectively reduced lead-based pollution. The DDPP studies found that for sectors that do not respond well to prices because of market failures or behavioral issues, the introduction of performance-based, potentially tradable GHG-intensity standards can approach or exceed the efficiency and effectiveness of carbon pricing (Jaffe, Newell, and Stavins 2005; DDPP, 2017). Renewable portfolio standards[31] can be combined with tradable renewable certificates and implemented with carbon pricing (Bertoldi and Huld 2006). In general, performance standards can be designed so that they are efficient, but policy makers need to duly consider the information and monitoring costs associated with their implementation.

Other policies can influence investment and purchase decisions. Feebates, that is, the combination of rebates for lower-carbon investments or purchases and a fee for carbon-intensive investments,

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[31] *Renewable Portfolio Standard*, a regulatory mandate to increase production of energy from renewable sources such as wind, solar, biomass, and other alternatives to fossil and nuclear electric generation. It’s also known as a renewable electricity standard.

have the advantage of being revenue-neutral (provided the scheme is properly developed and consumer reactions are anticipated correctly). Given that such fiscal incentives to encourage desirable investments gradually transform the productive structure without affecting the owner of old capital, they can more easily be used in the early stages of the transition, and then gradually be phased-out and replaced by economy-wide pricing instruments as their social and political acceptability improves (Rozenberg, Vogt-Schilb, and Hallegatte 2014).

Massive investments are needed, and the financial sector regulations combined with financial instruments can either facilitate or impair the transition. Financial instruments that can be used include direct intervention through concessionary financing (or loan subsidies, directed credit), and instruments that rebalance risk perception between low-carbon and brown projects, thus facilitating access to finance through direct market creation (for example, Fornadin in Mexico). Multilateral or national development banks (such as the Brazilian National Bank for Economic and Social Development) reduce government-induced policy risk through their participation, help in designing the policy that can reduce such risk, and act as trusted conveners to bring in other financing institutions. Moreover, their set of instruments (including equity and guarantees) can help manage risks in the early stages of projects, where financing is most challenging.

Regulations forcing financial institutions to be transparent about the risk of stranded assets in fossil fuels encourage green investment, and reduce financial sector risk, as stressed in Mark Carney statements and reports from the Task Force on Climate-related Financial Disclosures. Bridging the finance gap requires looking at banking and financial regulations, and considering how they could be used to make long-term investments more attractive for investors and intermediaries (Campiglio 2016; Shukla et al. 2017). As many investments are necessarily long-term, dealing with the short-termism of the financial sector becomes particularly important.[32]

Decarbonization benefits from technological improvements can be supported by technology policies and R&D subsidies. Carbon prices can help overcome this constraint but it does require setting a carbon price higher than what would be needed in the presence of innovation policies, entailing high costs in the short term. A wide range of policies could instead be used to tackle this challenge, such as direct support for low-carbon sectors. Supporting investments in low-carbon technologies and sectors (Acemoglu et al. 2012; Rosendahl 2004) can likewise encourage investments in innovation in solar panels, electric cars, and the like (Gerlagh, Kverndokk, and Rosendahl 2014; Smulders, Withagen, and Toman 2014). Particularly promising technologies can also be promoted through targeted support. If one low-carbon technology displays high potential but high costs, specific support can be provided through feed-in tariffs, for example (del Rio Gonzalez 2008). Public procurement can be another tool to drive low-carbon innovation and generate economies of scale—especially in sectors where government demand is significant.

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[32] See Stiglitz et al. (2015), and Bolton, Samama, and Stiglitz (2011).

Combined with estimates of knowledge spillovers, the potential of specific new technologies, and proposed roadmaps, a carbon value can be used to design specific policies to support innovation and the deployment of low-carbon technologies. Innovation in low-carbon technologies can also ease the adoption of carbon prices by aiding in the provision of alternatives to carbon-intensive technologies and lifestyles.

The restructuring process can be done quicker and more efficiently if it is supported by education, migration, and trade policies that accelerate technology transfers and innovation.

Decarbonization poses the usual challenges for policy makers trying to facilitate the restructuring and reduce the labor market adjustment costs, including those derived from a changing skills mix. Skill shortages may already be impeding the transition to green growth (World Bank 2012a). In 2011, the OECD (2011b) drew attention to widespread skill shortages in energy-efficient construction and retrofitting; renewable energy; energy and resource efficiency; and environmental services.

7

CONCLUSION

This Commission was tasked with identifying carbon-pricing corridors that, combined with other policies and international collaboration, could deliver on the Paris target of limiting global warming to "well below 2°C." The Commission's conclusions are based on its members' experience and judgment, and draw on multiple lines of evidence—including technological roadmaps and technology assessments, national pathway analyses, and integrated assessment models—taking into account the strengths and limitations of these various information sources. As all of these approaches inevitably involve many uncertainties, the focus has been on identifying carbon-price *ranges* rather than specific prices.

The Commission recognizes that different countries will choose different instruments to implement their climate policies and put a price on carbon, depending on national and local circumstances and on the support they receive.

Based on evidence from industry, policy experience, and relevant literature, and taking into account the strengths and limitations of the respective information sources, this Commission concludes that, in a supportive policy environment, the explicit carbon-price level consistent with the Paris temperature target is at least US$40–80/t$CO_2$ by 2020 and US$50–100/t$CO_2$ by 2030. The implementation of carbon pricing would also need to duly consider the non-climate benefits of carbon pricing (for instance, the generation of additional government revenue), the local context, and the political economy (including the policy environment, the adjustment costs, the distributional impacts, and the political and social acceptability of the carbon price).

Depending on the other particular policies adopted, large co-benefits may be derived that go beyond climate such as lower pollution and congestion levels, healthier ecosystems, broader access to modern energy, and so on. Furthermore, in a realistic context where domestic and international compensatory transfers are limited, imperfect, and costly, distributional and ethical considerations cannot be disregarded when designing climate policies. The appropriate carbon-price levels will therefore vary across countries. In lower-income countries they may actually be lower than the ranges proposed here, in part because complementary actions taken may be less costly or because the distributional and ethical issues to be tackled may be more complex.

The Commission believes that the carbon-price ranges suggested above would be able to deliver on the temperature objective of the Paris Agreement, provided the pricing policy is complemented with targeted actions and a supportive investment climate—in the absence of these elements, the carbon-price range required is likely to be higher. The temperature objective of the Paris Agreement is also achievable with lower near-term carbon prices than indicated above, but doing so would require stronger action through other policies and instruments and/or higher carbon prices later, and may increase the aggregate cost of the transition.

The proposed carbon-price range is narrower than the one that would have been derived from a simple literature review because the Commission has used its own judgment in assessing the relevance and appropriateness of some of the more extreme calculations.

- ***Lower bound.*** While governments do have some flexibility in the use of instruments at the country level, the Commission believes that decarbonizing the economy with very low carbon prices, and a relatively large focus on other instruments could be unnecessarily inefficient, due to the potential misallocation of efforts across sectors. In addition, a high short-term price gives a clear signal on the transition to investors and consumers, helps raise awareness of and attract attention to emission reduction opportunities, and may help tackle cognitive and behavioral biases. These elements explain the lower range of US$40–50 for the period 2020–30 for the carbon prices that are considered consistent with an efficient achievement of the temperature objectives of the Paris Agreement. National circumstances (related to adjustment costs and market failures, distributional impacts, social and political acceptability, etc.) may make it preferable to initially implement a lower carbon-price level. Yet strong investment decisions aimed at reducing emissions require absolute clarity that carbon prices will rise over the next few decades.
- ***Higher bound.*** Scenarios that suggest that the carbon prices consistent with the Paris Agreement are higher than US$80–100/t$CO_2$ in the period 2020–30 generally make more pessimistic assumptions regarding (the pace of) technological change and the impact of socioeconomic trends, or assume an unsupportive policy environment and little action being taken through other policy instruments.

Of vital importance for the effectiveness of climate policy, particularly carbon pricing, is that future paths and policies not only be clear but also credible. New evidence will emerge continually and new lessons drawn; indeed, the implementation of carbon pricing should foster knowledge generation and technical progress, and practical experience should be taken into account. It is also important to monitor and regularly review the evolution of emissions, technological costs, and the pace of technological change and its diffusion so that carbon prices can be adjusted, particularly upward, if existing prices fail to bring about the required changes. There is a rich and active area of research that can be very helpful in implementation and revision over time of carbon pricing instruments. It is desirable that the carbon-price ranges across countries narrow in the long term, in a time frame that depends on a number of factors—including the extent of international support and the degree of convergence of living standards across countries.

The carbon-pricing and complementarity measures indicated in this report are substantially stronger than those currently in place—85 percent of global emissions are currently not priced at all, and about three quarters of the emissions that are covered by a carbon price, are priced below US$10/t$CO_2$e (World Bank, Ecofys, and Vivid Economics 2016; Partnership for Market Readiness 2017). This statement is consistent with the observation made in the Paris Agreement that the NDCs for 2030 associated with the Agreement represent substantially smaller emission reductions than necessary for achieving the Paris temperature increase target of “well below 2°C.”

APPENDIX A: THE SOCIAL COST OF CARBON

While this report does not provide an estimation and evaluation of the climate change impacts that could be avoided, it did review the relevant literature on the matter. The Commission concluded, as did the fifth Assessment Report (AR5) of the IPCC and other review studies, that many of the impact functions used in modeling exercises to calculate the social costs of carbon are biased downward because they fail to consider many vitally important risks and costs associated with climate change—particularly the widespread biodiversity losses, long-term impacts on labor productivity and economic growth, impacts on the poorest and most vulnerable, rising political instability and the spread of violent conflicts, ocean acidification, large migration movements, as well as the possibility of extreme and irreversible changes (IPCC 2014a,b; Tol 2012; Stern 2013; Weitzman 2014; Dietz and Stern 2015).

According to some recent reviews, climate change impact on total factor productivity combined with the presence of discontinuity and tipping points may significantly increase the social cost of carbon (Moyer et al. 2014; Moore and Diaz 2015). The valuation of non-market impacts can also be an important driver for higher climate impacts (van den Bergh and Botzen 2014; Ackerman et al. 2009). Because poorer households and countries are more severely affected by climate impacts, the social cost of carbon may have to be adjusted upward, if the implementation of policies to reduce those inequalities is not feasible (Dennig et al. 2015; Mendelsohn, Dinar, and Williams 2006; Hallegatte and Rozenberg 2017).

For these reasons, many past modeling exercises to calculate the global social costs of carbon have produced numbers that *probably underestimate these costs by very large margins*. Some expert assessments have recommended updates to the methodologies being used to strengthen the scientific basis and improve the characterization of the uncertainties in these estimates (National Academies of Sciences, Engineering, and Medicine 2017; Rose et al. 2014; Pindyck 2013).

B APPENDIX B: THE SOCIAL VALUE OF MITIGATION ACTION

Carbon mitigation actions entail direct costs, co-benefits, and adverse side effects (IPCC, 2014b). Potential co-benefits include the following:

- The ***immediate benefits*** of avoided GHG emissions: (i) less adverse effects from local air pollution on health and agricultural productivity (Clarke et al. 2014); and (ii) countries' greater energy security and lower vulnerability of their trade balance to the volatility of oil price.
- An ***acceleration of technological change*** when early investments in low-carbon technologies deliver learning-by-doing effects with positive spillovers on technological change in the form of a "Schumpeterian" innovation wave (Stern 2015b; Bramoullé and Olson 2005).
- The ***short-term knock-on effects and long-term development benefits*** of a well-conducted low-carbon transition: (i) improving the use of savings by redirecting financial flows toward productive investments; (ii) strengthening the industrial fabric of each country through investing in low-carbon technologies and local resources; and (iii) reducing poverty through higher growth, higher employment, and better access to modern energy, transport, and housing infrastructures (Arezki et al. 2016).

The social value of mitigation action (SVMA) can be defined as the economic and environmental value of voluntary mitigation actions and their co-benefits for adaptation, health, and sustainable development (UNFCCC 2015, Para 108). The international community could encourage the use of SVMAs, taking into account avoided climate change impacts and global co-benefits from reducing emissions and stabilizing climate change, and use them, for instance, to design sectoral measures in carbon-intensive sectors or global financial instruments.

In a world with imperfect markets and constraints on compensatory transfers, SVMAs would differ across countries. Such national SVMAs would encompass the national benefits of keeping global warming below a globally agreed target (i.e., avoided climate change impacts) and the local development co-benefits of national mitigation activities. National SVMAs could be used as notional carbon prices, for instance, by being incorporated in financial mechanisms to redirect savings toward low-carbon investments or investments that are not based on some public decision-making process.

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During the 22nd Conference of the Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) held in Marrakech, Morocco, in 2016, at the invitation of the Co-Chairs of the Carbon Pricing Leadership Coalition (CPLC) High Level Assembly, Ségolène Royal and Feike Sijbesma, Joseph Stiglitz, Nobel Laureate in Economics, and Lord Nicholas Stern, accepted to chair a new High-Level Commission on Carbon Prices comprising economists, and climate change and energy specialists from all over the world, to help spur successful implementation of the Paris Agreement.

The Commission’s objective is to identify indicative corridors of carbon prices that can be used to guide the design of carbon-pricing instruments and other climate policies, regulations, and measures to incentivize bold climate action and stimulate learning and innovation to deliver on the ambition of the Paris Agreement and support the achievement of the Sustainable Development Goals.