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FISCAL POLICIES FOR PARIS CLIMATE STRATEGIES—FROM PRINCIPLE TO PRACTICE

EXECUTIVE SUMMARY

190 countries submitted climate strategies for the 2015 Paris Agreement. Most strategies include objectives for both mitigation (reducing emissions) and adaptation (building resilience to climate change). This paper discusses the role of, and provides practical country-level guidance on, fiscal policies for implementing climate strategies using a unique and transparent tool laying out trade-offs among policy options.

On mitigation, this tool shows that carbon taxes or equivalent pricing for fossil fuels can be attractive on CO_2, fiscal, domestic environmental, and economic grounds. Revenues might be used for lowering distortionary taxes or funding public investment. Fiscal instruments could also reduce other emissions (e.g., from forestry and international transportation). Many countries would need high carbon prices to meet their commitments however, and there can be a tension between efficiency and acceptability which (among other reasons) may imply a role for other instruments.

Accompanying measures at domestic and international levels would be needed. Domestically, research and development (R&D), infrastructure investment, and financial market policies can enhance the effectiveness of carbon mitigation, while measures are needed to relieve vulnerable groups and address broader political acceptability. Internationally, a carbon price floor arrangement among willing countries could reinforce the Paris process and partly address inefficiencies from the wide cross-country divergence in prices implied by current mitigation pledges.

A holistic strategy, going well beyond physical investment, is needed for adaptation. National strategies should encompass risk diversification across a range of fiscal and financial instruments; full integration of climate risks, fiscal buffers, and climate finance into a sustainable macro-fiscal framework; and inclusion of climate investments into national budgeting procedures. Development of capacity in debt sustainability and public investment management is required in many countries.

The Fund can advise on the implications of climate commitments for macro and fiscal policy given its expertise, universal membership, and close relationship with finance ministries. Finance ministries have a key role in integrating carbon charges into fuel taxes; allocating carbon pricing revenues; integrating climate risks and financing into macro-fiscal frameworks; addressing political economy aspects; and coordinating strategies across ministries.

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Glossary of Technical Terms and Abbreviations

BCAs	Border Carbon Adjustments. These measures impose charges on the embodied carbon content of certain products imported in a country and (in some proposals) provide relief for domestic carbon pricing for categories of exported products.
Burden or incidence	Refers to whose economic welfare is reduced by a policy and by how much. It is quite different from the formal or legal incidence – fuel suppliers, for example, may be responsible for remitting tax payments to the national tax authority, but they may bear little economic incidence if they can charge higher prices.
BAU	Business as Usual. Economic outcomes that would occur in the absence of a new policy or policy change.
CCS	Carbon Capture and Storage. An (as yet unproven) technology for extracting CO_2 emissions from smokestacks and transporting them via pipelines to underground geological storage sites.
CO_2	Carbon Dioxide. The main GHG, produced from burning fossil fuels, manufacturing cement, and forest practices. CO_2 has an average atmospheric residence time of 100 years.
Carbon tax	A tax imposed on CO_2 releases emitted largely through the combustion of carbon-based fossil fuels. Administratively, the easiest way to implement the tax is through taxing the supply of fossil fuels—coal, oil, and natural gas—in proportion to their carbon content.
CO_2 equivalent	The warming potential of a GHG over a long-time period expressed in terms of the amount of CO_2 that would yield the same amount of warming.
Distribution-neutral policy	A policy that imposes approximately the same burden as a proportion of consumption (or some other measure of household well-being) on all different income groups.
Economic welfare cost	Losses in consumer and producer surplus (net of any gains/losses to the government) from a policy change, leaving aside environmental effects. For carbon taxes, it reflects the value of the reduction in fuel consumption below levels that consumers would prefer without the carbon tax.
Emissions leakage	Refers to a possible increase in emissions in other regions in response to an emissions reduction in one country or region. Leakage could result from the relocation of economic activity, for example, the migration of energy-intensive firms away from

	countries whose energy prices are increased by climate policy. Alternatively, it could result from increased demand for fossil fuels in other countries as world fuel prices fall in response to reduced fuel demand in countries taking mitigation actions.
ETS	Emissions Trading System or Scheme. A market-based policy to reduce emissions (sometimes referred to as cap-and-trade). Covered sources are required to hold allowances for each tonne of their emissions or (in an upstream program) embodied emissions content in fuels. The total quantity of allowances is fixed, and market trading of allowances establishes a market price for emissions. Auctioning the allowances provides a valuable source of government revenue.
Externality	A cost imposed by the actions of individuals or firms on other individuals or firms (possibly in the future, as in the case of climate change) that the former does not consider.
F-gases	Fluorinated Gases. Gases caused by human activity that remain in the atmosphere, thus leading to global warming. The most important F-gas is HFCs.
Feebate	This policy would impose a sliding scale of fees on firms with emission rates (e.g., CO_2 per kilowatt-hour) above a 'pivot point' level and corresponding subsidies for firms with emission rates below the pivot point. Alternatively, the feebate might be applied to energy consumption rates (e.g., gasoline per kilometer driven) rather than emission rates. Feebates are the fiscal analog of an emissions (or energy) standard, but they can better accommodate uncertainty (e.g., over future technology costs and fuel prices).
GHG	Greenhouse Gas. A gas in the atmosphere that is transparent to incoming solar radiation but traps and absorbs heat radiated from the earth. CO_2 is easily the most predominant GHG.
GWP	Global Warming Potential. A measure of how much heat a tonne of a non-CO_2 GHG traps in the atmosphere over a given period (usually a century) relative to the amount of heat trapped per tonne of CO_2.
HFCs	Hydrofluorocarbons. An F-gas, with especially high GWPs, used for example, in refrigeration and air conditioning.
INDC	Intended Nationally Determined Contribution. Commitments to climate mitigation (via a reduction in GHG emissions) and adaptation submitted by 190 countries for the Paris Agreement.

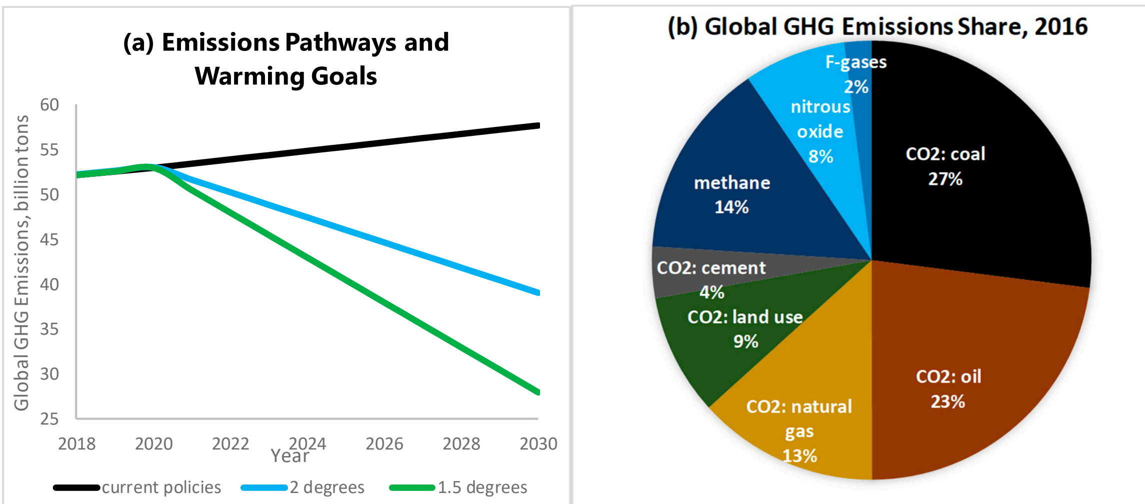
	Following ratification of the Paris Agreement in November 2016, INDCs reverted to NDCs.
Input-Output Table	This provides detailed information on the value of output and value of various categories of input (including fuels and electricity use) by industries producing both intermediate goods and final consumer goods. These tables can be used to trace through the effects of carbon pricing (via higher energy prices) on the price of final goods (assuming all of the carbon price is ultimately reflected in higher consumer prices).
ITMOs	Internationally Transferred Mitigation Outcomes. Under Article 6.2 of the Paris Agreement countries exceeding their NDC mitigation pledges can sell excess mitigation credits—ITMOs—to other countries, enabling the latter to meet part of their mitigation pledge through ITMOs rather than domestic actions.
NDC	Nationally Determined Contribution. Formerly known as INDC. Countries are required to report progress on implementing NDCs every two years and (from 2020 onwards) to submit revised NDCs (which are expected to contain progressively more stringent mitigation pledges) every five years.
Negative emissions technology	A technology that on net reduces atmospheric concentrations of GHGs (e.g., co-firing biomass in power plants that have installed CCS technologies).
Non-CO_2 GHGs	These gases, which include methane, nitrous oxide, and F-gases, have relatively high GWPs.
Output-based rebate	In the context of a carbon price, this is a payment per unit of output to compensate firms whose production costs rise significantly in response to higher energy prices.
Paris Agreement	An international agreement (ratified in 2016) from within the UNFCCC, on climate mitigation, adaptation, and finance. As of March 2019, 195 UNFCCC members had signed the agreement. The Agreement's central objective is to contain global average temperature increases to 1.5-2^{o}C above pre-industrial levels.
Passed forward	The extent to which a (carbon) tax is reflected in higher prices for energy consumers (rather than lower producer prices).
R&D	Research and Development.
REDD	Reducing Emissions from Deforestation and Forest Degradation. This is an effort to create a financial value for the carbon stored in forests and thereby offer incentives for developing countries to reduce CO_2 emissions from deforestation and forest degradation.

	"REDD+" goes further and rewards forest conservation and management practices that sequester carbon.
Revenue recycling	Use of (carbon) tax revenues to, for example, lower other distortionary taxes.
Runaway warming	Reinforced (non-linear) global warming, that might be caused by (poorly understood) unstable feedback mechanisms in the climate system (e.g., release of underground or underwater methane).
SDSs	Small Developing States. A group of countries sharing similar sustainable development challenges, including small but growing populations, limited resources, remoteness, susceptibility to natural disasters, vulnerability to external shocks, excessive dependence on international trade, and fragile environments.
SDGs	Sustainable Development Goals. A collection of 17 goals set by the UN General Assembly in 2015 covering global warming, poverty, health, education, gender equality, water, sanitation, energy, urbanization, environment, and social justice. Each goal has a set of targets to achieve and in total there are 169 targets.
Tonne	1,000 kilograms. This is the standard unit for measuring CO_2 emissions (rather than a short ton, which is 2,000 pounds or 907 kilograms).
UNFCCC	United Nations Framework Convention on Climate Change. This is an international environmental treaty produced at the 1992 Earth Summit. The treaty's objective is to stabilize atmospheric GHG concentrations at a level that would prevent 'dangerous interference with the climate system'. The treaty itself sets no mandatory emissions limits for individual countries and contains no enforcement mechanisms but instead provides for updates or 'protocols'.
WTO	World Trade Organization. An organization that seeks to promote and liberalize international trade.

CONTEXT: ISSUES AND CHALLENGES IN MEETING PARIS COMMITMENTS

1. **While analytical work at the IMF over the last decade lays out general principles for mitigation and adaptation using fiscal instruments,[1] and efficient pricing of energy,[2] this paper focuses on the practical policy implementation issues for meeting climate commitments on a country-by-country basis.** This section provides the policy context and the following two sections cover, respectively, mitigation (the major focus, given its universal relevance and amenability to quantitative, cross-country analysis) and adaptation. A final section summarizes the Fund's role and next steps.

Figure 1. The Global Mitigation Challenge



Sources: Panel (a): CAT (2018) (based on IPCC 2018). Panel (b): Le Quéré and others (2018), Tollefson (2018).
Note: In panel (a) emissions pathways average across different scenarios. In panel (b) oil includes international aviation and maritime emissions.

2. **Progressing on the temperature stabilization goals of the Paris Agreement would imply immediate and rapid transitions to low-emission economies.** Meeting the Paris goals of containing projected warming to 2°C—with an aspirational target of 1.5°C—would imply immediate and dramatic reductions in carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions. For example, cutting emissions by a third below business as usual (BAU) levels in 2030 would be consistent with the 2°C target (Figure 1a). Without action, in central case scenarios global average temperatures are projected to rise 4°C above pre-industrial levels over the 21st century (they are already 1°C above), with increasing (but poorly understood) risks of globally catastrophic scenarios

[1] For general discussions of mitigation policy see IMF (2008a and 2008b), Parry and others (2012), Parry and others (2015a); for adaptation policy see IMF (2016 and 2019); and for both see Farid and others (2016) and IMF (2015a).

[2] For example, Clements and others (2013), Parry and others (2014), Coady and others (2015, 2019).

such as runaway warming (e.g., from sub-surface methane releases), collapsing ice sheets, and flipping ocean circulatory systems.[3] 17 of the 18 warmest years on record have occurred since 2000.[4]

3. BAU fossil fuel CO_2 emissions—growing much faster than most other emission sources—are projected to roughly double by 2100. Atmospheric CO_2 concentrations under the BAU are projected to reach about three times their pre-industrial levels by the end of the century.[5] Annual GHG emissions are currently about 50 billion (metric) tonnes of CO_2 equivalent, with 63 percent from fossil fuel CO_2 emissions (Figure 1b). National governments may lack incentives to mitigate GHGs however—the free rider problem—as the potential global climate benefits mostly accrue to other countries and (due to the long atmospheric residence times of GHGs[6] and gradual adjustment of the climate system) to future generations.

4. Climate change is potentially macro-critical at the global, and in many cases national, level, and mitigation policies have large fiscal implications. Central case scenarios suggest warming of 4ºC would permanently lower global GDP by around 3.5 percent below GDP levels with no climate change.[7] The overriding concern however is tail risks that are difficult to incorporate in these estimates and that could imply considerably larger global damages.[8] Indeed the World Economic Forum[9] now ranks climate change as the greatest threat to the planet. Some countries are more at risk than others: simulations suggest BAU temperature rises (let alone other climatic effects) would lower GDP for a typical low-income country by 9 percent in 2100.[10] Many small island states are no higher than a few meters above sea level and face an existential threat from projected sea level rises of 0.3-2.5 meters by 2100.[11] As climate change builds up over time, not only low-income countries but also advanced economies may experience substantially worse macroeconomic effects.[12] On the mitigation side, carbon pricing could have potentially large impacts on fiscal balances for most countries (see below).

5. The 2015 Paris Agreement established a process that could lead to meaningful mitigation action,[13] consistent with other Sustainable Development Goals (SDGs). Of the 195

[3] NAS (2018). For BAU temperature projections see, for example, Kriegler and others (2015), Figure 1, Nordhaus (2018).

[4] NASA (2018).

[5] Projections are from Nordhaus (2018).

[6] CO_2 emissions have an expected atmospheric residence time of about 100 years.

[7] See Nordhaus (2018), pp. 345, though impact assessments remain contentious (e.g., Pindyck 2017).

[8] Weitzman (2011).

[9] WEF (2019).

[10] IMF (2017).

[11] NOAA (2018).

[12] Burke and others (2015), IMF (2017), Ch. 3.

[13] See UNFCCC (2016), UNFCCC (208a), and Stern (2018).

signatories to the Agreement, 190 submitted 'Intended Nationally Determined Contributions' (INDCs) containing (in 180 cases) mitigation strategies, mostly to be met by 2030. INDCs reverted to 'Nationally Determined Contributions' (NDCs) following ratification of the Paris Agreement in 2016.[14] Countries are required to report progress on implementing NDCs every two years and (from 2020 onwards) to submit revised pledges (which are expected to be progressively more stringent) every five years. Curbing fossil fuel use need not conflict with other SDGs (though it may affect the means and cost of achieving them). For example, expanded energy access could come from clean sources or fossil fuels priced to reflect their full supply and environmental costs.

Table 1. Paris Mitigation Contributions and CO_2 Emissions Data, Selected Countries

Country	Paris Mitigation Contribution[a]	2030 BAU		
		Share of Global CO_2	Tonnes CO_2/US$1000 Real GDP	Tonnes CO_2 Per Capita
Argentina	Reduce GHGs 15% (30%) below BAU in 2030	0.5	0.40	4.1
Australia	Reduce GHGs 26-28% below 2005 by 2030	1.1	0.26	14.3
Canada	Reduce GHGs 30% below 2005 by 2030	1.5	0.28	13.8
China	Reduce CO_2/GDP 60-65% below 2005 by 2030	33.1	0.58	9.1
Colombia	Reduce GHGs 20% (30%) below BAU by 2030	0.2	0.23	1.8
Costa Rica	Reduce GHGs 44% below BAU by 2030	0.0	0.11	1.5
Côte d'Ivoire	Reduce GHGs 28% below BAU by 2030	0.1	0.23	0.6
Ethiopia	Reduce GHGs (64%) below BAU by 2030	0.0	0.10	0.1
France	Reduce GHGs 40% below 1990 by 2030	0.7	0.10	4.2
Germany	Reduce GHGs 40% below 1990 by 2030	1.8	0.17	8.4
India	Reduce GHG/GDP 33-35% below 2005 by 2030	9.2	0.64	2.3
Indonesia	Reduce GHGs 29% (41%) below BAU in 2030	1.5	0.37	1.9
Iran	Reduce GHGs 4% (12%) below BAU by 2030	1.4	1.54	5.8
Jamaica	Reduce GHGs 7.8% (10%) below BAU by 2030	0.0	0.41	2.3
Japan	Reduce GHGs 25.4% below 2005 by 2030	2.7	0.22	8.8
Kazakhstan	Reduce GHGs 15% (25%) below 1990 by 2020	0.7	0.96	12.0
Macedonia, FYR	Reduce GHGs 30% (36%) below BAU in 2030	0.0	0.47	3.5
Mexico	Reduce GHGs 25% (40%) below BAU in 2030	1.2	0.33	3.4
Morocco	Reduce GHGs 13% (25%) below BAU by 2030	0.2	0.40	1.7
Pakistan	No specific target. Min. (10%) below BAU by 2030 mentioned in NDC	0.5	0.49	0.8
Philippines	Reduce GHGs (70%) by 2030 relative to BAU of 2000-2030	0.4	0.26	1.2
Russia	Reduce GHGs 25-30% below 1990 by 2030	3.4	0.88	9.5
Saudi Arabia	Reduce GHGs 130 million tonnes below BAU by 2030	1.2	0.58	11.2
South Africa	Reduce GHGs 398-614 million tonnes in 2025 and 2030	1.0	0.97	5.6
Tanzania	Reduce GHGs 10-20% below BAU by 2030	0.0	0.15	0.2
Turkey	Reduce GHGs up to 21% below BAU by 2030	1.0	0.43	4.0
United Arab Emirates	Clean energy from 0.2% to 24% of energy consumption by 2021	0.6	0.43	14.6
United Kingdom	Reduce GHGs 40% below 1990 by 2030	0.9	0.13	5.3
United States	Reduce GHGs 26-28% below 2005 by 2025	12.3	0.23	13.7
Vietnam	Reduce GHGs 8% (25%) below BAU in 2030	0.7	0.60	2.6

Source: UNFCCC (2018b), IMF staff calculations (see below).
Notes: [a] Some countries have specified both conditional and unconditional pledges, where the former are contingent on external finance and other support—in these cases the conditional pledges are in parentheses. CO_2 refers to fossil fuel emissions only.

6. **But pledges are heterogenous, insufficient to meet temperature targets, and may have limited impacts for some large emitters**. Pledges vary (see Table 1 for selected countries and Appendix I for additional countries) in terms of: (i) target variables (e.g., emissions, emissions intensity, clean energy shares); (ii) nominal stringency (e.g., emission reduction goals vary between 8 and 70 percent in Table 1); (iii) baseline years against which reduction targets apply (e.g., historical versus projected BAU emissions); and (iv) whether they are contingent on external finance and other (e.g., technical) support.[15] This heterogeneity hinders comparison of effort levels and implies quite

[14] See UNFCCC (2018a and 2018b), WBG (2018), pp. 73-74.

[15] Pledges are also voluntary as they cannot be enforced across the entire international community (under a mandatory approach, countries might be less ambitious—e.g., Stern 2018).

considerable cross-country dispersion in emissions prices implicit in NDCs (see below). Current NDCs are consistent with a global emissions trajectory stabilizing projected warming at about 3°C.[16] China, India, and the United States account for 33, 9, and 12 percent respectively of projected BAU (fossil fuel) CO_2 emissions in 2030 (Table 1). Mitigation pledges in China and India will, however, require smaller proportionate emissions reductions than for many other large economies (see below)—partly reflecting their smaller contribution to historical atmospheric CO_2 accumulations—and the United States has announced its withdrawal from the Paris Agreement in 2020.

7. Quantitative, country-level analysis of policy options can help move carbon pricing and other mitigation policies forward. Besides a global climate concern going beyond its own interests, countries may have incentives to act unilaterally if this: generates substantial domestic environmental co-benefits (e.g., fewer air pollution deaths); mobilizes domestic revenues; puts peer pressure on others; and leverages external finance. Mitigation policies are proliferating. For example, many countries now have energy efficiency and renewables policies[17] and over 50 national or sub-national governments have implemented pricing through carbon taxes or emissions trading systems (ETSs)[18] (Table 2), though the global average CO_2 price is currently only US$2 per tonne.[19] To design, and scale up, national mitigation strategies, it is helpful for governments to have transparent, quantitative frameworks for projecting the emissions requirements for their NDC commitments, and for assessing the environmental, fiscal, and economic impacts of carbon pricing and alternative policy options. Consistent, cross-country procedures for evaluating mitigation pledges and their implicit prices can also

Table 2. Selected Carbon Pricing Schemes Around the World, 2018

Country/Region	Year Introduced	Price 2018, US$/Tonne CO2	Coverage, %GHGs
Carbon taxes			
Chile	2017	5	39
Colombia	2017	6	40
Denmark	1992	29	40
Finland	1990	77	38
France	2014	55	37
Iceland	2010	36	50
Ireland	2010	25	48
Japan	2012	3	68
Mexico	2014	1-3	47
Norway	1991	56	63
Portugal	2015	8	29
S. Africa	2019	10	10
Sweden	1991	139	40
Switzerland	2008	101	35
ETSs			
California	2012	15	85
China	expected 2020	na	na
EU	2005	16	45
Kazakhstan	2013	2	50
Korea	2015	21	68
N. Zealand	2008	15	52
RGGI	2009	4	21
Carbon price floors			
Canada	2016	18	70
UK	2013	25	24

Source: WBG (2018), and authors calculations.
Note: Coverage rates for fossil fuel CO_2 emissions are significantly higher than for total GHGs.

[16] UNEP (2018).

[17] IEA (2018a).

[18] Under these systems, covered sources are required to hold allowances for each tonne of emissions; the government caps the quantity of allowances and market trading establishes the emissions price.

[19] Calculated from WBG (2018).

inform international dialogue over revisions to NDCs.

8. Pricing and finance at the international level can also help. An international carbon price floor arrangement—requiring participants to impose a minimum price on carbon—could reinforce domestic mitigation efforts, accommodate diversity in prices and pricing instruments, and provide some reassurance against competitiveness impacts; and the technicalities seem manageable (see below). There also appear feasible pathways for meeting the advanced economies' pledge to mobilize US$100 billion a year (from both public and private sources in unspecified proportion) from 2020 onwards for climate projects in developing countries. However, the measurement of finance flows will likely remain contentious,[20] and total investment needs are at least an order of magnitude larger than pledged finance.[21]

9. Political economy aspects can, however, be challenging. To enhance the acceptability of fuel price reform, Fund advice has emphasized the importance of a broad strategy that includes specifics on how revenues are to be used, assistance to vulnerable households and firms, gradual price reform, stakeholder consultation, and public communication.[22] But pricing may also need to be part of a broader fiscal and regulatory reform agenda that is perceived as fair overall and it can be difficult to anticipate public opposition. For example, resistance to carbon pricing can be compounded if it is introduced simultaneously with broader tax reductions perceived as benefitting the wealthy. If political obstacles are insurmountable or might require using up all the fiscal dividend in universal compensation schemes, fiscal instruments which are less efficient but avoid increases in energy prices (e.g., that tax/subsidize activities or products with above/below average emissions intensity), or regulations (e.g., emission standards for vehicles, appliances, and power generation), may provide a reasonable 'second-best' approach.

10. 140 NDCs include physical adaptation investment plans[23] though a more overarching resilience-building strategy is needed. These strategies should promote risk diversification across *ex ante* buffers (e.g., contingency funds, reduced debt) and *ex post* instruments (e.g., catastrophe bonds, regional insurance). They should ensure sustainable macro-fiscal frameworks accounting for climate/disaster risks, domestic financing of climate investments and fiscal buffers, as well as positive GDP effects from greater physical/fiscal resilience. Climate investments should also be integrated into national processes to ensure they are prioritized and the funds are efficiently spent. A complementary paper[24] addresses these issues in depth—here the focus is on the fiscal policies,

[20] UNFCCC (2018c), Figure 1, put flows for 2016 at US$74.5 billion, with 45, 26, 21, and 8 percent from bilateral sources, multilateral development banks, privately-leveraged sources and miscellaneous sources (e.g., climate funds) respectively, though Government of India (2016) suggests that only a small amount of recorded finance could be rigorously defended.

[21] For example, a review of NDCs and other policies in 21 developing economies (representing half of global GHGs) found an initial investment need of US$23 trillion from 2016 to 2030 for mitigation alone (IFC, 2016).

[22] Clements and others (2013).

[23] GIZ (2016).

[24] IMF (2019).

institutions and systems required to enable climate-vulnerable states to boost their resilience to the impacts of climate change.

MITIGATION

This section reviews instrument choice and design principles for domestic mitigation; presents country-specific results on the impacts of carbon pricing and trade-offs with other instruments; and discusses international pricing regimes. The focus is mostly on fossil fuel CO_2 emissions (given their large and growing share of global GHG emissions, the practicality of pricing them, and the availability of cross-country data for quantifying policy impacts). The potential for fiscal instruments to mitigate forestry, non-CO_2 GHGs, and other emissions is also highlighted.

A. General Principles for National-Level Mitigation[25]

11. Mitigation strategies will reflect countries' differing initial positions, political constraints, and circumstances, but carbon pricing has considerable attractions. Comprehensive carbon pricing can provide: (i) across-the-board incentives for energy conservation and shifting to cleaner fuels; (ii) substantial government revenue (which could be especially valuable where informality constrains revenue mobilization from standard fiscal instruments); and (iii) substantial domestic environmental gains (e.g., fewer local air pollution deaths). Carbon pricing has become the focal point for international dialogue on mitigation.[26] At the same time, the political difficulty of carbon pricing, due to its first-order impact on energy prices, underscores the need for accompanying measures to address sensitivities and understanding of the trade-offs with other (possibly more acceptable) instruments.

12. Ideally, carbon pricing should be comprehensive, well designed (with prices rising predictably over time and effectively targeted for mitigation), with the revenues used wisely. In fact, efficient revenue use can be critical for maintaining the economic case for pricing over other (e.g., regulatory) approaches and raises questions (from an efficiency perspective) about diverting large amounts of carbon pricing revenues from the general budget for lump-sum dividends, earmarked spending, or free ETS allowance allocations (see Box 1).

[25] This section builds on earlier discussion in Farid and others (2016), Section III.

[26] See, for example, activities of the Carbon Pricing Leadership Coalition (www.carbonpricingleadership.org).

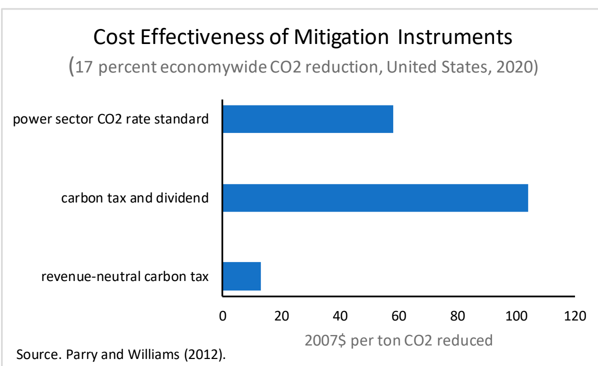
Box 1. The Importance of Using Carbon Pricing Revenues Efficiently

A large, somewhat technical, literature[1] decomposes the linkages between carbon taxes and the broader fiscal system into two effects.

First is the potential economic efficiency gain from 'revenue recycling'. This could reflect gains from using revenues to reduce broader (e.g., income and payroll) taxes that distort the economy by deterring investment and labor force participation, promoting informality, creating a bias towards tax-preferred spending like housing and fringe benefits, etc. More generally, using revenues to fund public investments—perhaps to meet SDGs—or reduce fiscal deficits, could generate comparable efficiency gains.

The second effect is the efficiency loss from the potential impact of higher energy costs on reducing overall investment and employment (which are already inefficiently low, due to harmful incentive effects of labor, capital, and other taxes)—put another way, taxes on fuels act like implicit taxes on labor and capital. The effects are complex, however, depending, for example, on the labor intensity of the expanding (green) sectors relative to the contracting (polluting) sectors.

The first effect can dominate the second effect in some cases. The more important point however, is that if carbon pricing revenues are not used to increase economic efficiency, pricing can be substantially less cost effective in a broad sense than regulatory combinations or similar policies mimicking many of the behavioral responses from carbon pricing (e.g., emissions standards for power generators, vehicles, and electricity-using products). This is because the latter policies avoid a large first-order impact on energy prices, thereby limiting the increase in energy costs and potentially adverse economy-wide reductions in employment and investment.



These results are illustrated in the figure, based on estimates for the United States.[2] Cutting economy-wide CO_2 emissions by 17 percent below BAU levels in 2020 costs an estimated US$13 per tonne if the reduction is induced by a revenue-neutral carbon tax (i.e., with offsetting reductions in distortionary income taxes), but US$104 per tonne if induced by a carbon tax with revenues returned in lump-sum dividends, and US$58 per tonne if the reduction comes from setting a carbon emission rate standard for the power sector (achieving the same economy-wide CO_2 reduction). Lump-sum dividends do not generate any efficiency benefits for the economy as they do not, for example, improve incentives for work effort or capital accumulation. But, at the same time, some suggest they would help with political acceptability.[3]

[1] See, for example, Bovenberg and de Mooij (1994), Bento and others (2018), Goulder and others (1999), Parry and Williams (2012).
[2] From Parry and Williams (2012).
[3] For example, the Climate Leadership Council (www.clcouncil.org).

13. **Carbon taxes might be viewed as the most natural instrument for meeting these criteria, though they have fallen somewhat short in practice.** Carbon taxes are charges on fossil fuels, with rates equal to the fuel's CO_2 emissions factor multiplied by a CO_2 emissions price. They can be comprehensively applied to fuels by collection upstream (i.e., integrated into fiscal regimes for extractives), or midstream (i.e., integrated into excises for processed fuels) and (for the purpose of meeting NDCs, which are focused on domestic emissions) should cover imported but not

exported fuels.[27] Carbon taxes with clearly specified rate schedules can establish predictable prices, with revenues accruing to finance ministries. As of 2018, 16 national governments had introduced carbon taxes (Table 2), though typically with only partial coverage (e.g., Colombia and Mexico exclude some, or all, natural gas). Moreover, current CO_2 prices, mostly about US$5-35 per tonne, are often below levels needed for mitigation pledges (see below). Globally, an estimated 44 percent of carbon tax revenues have been used for lowering other taxes, 28 percent for general funds, and 15 percent for environmental spending.[28]

14. ETSs could also meet the criteria but have fallen short in practice as well. Several ETSs are now in place (Table 2), most notably the EU ETS in which 31 countries participate. Additionally, a national-level ETS is slated for introduction in China in 2020. Such schemes may be chosen over carbon taxes on practical or legal grounds.[29] ETSs have been applied downstream to power generators and large industry, which, however, typically misses around 50 percent of emissions (from vehicles, buildings, and small enterprises). Moreover, the administrative costs of monitoring emissions and allowance markets may be prohibitive for a small jurisdiction or a capacity-constrained developing country (while much of the legal and administrative infrastructure for taxes would typically exist).[30] Prices in ETSs are uncertain and sometimes depressed by overlapping instruments[31]—recent prices have been around US$5-25 per tonne of CO_2 (Table 2). Furthermore, prospects for large budget revenues can be diminished by: (i) the much narrower base for emissions pricing; (ii) the possibility of free allowance allocations; and (iii) earmarking of revenues from allowance auctions—in striking contrast with taxes, globally an estimated 70 percent of ETS revenues have been used for environmental spending, 21 percent for general funds, and 9 percent for lowering other taxes.[32] These shortcomings could be overcome, however: ETSs could be extended midstream to cover fuels for small-scale users (though this would duplicate fuel tax administration); minimum auction prices or other mechanisms can (and often do) promote price stability;[33] and allowances could be fully auctioned with revenues remitted to finance ministries.

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[27] Rebates are ultimately needed for downstream fuel users (e.g., fossil fuel plants) to promote adoption of CCS technologies (which might become viable with carbon prices around US$70 per tonne—see Rubin and others 2015). Calder (2015) and Metcalf and Weisbach (2009) provide comprehensive discussions of administrative issues for carbon taxes (in a US context).

[28] Carl and Fedor (2016), Table 2.

[29] For example, ETSs can meet annual emissions targets with more certainty; they may be a more natural extension of pre-existing air pollution regulations applied at the point of combustion; and they may be a more suitable instrument if mitigation policy is under the purview of environment ministries. Unanimity requirements may have precluded a carbon tax in the EU.

[30] Markets may also be too thin to support trading (South African National Treasury 2013).

[31] For example, energy efficiency and renewable policies lower emissions prices without affecting emissions when emissions are capped by an ETS.

[32] Carl and Fedor (2016), Table 1.

[33] Flachsland and others (2018).

15. Carbon price trajectories can be aligned with mitigation objectives in NDCs. This requires projecting fuel use and emissions by sector with and without carbon pricing (see below) and periodically updating prices if emissions targets are systematically unmet. Other approaches in the literature (not tied to country commitments) look at globally efficient prices. One strand focuses on cost-effective carbon price trajectories consistent with temperature stabilization goals, while another focuses on 'Pigouvian' taxes to reflect environmental damages. The former approach implies that emissions prices of around US$50–100 per tonne by 2030 would (along with other policies) be consistent with the 2°C goal, while a recent assessment of the latter suggests prices of US$55 per tonne by 2030 (all prices in US$2015).[34]

16. Carbon taxes are not new and existing taxes often amount to substantial carbon prices. Averaged globally, road fuel taxes are currently around US$1 per liter, or US$380 per tonne of CO_2 emissions from these fuels, while average royalty rates for oil and gas extraction are around 12 and 6 percent respectively, implying taxes equivalent to US$33 and US$10 per tonne of CO_2 respectively.[35] Carbon charges need to be imposed on top of these taxes because existing taxes are embedded in BAU fuel use projections and may be addressing non-carbon externalities and fiscal needs.

17. For acceptability or other reasons, alternative, second-best mitigation instruments may be used, but the same basic design principles should apply. Pricing might be combined with other (less efficient but perhaps more acceptable) instruments that do not raise energy prices. Ideally, other instruments would mimic, insofar as possible, the behavioral responses of carbon pricing, with certainty over emissions prices and combined prices from the policy package aligned with mitigation objectives. Although other approaches have tended to focus on regulations (e.g., vehicle emission rate standards), their fiscal analogue—revenue-neutral feebates—are a promising alternative. These policies involve a sliding scale of fees on firms or products with above average energy/emissions intensity and corresponding rebates for firms or products with below average energy/emissions intensity.[36] A limitation of feebates, however, is that they do not promote the full range of mitigation opportunities: for example, they do not encourage people to drive less (unlike fuel taxes which raise the marginal costs of driving).

[34] See Stern and Stiglitz (2017) and Nordhaus (2017) respectively. Pigouvian tax estimates are however highly sensitive to differing perspectives on intergenerational discounting and treatment of extreme risks (e.g., Stern 2007, Weitzman 2011), and the severity of damage risks varies across countries, raising questions about the practicality of operationalizing them in international agreements.

[35] The first estimate is calculated from a spreadsheet tool on energy prices and subsidies described in Coady and others (2019). The second estimate is calculated from a sample of 59 countries (accounting for a quarter of global petroleum production) using 2017 Rystad Energy data on petroleum volume and value and staff data on fiscal regimes, assuming royalties are minimum taxes from application of ad-valorem royalties, binding cost recovery limits, and government profit petroleum shares.

[36] Feebates have been integrated in vehicle tax systems (as in, for example, Denmark, France, Germany, Mauritius, the Netherlands, Norway, Sweden and the United Kingdom—see Bunch and others 2011, Cambridge Econometrics 2013) to promote low-emission vehicles. But they could also be applied to promote more energy-efficient appliances, lightbulbs, air conditioners, machinery, and so on or to lower emissions intensities for power generators.

18. Research and development (R&D) into clean technologies is an important complement to carbon pricing (in large economies). Two market failures—emissions externalities and knowledge spillovers—need to be addressed in mitigating climate change and require acting on both fronts simultaneously.[37] Even with a robust global CO_2 price, targeted incentives are also needed at various stages of the R&D process. Furthermore, technology barriers may be more severe for clean energy than for other sectors as energy technologies often require networks and have long lifetimes, high upfront costs, and uncertain returns (due to uncertainty over future mitigation policy).[38] At the basic research stage, government support is needed, and some analysts recommend gradually increasing current spending.[39] At the applied R&D stage, further interventions are needed to counteract spillovers from new technologies (e.g., prizes for technologies that are, and patents for technologies that are not, easy to identify in advance). At the deployment stage, incentives (e.g., tax rebates, subsidies, loan guarantees) may be needed (e.g., to address learning-by-doing spillovers from use of new technologies) and should be designed with care (e.g., to avoid forcing new technologies irrespective of their future costs).[40]

19. Complementary infrastructure and financial market policies are also needed. Infrastructure investments might include, for example, power grid upgrades to integrate (intermittent and remotely-located) renewables and natural gas or charging stations for electric vehicles. Accommodating frameworks for financial markets can also help to lubricate private investment for mitigation in response to price signals (Box 2).

Box 2. Financial Sector Policies to Complement Mitigation and Adaptation

The financial system can play a key role in supporting price signals to redirect finance towards clean technologies, without losing sight of financial stability. It already has a crucial role in financial protection through insurance and other risk-sharing mechanisms to reduce the cost of disasters when they occur.

Most climate finance is likely to be intermediated through the financial system. Advanced economies pledged to mobilize US$100 billion a year from 2020 for mitigation and adaptation in developing economies. The needs for global finance are an order of magnitude higher, with estimated infrastructure needs[1] about US$6 trillion per year to 2030. This would require both public and private finance.

Climate change, and the public and private sector's responses, can give rise to financial risks, including physical risks (climate-related disasters) and risks related to the transition to a low-carbon economy. A manifestation of the physical risks are the annual global weather-related insured losses, which increased from about US$10 billion in the 1980s to about US$50 billion in the last decade and US$138 billion in 2017—the highest since 1980.[2] Transition risks are challenging to quantify, but recent data illustrate how disruptive changes, linked to policy, technology, and other economic factors, cause sharp changes in valuations, such as drops in the values of 'stranded assets'. Market valuation of top U.S. coal producers, which fell by 95 percent between 2010 and 2017,[3] provides an early illustration of the potential disruptions.

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[37] Acemoglu and others (2012).

[38] For example, Dixit and Pindyck (1994).

[39] About US$6 billion and €4 billion a year in the United States and European Union respectively (see Dechezleprêtre and Popp 2017, Newell 2015).

[40] In light, too, of general concerns that arise with the use of tax incentives: see IMF and others (2015).

Box 2. Financial Sector Policies to Complement Mitigation and Adaptation (Concluded)

The low-carbon economy transition may take many years, but technological breakthroughs or abrupt changes in policies may change asset valuations, triggering financial instability. Recent stress tests for some advanced economy financial institutions suggest that their losses from a disruptive energy transition—meaning abrupt policy measures and technological changes that lower CO_2 emissions but also disrupt parts of the economic system, creating short-run economic losses—would be sizeable but manageable.[4]

Integrating sustainability into financial decisions requires appropriate incentives for financial institutions. Carbon pricing can provide strong price signals to help catalyze private sector finance. To help ensure this is done efficiently and in line with maintaining financial stability, governments, central banks, regulators, and others can support carbon pricing by: (i) improving financial system information through guidance, labeling schemes, and mandatory requirements; (ii) strengthening risk management by integrating environmental factors into oversight, supervision, and stress testing; and (iii) clarifying legal frameworks including financial institutions' fiduciary responsibilities with respect to long-term risks.

Closing data gaps is critical for aligning incentives, results measurement, proper asset valuation, and effective risk management. Systematic data on private flows are lacking. Encouragingly, financial institutions responsible for managing US$80 trillion of assets have supported the G-20 Task Force for Climate-Related Disclosures. Disclosures are still uneven across asset classes and jurisdictions, although consensus is building around methodologies for disclosing some information, such as the carbon footprint of investment portfolios.

Major central banks and supervisors have been working to develop supervisory approaches to ensure the financial system is fit for the transition. Twenty-four central banks and supervisory agencies from five continents have teamed up to enhance the financial system's role in managing risks and mobilizing capital for green and low-carbon investments in the context of environmentally sustainable development.[5]

The IMF supports these efforts. In addition to the Climate Change Policy Assessments, which enhance countries' prospects for attracting finance (below), Fund staff have undertaken other activities to support resilience, provided inputs for G-20 study groups, liaised with central banks and other agencies, and worked on improvements in stress testing for climate risks (including in the Financial Sector Assessment Program).

[1] OECD (2017).
[2] Munich Re (2017).
[3] Breeden (2018).
[4] Vermeulen and others (2018).
[5] Central Banks and Supervisors Network for Greening the Financial System (https://www.banque-france.fr/en/financial-stability/international-role/network-greening-financial-system).

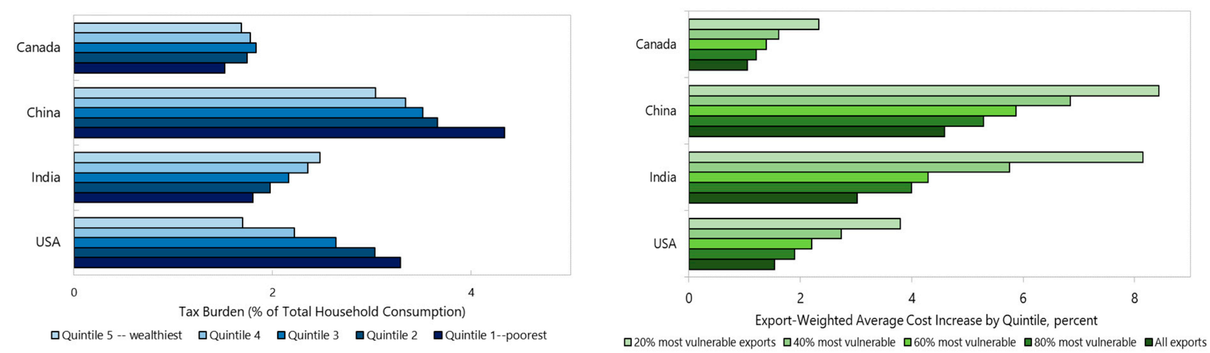
20. Country circumstances matter for the household incidence of carbon pricing. Carbon pricing can be (Figure 2a) anything from moderately regressive (as in China and United States), to distribution neutral (as in Canada), to moderately progressive (as in India)—with burdens measured relative to consumption. In China and the United States, for example, carbon pricing has a disproportionately larger impact on electricity prices than in Canada (where there is greater reliance on renewable generation) and lower income households tend to have larger budget shares for electricity than wealthier households. In India, on the other hand, burdens on low-income households are relatively smaller, due to their limited access to electricity and vehicle ownership.[41] The fraction of carbon pricing revenues needed to compensate the bottom income quintile for these

[41] See Dorband and others (2019) for more country-level incidence results.

burdens—around 2-4 percent of their consumption in 2030 for a US$35 per ton carbon price—is minor, as most of the burden of higher energy prices is borne by higher income groups.

Figure 2. Incidence of US$35 per tonne Carbon Price, 2030

(a) Households *(b) Firms*



Source: IMF staff estimates.
Note: Household incidence uses standard IMF procedures (e.g., Fabrizio and others 2016) involving input-output tables and household expenditure surveys to obtain first order approximations of impacts, assuming carbon prices are fully passed forward into intermediate and final product prices. Household burdens (capturing direct impacts from higher electricity and fuel prices and indirect effects from higher prices for consumer products in general) are defined relative to consumption rather than income as the former is generally viewed as a better proxy for lifetime income. Incidence effects tend to be more regressive when measured against income. The above estimates are forward-looking (burdens are estimated, given 2030 energy price changes from IMF spreadsheet model) and account for the declining energy intensity of consumption and production over time. For additional information on methodology and sources, see Parry and others (2018a).

21. The same applies for burdens on vulnerable firms. Averaged across all exporters (Figure 2b), a US$35 carbon price in 2030 increases costs moderately in Canada (1.0 percent), the United States (1.5 percent) and India (3.0) and somewhat more significantly in China (4.6 percent) (where, for example, power generation has the highest CO_2 intensity). Of more concern are the most vulnerable exporters (e.g., basic metals), and here the cost increases (for the 20 percent of most vulnerable exporters) are more significant: Canada (2.3 percent), United States (3.8 percent), India (8.2 percent) and China (8.4 percent).[42]

22. Targeted measures can compensate vulnerable households and workers, though they can bring their own efficiency concerns. Targeting limits revenue diversion from the general budget thereby helping to contain overall policy costs to the economy (Box 1), but there are trade-offs among instruments. For example, payroll tax rebates and earned income tax credits disproportionately benefit low-income households while also promoting labor force participation, but they do not reach the non-working poor. Transfer payments or categorical benefits (e.g., child benefits, and social pensions) can reach the latter, but do not promote extra work effort, may increase administrative burdens, and may (through means-testing) distort work incentives.

[42] Some minor fraction of the burden of carbon pricing may be passed backward in lower producer prices, though the incidence implications become difficult to estimate (Fullerton and Heutal 2011).

Assistance programs are also needed for displaced workers and would typically require a negligible fraction of carbon pricing revenues.[43]

23. The same applies for compensating vulnerable firms. Efficient resource allocation generally implies that industries unable to compete when energy is efficiently priced should shrink or adapt, though policy adjustment should be gradual with programs to ease transitions, and competitiveness concerns are less pronounced with global action on mitigation. Transitory relief might be provided to vulnerable firms through output-based rebates (or, equivalently, exemptions/credits for infra-marginal emissions or fuel use).[44]

24. Border carbon adjustments (BCAs)[45] can in principle have beneficial efficiency effects through reducing emissions leakage,[46] but may have limited effectiveness and raise practical issues. BCAs levy charges on imports and may remit charges on exports to ensure a level playing field given carbon prices levied elsewhere. However, BCAs may have limited impacts on reducing emissions leakage, much of which occurs though changes in global fossil fuel prices rather than firm migration.[47] Moreover, measuring embodied carbon in traded goods can be contentious, BCAs risk retaliation, there is a possibility of their being used for protectionist purposes, and they could be subject to challenge under World Trade Organization (WTO) rules. Furthermore, non-price mitigation policies in other countries may need to be converted into carbon price equivalents to avoid the possibility of BCAs penalizing countries meeting their Paris pledges through non-pricing measures. Furthermore, it is not obvious that BCAs should impose the same penalty on countries whose mitigation pledges imply very different implicit carbon prices (see below).

25. General guidance on carbon pricing needs to account for potentially challenging political economy issues. Necessary ingredients for the successful reform of carbon and energy pricing might include a comprehensive, gradually phased, and well communicated strategy, with clearly specified use of revenues and measures to assist vulnerable groups. But in practice these principles may not be sufficient. For instance, sometimes opposition to higher fuel prices comes from the middle classes and compensating them through adjustments to existing tax and public investment programs may not be transparent, in which case approaches that avoid raising energy prices may be preferred (see Box 1 again). Sometimes it takes dynamic leadership to push reform through, while other times well-designed energy price reforms might be de-railed by a general backlash against broader economic policy or an ideological change in government. Getting reform

[43] See, for example, Morris (2016).

[44] See Fischer and others (2015).

[45] For example, as proposed by the Climate Leadership Council.

[46] Keen and Kotsogiannis (2014).

[47] Estimates of emissions leakage rates (i.e., the fraction of the reduction in domestic emissions offset by increased emissions in other countries) are typically in the range of about 5-20 percent. See Böhringer and others (2012), Burniaux and others (2013).

done is more art than science, and the prospects for success will vary with national circumstances, over time, and with what is happening in other countries.

26. Fiscal instruments could also exploit GHG mitigation opportunities beyond fossil fuel CO_2. Feebate (tax-subsidy) schemes might promote forest carbon storage in cases where property rights are well defined (Box 3). In principle, if all (practically feasible) GHGs were priced (at US$70 per tonne) in 2030, reductions from fossil fuel CO_2 would account for an estimated 66 percent of the global GHG reduction, forestry 13 percent, methane from fossil fuel field operations 6 percent, F-gases (fluorinated gases used, for example, in refrigerants) 5 percent, cement 4.5 percent, while all other sources combined, like livestock emissions, would account for about 5 percent (see Table 3 and Appendix II for details). Although new capacity would be needed, F-gases and clinker use in cement production are reasonably straightforward to tax based on their emissions factors, while fugitive and venting methane emissions from coal and petroleum extraction could (at least in countries with adequate capacity) be priced based on default emission rates, perhaps with rebates provided to firms demonstrating their emission rates are lower than the default rate. Other emissions are more amenable to offset schemes[48] (e.g., sources that are difficult to monitor, such as those from small-scale livestock operations) or direct regulation (e.g., methane emissions from publicly managed landfills and wastewater systems), though their potential contribution to global mitigation is modest. See Appendix II for further discussion.

Box 3. Fiscal Instruments for Promoting Forest Carbon Storage[/1]

Net forestry emissions are projected (albeit with considerable uncertainty) to progressively decline by around 50 percent by 2050 and 100 percent by 2100, reflecting the progressive depletion of opportunities for deforestation.[2] Nonetheless, studies suggest that forest carbon storage could contribute, cumulated over the century and mostly in tropical countries, roughly 20 percent to an efficient global CO_2 mitigation strategy[3] through reduced deforestation, afforestation, and enhanced forest management (e.g., planting larger trees, fertilizing, tree thinning).

At an international level, the REDD+ program[4] seeks to provide finance for promoting forest carbon storage. To complement this program at the domestic level (in countries with adequate capacity), one potentially promising instrument is a nationwide feebate applying a sliding scale of fees/rebates to landowners who reduce/increase carbon storage relative to a baseline level. Feebates can cost-effectively promote all mitigation opportunities across all landowners, can be designed (through appropriate scaling of the baseline) to be revenue-neutral in expected terms, and could be administered through finance ministries once a registry of landowners is established.

In addition, feebates are easily scaled up (through raising the price for stored carbon), and their technical feasibility is improving given that capacity for measuring, and routinely updating, carbon storage inventories is being developed (for 47 tropical countries) under the REDD+ Readiness program.[5]

[48] An emissions offset occurs when an entity covered by a pricing scheme pays for a mitigation project in a sector or country outside of the pricing scheme and counts the emissions savings from the offset as a credit to lower its obligations to pay taxes or acquire emissions allowances. The onus of demonstrating valid emissions reductions would be on the entities claiming offsets rather than government agencies.

Box 3. Fiscal Instruments for Promoting Forest Carbon Storage (Concluded)

In contrast, project-based approaches focus on a narrower range of behavioral responses and landowners, contain no automatic pricing mechanism for prioritizing cost-effective projects, and scaling up may be constrained by high administrative costs from contracting on a landowner-by-landowner basis and the need for finance.

A key limitation of feebates is that they require clearly established property rights, so taxes and subsidies can be applied to the relevant individuals or entities, and private landowners currently account for only around 15 percent of tropical forest ownership.[6] However, marginal land (at the frontier between forest and farmland) and tree farms, both of which are more likely to be privately owned, provide the most important opportunities for enhanced storage.

[1] The discussion here is large based on Mendelsohn and others (2012) and Parry (2019).

[2] IPCC (2014).

[3] This is larger than forestry's current and future emissions share because forestry emissions are relatively more responsive to pricing than energy emissions (e.g., Favero and others 2017, Mendelsohn and others 2012, IPCC 2014).

[4] Reducing emissions from deforestation and forest degradation, where the '+' also rewards forest conservation and management practices that sequester carbon. See www.un-redd.org.

[5] See for example www.forestcarbonpartnership.org/readiness-fund-0.

[6] Whiteman and others (2015), Figure 1.

Table 3. Potential Contribution of Emissions Sources to Mitigation and the Practicality of Exploiting them with Fiscal Instruments

	Emissions Source	Share of Globally Efficient Mitigation, 2030	Administrative Ease of Emissions Taxes/Feebates	
	Fossil fuel (CO_2)	65.8%	Generally straightforward extension of capacity for fuel tax collection	
↓ GHG mitigation potential	Cement (CO_2)	4.5%	Requires new capacity but administrative costs low	↓ Decreasing practicality of fiscal instruments
	F-gases	5.3%		
	Acid feedstocks (N_2O)	0.4%	Requires significant new capacity; may not be feasible for capacity-constrained countries	
	Forestry (CO_2)	13.3%		
	Fuel extraction (CH_4)	6.0%		
	Landfills (CH_4)	2.1%	Regulatory approaches (e.g., specifiying methane capture at landfills or treatment systems for water) may be most practical given public management	
	Wastewater (CH_4)	0.8%		
	Livestock (CH_4, N_2O)	1.0%	Generally best incorporated through offsets	
	Rice (CH_4, N_2O)	0.7%		
	Other agriculture (CH_4, N_2O)	0.2%		

Sources: IMF staff calculations combining results for: (i) a US$70 per tonne carbon price imposed in 2030 for fossil fuels (see below, assuming BAU global emissions increase in the same proportion as for G-20 countries and have the same price responsiveness); (ii) forestry (from IPCC 2014, Figure 11.13); (iii) cement (from van Ruijven and others 2016, Figure 9); and (iv) non-CO_2 GHGs (EPA 2014). Where needed, results are roughly scaled to be consistent with a US$70 emissions price. See Appendix II for details.

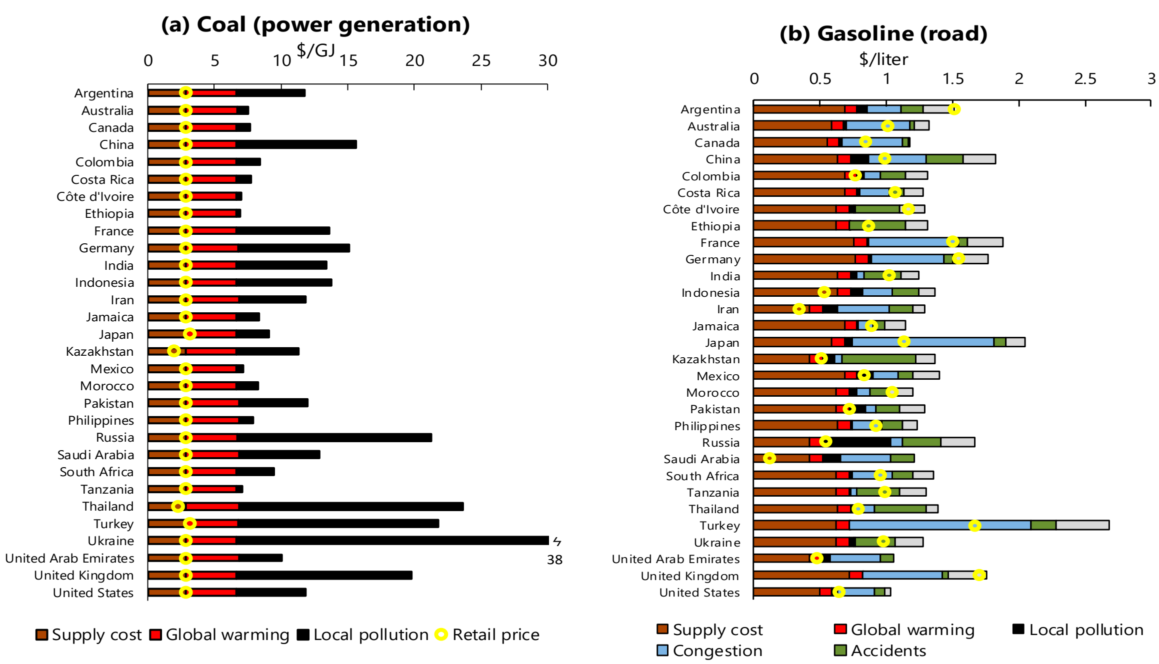
Note: Agriculture accounts for nearly half of BAU non-CO_2 GHG emissions, but practical mitigation opportunities for this sector are limited (e.g., for small-scale operations).

27. Carbon pricing could be embedded in part of a broader reform of energy prices to comprehensively reflect the full range of environmental impacts, including local air pollution. Even with carbon charges, significant additional taxes on coal use may be warranted in countries with high local air pollution, mortality rates from coal combustion, and where road fuels are pervasively underpriced (despite their often being subject to high excises—see Box 4).

28. Carbon pricing in large developing countries could catalyze, and efficiently allocate, private sector finance but is less urgent in low-income, low emitting countries. Unlike under carbon pricing, top-down finance provides no automatic mechanism for ensuring that the most cost-effective projects are selected first. Also, high transaction costs may prevent funding for small-scale opportunities (e.g., adoption of energy efficient vehicles, appliances, or lighting). Although low-income, low emitting countries contributed mitigation pledges for the Paris Agreement (Appendix I), their individual (and collective) contribution to global emissions is minimal and their capacity for enforcing carbon pricing may be weak (e.g., in some cases because it might promote informal use of charcoal and firewood). Developing capacity and financing adaptation strategies is generally the more important priority for these countries.

Box 4. Reflecting the Full Range of Environmental Costs in Energy Prices

To be economically efficient, fuel prices should in principle reflect supply costs, environmental costs—not just global warming, but also local air pollution and, in the case of road fuels, traffic congestion, accidents, and road damage. For fuels consumed by households, general consumption taxes should also be reflected in fuel prices. Although environmental costs are uncertain and contentious, undercharging for an unbiased estimate of them involves inefficiencies, just as with undercharging for supply costs. And although other instruments are needed (e.g., incentives for flue gas desulfurization technologies in coal plants, peak period congestion pricing on busy roads) these lower, but do not eliminate, the fuel tax required to efficiently reflect environmental costs.[1]



Box 4. Reflecting the Full Range of Environmental Costs in Energy Prices (Concluded)

The above figures provide country-level estimates of fully efficient prices for coal (used in power generation) and gasoline (used in vehicles) for selected countries in 2015 and compares them with actual prices. For coal (see panel a), global warming costs (assumed in this figure to be US$40 per tonne) are larger than supply costs. Air pollution costs can be larger than global warming costs, though they vary considerably across countries (with differences in emissions rates, population sizes exposed to pollution, the age and health of the population, and people's willingness to pay for lower health risks). Current prices for coal (which is not subject to large excises) essentially cover supply costs but not environmental costs. Prices for gasoline are usually (though with some exceptions) well above supply costs but tend to fall short of estimates of their fully efficient levels (panel b). In this case, however, (aside from supply costs) the main components of efficient prices are congestion and accident externalities, as well as general consumption taxes, rather than global warming and air pollution costs. Natural gas and (road) diesel fuel also tend to be underpriced, though less severely than for coal (due to smaller environmental costs in the former case and generally high excises in the latter). Subsidies implicit in the undercharging for fossil fuels, aggregated to the global level, amounted to US$4.7 trillion (6.3 percent of global GDP) in 2015.

Source: Coady and others (2019).
Note. Supply costs are based on regional international reference prices.

[1] For example, coal taxes are still needed to promote efficient switching to cleaner fuels and energy conservation and road fuel prices should reflect unpriced congestion costs, at least until road networks are comprehensively covered by peak period pricing.

B. Methodology for Analyzing Domestic Mitigation Policies

29. Fund staff have developed a spreadsheet tool to help countries evaluate progress towards their Paris mitigation pledges. The tool provides standardized analyses, on a country-by-country basis for 135 member countries, of carbon pricing and other mitigation instruments. Appendix III provides mathematical, parameter, and data details. The model starts with use of fossil and other fuels for the power generation, transport, industrial, and household sectors and projects this forward in a BAU scenario using assumptions about: (i) future GDP growth; (ii) income elasticities for energy products; (iii) rates of technological change (e.g., that improve energy efficiency); and (iv) future international energy prices. The power sector includes a model of switching among generation fuels, and the price-responsiveness of fuels in other sectors as well as electricity demand reflects changes in energy efficiency, reduced product use, and switching to cleaner fuels. The impact of mitigation policies on fossil fuel use and CO_2 emissions depends on: (i) their proportionate effect on fuel prices; and (ii) fuel price responsiveness. Price elasticities for electricity and fuels are generally taken to be around -0.5 to -0.8, based on extensive cross-country evidence and results from much more detailed energy models.[49]

30. The model provides consistent and transparent cross-country results and integrates domestic externalities from fuel use. The BAU is defined with no new (or tightening of existing) mitigation policies. Capital dynamics, which diminish fuel price responsiveness in the shorter term, are not modelled, the focus being on the longer-term impacts of (anticipated and gradually phased)

[49] Earlier versions of the spreadsheet model were applied to China, India, and G-20 countries (see Parry and others 2016, 2017, and 2018a respectively).

policies. Supply curves are assumed to be perfectly elastic which may lead to some overestimate of the impact of carbon pricing on fuel use and emissions—however, the underlying price-responsiveness of emissions is broadly in line with computational models with more complex effects and disaggregation (Appendix III).[50] Finally, GDP growth is exogenous to mitigation policy.

C. Quantitative Policy Results for Selected Countries

Emissions projections and policy analyses are presented below for selected countries/country groups[51] and in Appendix IV for 135 countries.

BAU Scenarios

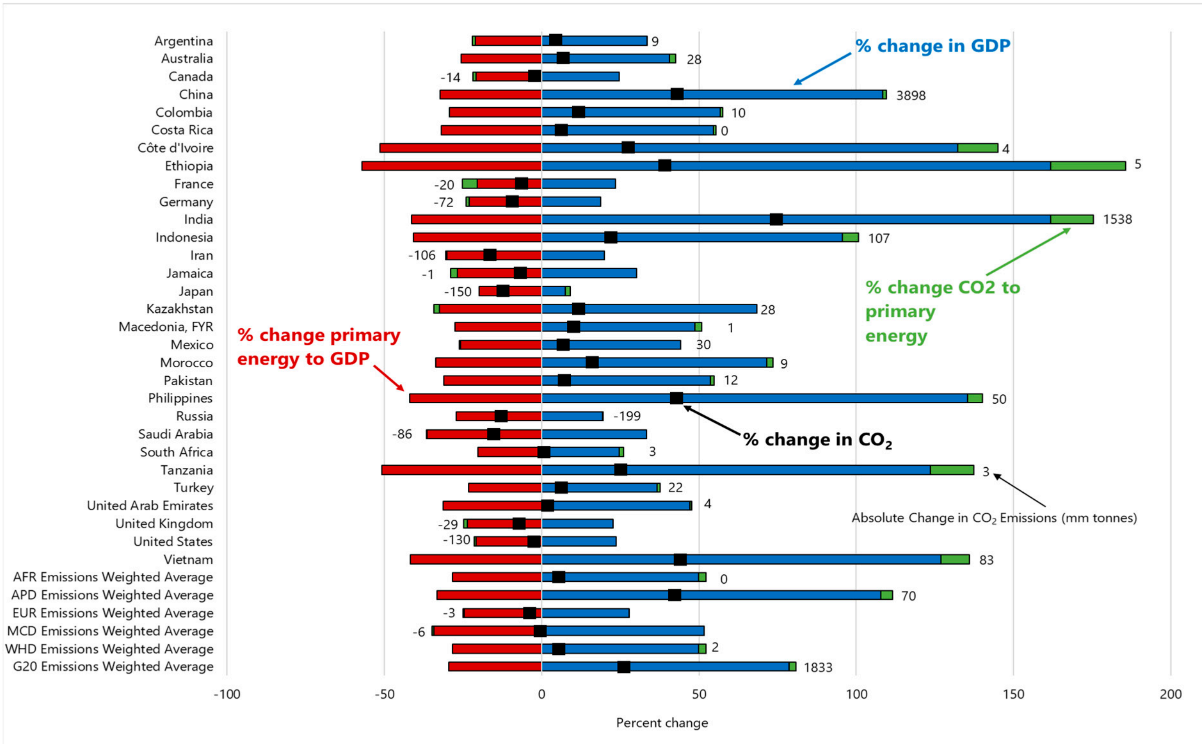
31. BAU growth in fossil fuel CO_2 emissions falls well short of GDP growth and differs considerably across countries (see Figure 3 and Appendix IV). Projected GDP expands rapidly between 2017 and 2030 in emerging market and developing economies. There are significant offsetting effects on CO_2 emissions however as energy demand lags GDP growth due to: (i) below unitary income elasticities for energy; (ii) improving energy efficiency (reflecting technological change and turnover of capital); and (iii) a slight dampening effect on energy demand from gradually rising international petroleum prices. The net result for all G-20 countries taken together—which collectively account for about 80 percent of current global CO_2 emissions—is that emissions increase by 26 percent.[52] In proportionate terms, the largest expansion (75 percent) is in India, while emissions are approximately constant in some cases (e.g., Canada, South Africa, United States), and fall significantly in others (e.g., Japan, Saudi Arabia). In absolute terms, emissions growth over the period is dominated by emerging market economies—for example, 3.9 and 1.5 billion tonnes of CO_2 in China and India respectively (compared with less than 6 million tonnes of CO_2 in Sub-Saharan African countries), though advanced economies have contributed the most to historical atmospheric CO_2 accumulations.

[50] Other models do not produce country-level results across the IMF membership (see discussions in Aldy and others 2016, Fawcett and others 2015, IPCC 2014, IEA 2017, Liu and others 2019, Stern and Stiglitz 2017).

[51] These groups include weighted averages for G20 countries and regionally representative samples for Africa (AFR), Asia and Pacific (APD), European (EUR), Middle East and Central Asian (MCD), and Western Hemisphere (WHD) countries (see Appendix IV).

[52] From an econometric perspective, Cohen and others (2017) provide evidence on the decoupling of GHG emissions and GDP as incomes rise.

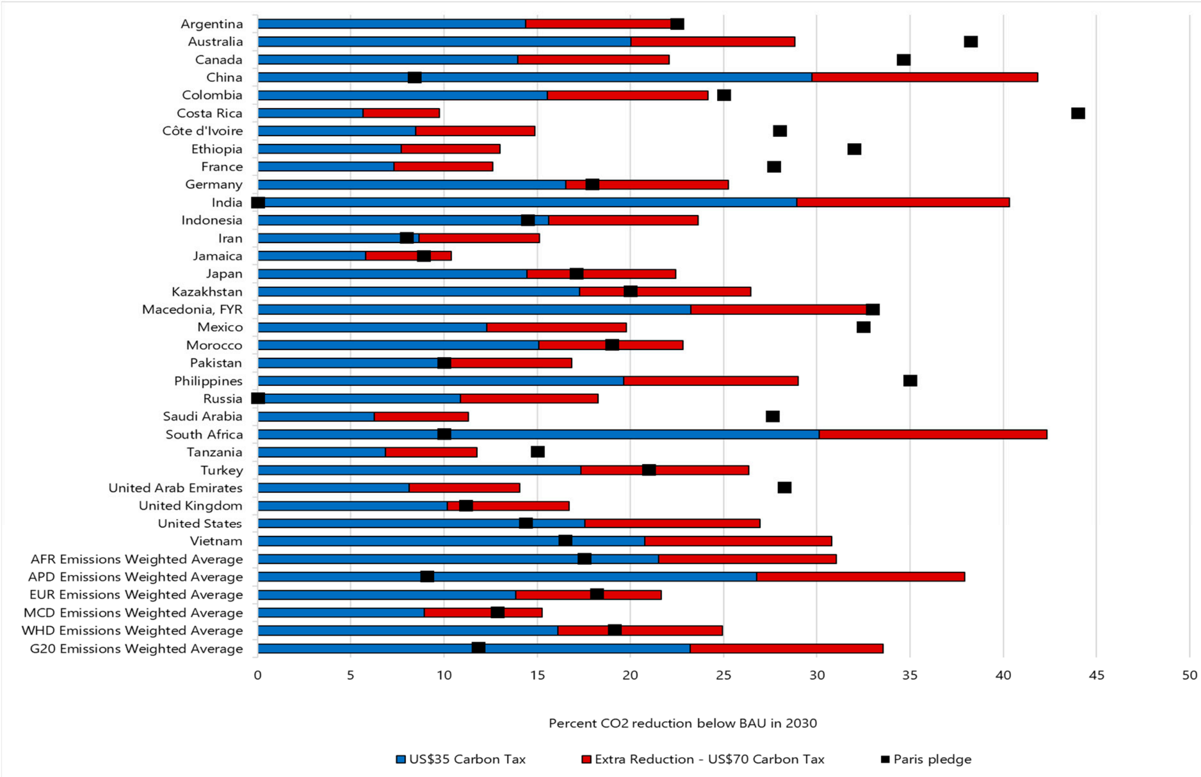
Figure 3. Change in BAU CO₂ Emissions, 2017-2030



Source: IMF spreadsheet model.
Note: BAU projections assume no new, or tightening of existing, CO_2 mitigation polices beyond those implicit in 2016 fuel use data. The bars indicate changes in CO_2 emissions from changes in GDP, the energy intensity of GDP, and the CO_2 intensity of energy, while the boxes indicate the net effect.

32. Many mitigation pledges would imply substantial emissions reductions, but the stringency of pledges differs considerably across countries (see black boxes in Figure 4). Implied emissions reductions below the BAU levels in the model in 2030 are above 30 percent in 7 cases (Australia, Canada, Costa Rica, Ethiopia, FYR Macedonia, Mexico, Philippines), between 10 and 30 percent in 18 cases, and less than 10 percent in 5 cases—most notably, 8 percent in China, while pledges are met in the BAU in India and Russia. This variation reflects differences in both nominal reduction targets and baseline years against which reductions apply (Table 1).

Figure 4. Reduction in CO_2 from Comprehensive Carbon Pricing, 2030



Source: IMF spreasheet model.

Impacts of Carbon Pricing

33. For illustration, carbon prices (in 2017 US$ and covering all fossil fuels) in 2030 of US$35 or US$70 per tonne of CO_2 are considered. A US$35 per tonne carbon price appears easily sufficient to meet mitigation pledges for large emitters on average. For the G-20 combined, Paris pledges imply reducing emissions 12 percent below BAU levels in 2030, while a US$35 per tonne carbon price reduces G-20 emissions by 23 percent (Figure 4). The US$70 per tonne carbon price reduces G-20 emissions by an estimated 33 percent, which is broadly in line with the 2°C target (see above).

34. There is however considerable cross-country dispersion in emissions prices implicit in individual country pledges—which implies inefficiency. According to estimates in Figure 4, nine countries need CO_2 prices below US$35 per tonne in 2030 to meet mitigation pledges, another nine countries need prices between US$35 and US$70 per tonne, while 12 countries need prices above US$70 per tonne.[53] This dispersion in needed prices reflects both differences in pledge stringency (as discussed above) and in the price responsiveness of emissions—for example, the US$35 carbon

[53] The impact of pricing on emissions is naturally sensitive to assumptions about fuel price responsiveness. For example, if fuel price responsiveness is 50 percent higher or lower than assumed above, the emissions reductions are typically around 30-40 percent larger or smaller respectively.

price reduces emissions by around 30 percent in coal-intensive China, India, and South Africa, but by less than 10 percent in 9 countries where coal use is minimal or zero including Côte d'Ivoire, Costa Rica, Ethiopia, France, Iran, Jamaica, Saudi Arabia, Tanzania, and UAE. Although cross-country equity and domestic environmental/fiscal factors mean that carbon prices should not be identical across all countries, given such wide dispersion in implicit prices (and incremental mitigation costs), there are likely substantial efficiency gains from some degree of price coordination, enabling the same reduction in global emissions to be met at a smaller global cost.

35. These carbon prices would significantly affect energy prices (Table 4). Coal prices are affected most dramatically, increasing by, on average, 107 percent above BAU prices in 2030 for a US$35 CO_2 price across selected countries. Impacts on other energy prices are more moderate but still significant—on average 33 percent for natural gas, 23 percent for electricity (but with a wide range of 0-54 percent depending on emissions intensity) and 8 percent for gasoline.

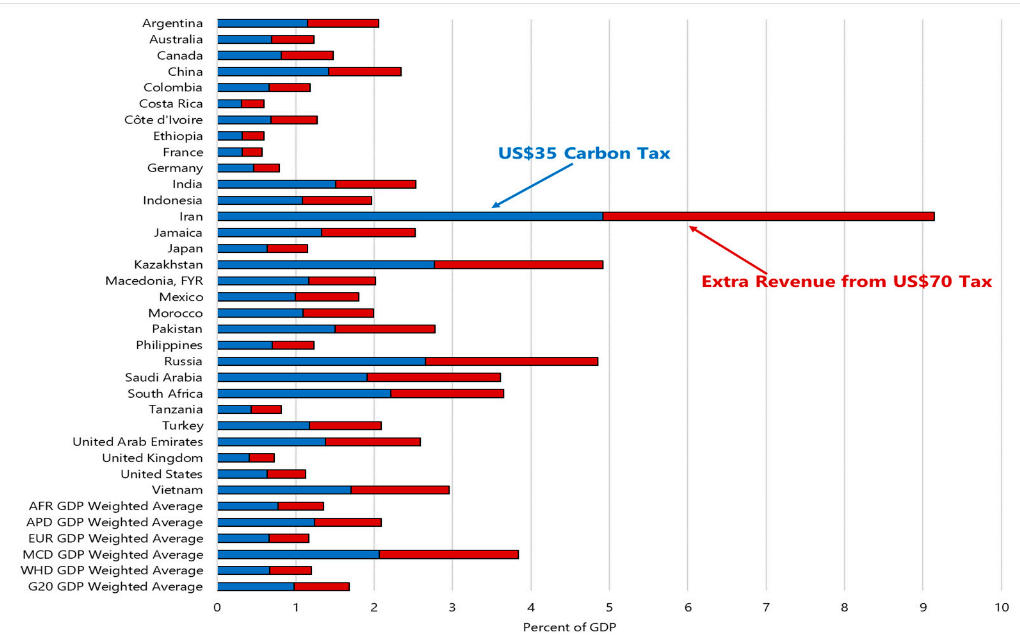
Table 4. Impact of US$35 Carbon Price on Energy Prices, 2030, Selected Countries

Country	Coal		Natural Gas		Electricity		Gasoline	
	BAU Price, $/GJ	% Price Increase	BAU Price, $/GJ	% Price Increase	BAU Price, $/kWh	% Price Increase	BAU Price, $/liter	% Price Increase
Argentina	3.1	134	3.0	62	0.1	27	1.5	6
Australia	3.1	119	9.7	20	0.1	44	1.3	7
Canada	3.1	113	3.0	60	0.1	6	1.1	8
China	3.1	108	9.7	19	0.1	39	1.2	6
Colombia	3.1	120	3.0	71	0.1	11	0.9	10
Costa Rica	3.1	128	3.0	63	0.1	0	1.2	7
Côte d'Ivoire	3.1	106	7.3	27	0.1	16	1.2	11
Ethiopia	3.1	109	7.3	26	0.1	0	1.0	8
France	3.6	80	7.6	25	0.1	1	1.8	4
Germany	3.7	88	7.6	27	0.1	17	1.8	4
India	3.1	104	9.7	12	0.1	49	1.3	6
Indonesia	3.1	108	9.7	17	0.1	35	0.6	15
Iran	3.1	136	7.3	25	0.2	22	0.6	13
Jamaica	3.1	93	3.0	63	0.3	9	1.1	7
Japan	3.1	104	9.7	22	0.1	23	1.4	5
Kazakhstan	3.1	95	7.3	25	0.1	38	0.6	14
Macedonia, FYR	3.1	117	7.3	26	0.1	30	1.5	5
Mexico	3.1	102	3.0	62	0.1	41	1.1	8
Morocco	3.1	103	7.3	27	0.1	35	1.3	7
Pakistan	3.1	109	7.3	24	0.2	8	0.9	11
Philippines	3.1	107	9.7	20	0.1	26	1.1	7
Russia	3.1	77	7.3	24	0.1	13	0.9	6
Saudi Arabia	3.1	106	7.3	25	0.2	18	0.6	13
South Africa	3.1	93	7.3	10	0.1	54	1.2	8
Tanzania	3.1	111	7.3	26	0.1	13	1.1	8
Turkey	3.1	105	7.3	26	0.1	22	1.6	4
United Arab Emirates	3.1	107	7.3	27	0.2	19	0.7	5
United Kingdom	3.9	116	7.6	26	0.1	11	1.8	4
United States	3.1	115	3.0	63	0.1	30	0.9	9
Vietnam	3.1	109	9.7	20	0.1	19	1.0	7
Simple Average	3.2	107	6.8	33	0.1	23	1.1	8

Source: IMF staff spreadsheet model.

36. Comprehensive carbon pricing also mobilizes substantial new revenue (Figure 5). A US$70 per tonne carbon tax would raise estimated revenues of around 1-3 percent of GDP for most countries in Figure 5 and substantially more in a few cases (Iran, Kazakhstan, Russia, Saudi Arabia, South Africa). Cross-country differences reflect (most importantly) differences in BAU emissions intensity in 2030 (Table 1) but also in the price-responsiveness of emissions. Revenues are about 70-85 percent higher under the US$70 per tonne carbon price compared with the US$35 price (they are less than double, due to tax base erosion). Higher energy costs tend to reduce employment and investment at the economy-wide level (Box 1), which will lower revenues from broader taxes, for example on labor and capital. The U.S. Treasury assumes this effect offsets 25 percent of the revenue from carbon taxes,[54] though there would be a counteracting increase in broader tax bases if carbon tax revenues were used to cut economically burdensome taxes or fund productive investments for SDGs. Eventually, however, carbon pricing revenues would need to be progressively replaced by other revenue sources, as emissions reductions become deeper over time.[55]

Figure 5. Revenue from Comprehensive Carbon Pricing, 2030



Source: IMF staff calculations.

37. For many countries, domestic environmental co-benefits from carbon pricing may be large, casting some doubt on both the free-rider basis. The annualized costs of carbon pricing—measured by the economic value of the foregone fossil fuel consumption[56]—are mostly between about 0.1 and 0.5 percent of GDP for the US$70 carbon price in 2030 (Figure 6), though costs are around 1 percent of GDP or more in six (high-emitting) cases (e.g., China, India, and South Africa). Counteracting and in most cases offsetting these costs—in addition to reduced harm from climate change—are the domestic environmental co-benefits from reduced fuel use, particularly reductions

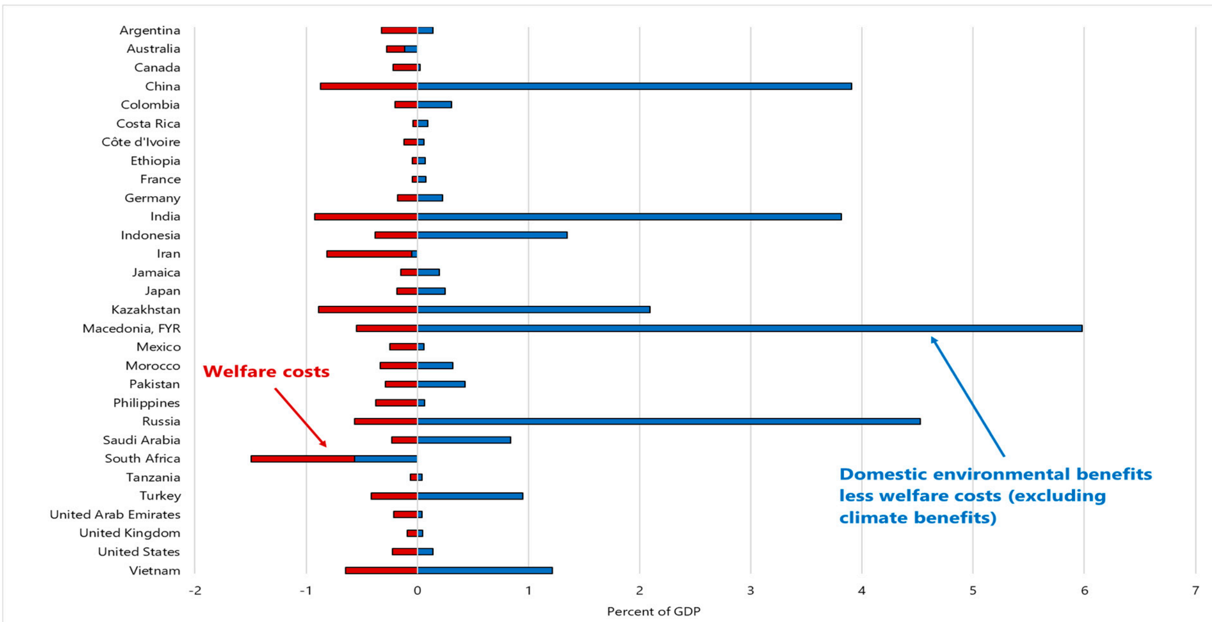
[54] Horowitz and others (2017).

[55] Carbon pricing revenues would be helpful but far from sufficient to meet funding needs for SDGs—for example, IMF staff estimate these needs at 6 percent of GDP in emerging market economies in 2030 and 14 percent of GDP in low-income developing countries (Gaspar and others 2019).

[56] That is, the losses in consumer surplus from higher fuel prices, less revenue gains to the government, accounting for prior fuel taxes. The estimates do not account for temporarily idled resources due to market frictions, linkages with distortions from the broader fiscal system (see Box 1), and potential terms of trade impacts—on the latter, Liu and others (2019), Figure 17, estimate significant losses to Australia, OPEC, and Russia, and significant gains to China, India, and United States from declines in international energy prices resulting from global action to meet Paris mitigation pledges.

in air pollution mortality but also reductions in motor vehicle traffic congestion and accident externalities. Figure 6 presents estimates of these co-benefits, net of the costs, though there are considerable uncertainties surrounding them (e.g., over much pollution is inhaled by exposed populations, the health impacts of such exposure, and people's valuations of health risks) and co-benefits vary dramatically across countries (e.g., with population density and local air emission rates).[57]

Figure 6. Unilateral Costs/Domestic Net Benefits of US$70 Carbon Tax, 2030



Source: IMF staff calculations.

38. **On net in Figure 6, only Australia, Iran, and South Africa are worse off under carbon pricing (excluding global warming benefits), 18 countries are no worse off or moderately better off (with net benefits of 0-0.5 percent of GDP), and several countries are considerably better off.** For example, net benefits exceed 2 percent of GDP in China, India, Kazakhstan, FYR Macedonia, and Russia. One implication is that, up to a point, it is in many countries' own interests to move ahead unilaterally with carbon pricing.[58] Another is that countries with more severe air pollution problems may want to price emissions somewhat more aggressively than others. The same may apply for those with greater needs for revenue mobilization.

[57] For a discussion of the methodologies for quantifying co-benefits see Parry and others (2015b).

[58] The prospects for net benefits diminish at higher levels of mitigation as domestic environmental benefits are proportional to fuel reductions, while economic costs increase by more than in proportion to fuel reductions.

Comparing Mitigation Instruments

39. Other mitigation instruments are less effective at reducing CO_2 than comprehensive carbon pricing (Table 5). Policies are compared for the same (explicit or implicit) CO_2 price (US$70 per tonne in 2030) and differ by the range of mitigation responses they promote. ETSs are typically around 40-70 percent as effective as broad carbon pricing, not because of the instrument itself but rather its assumed coverage (based on general practice to date) of power generators and large industry only. Road fuel taxes have effectiveness of mostly around 5-10 percent of carbon taxes as these fuels typically account for a minor proportion of emissions and carbon charging has a relatively modest impact on retail prices. In a few coal-intensive countries (e.g., China, India, Philippines, and South Africa), taxing coal alone can be almost as effective as a broad carbon tax.[59]

Table 5. CO_2 Reduction from Other Policies, 2030
(as a fraction of CO_2 reductions under US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 tax	Road Fuel Taxes	Energy Efficiency Combination
Argentina	0.04	0.46	0.16	0.42	0.04	0.37
Australia	0.77	0.83	0.36	0.84	0.03	0.26
Canada	0.26	0.40	0.03	0.37	0.07	0.33
China	0.95	0.79	0.20	0.73	0.01	0.23
Colombia	0.29	0.47	0.05	0.45	0.11	0.30
Costa Rica	0.23	0.19	0.00	0.13	0.43	0.43
Côte d'Ivoire	0.00	0.49	0.18	0.44	0.19	0.37
Ethiopia	0.31	0.37	0.00	0.24	0.22	0.38
France	0.24	0.28	0.00	0.24	0.08	0.38
Germany	0.72	0.71	0.13	0.68	0.02	0.22
India	0.94	0.87	0.30	0.83	0.01	0.23
Indonesia	0.68	0.72	0.27	0.68	0.12	0.30
Iran	0.04	0.35	0.20	0.31	0.06	0.44
Jamaica	0.10	0.50	0.18	0.41	0.12	0.39
Japan	0.69	0.67	0.26	0.63	0.02	0.31
Kazakhstan	0.69	0.59	0.22	0.54	0.03	0.34
Macedonia, FYR	0.86	0.90	0.23	0.87	0.03	0.18
Mexico	0.18	0.60	0.31	0.55	0.10	0.38
Morocco	0.68	0.76	0.31	0.75	0.07	0.28
Pakistan	0.30	0.53	0.08	0.42	0.13	0.33
Philippines	0.82	0.85	0.24	0.81	0.05	0.22
Russia	0.38	0.46	0.14	0.44	0.01	0.35
Saudi Arabia	0.00	0.51	0.41	0.45	0.11	0.48
South Africa	0.96	0.73	0.25	0.71	0.02	0.27
Tanzania	0.22	0.45	0.09	0.37	0.34	0.36
Turkey	0.74	0.64	0.17	0.60	0.02	0.28
United Arab Emirates	0.10	0.77	0.37	0.64	0.02	0.36
United Kingdom	0.33	0.55	0.10	0.54	0.04	0.28
United States	0.48	0.69	0.23	0.68	0.06	0.28
Vietnam	0.86	0.80	0.15	0.71	0.03	0.22

Source: IMF staff calculations.
Note: Other policies are scaled such that they impose the same CO_2 price on emissions affected by the policy. The energy efficiency combination imposes shadow prices across all sectors such that the improvement in energy efficiency is the same as under the carbon tax.

[59] Renewables policies are not analyzed here as the prospects for rapidly scaling them up are highly country-specific (e.g., depending on sunshine, wind speeds, and land availability). For previous modelling results comparing the effectiveness of a broad range of mitigation instruments (though focused on single country applications) see, for example, Krupnick and others (2010), Parry and others (2016, 2017).

40. Other instruments also raise far less revenue. For example, coal taxes raise less than one-third of the revenue raised by (equivalently-scaled) carbon taxes in all but 4 of the 30 countries in Table 6. And even if allowances are fully auctioned, the revenue potential of ETSs is generally around only 30-50 percent that of the carbon tax.

Table 6. Revenue from Other Policies, 2030
(as a fraction of revenue from US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Argentina	0.01	0.27	0.24	0.22	0.16	0.00
Australia	0.24	0.43	0.39	0.39	0.20	0.00
Canada	0.08	0.15	0.14	0.12	0.25	0.00
China	0.70	0.54	0.35	0.35	0.08	0.00
Colombia	0.11	0.24	0.16	0.14	0.37	0.00
Costa Rica	0.04	0.10	0.01	0.01	0.68	0.00
Côte d'Ivoire	0.00	0.32	0.34	0.26	0.33	0.00
Ethiopia	0.07	0.21	0.00	0.00	0.40	0.00
France	0.12	0.08	0.06	0.05	0.26	0.00
Germany	0.28	0.24	0.20	0.20	0.17	0.00
India	0.56	0.56	0.42	0.42	0.13	0.00
Indonesia	0.21	0.37	0.28	0.28	0.31	0.00
Iran	0.01	0.22	0.21	0.21	0.10	0.00
Jamaica	0.02	0.50	0.31	0.31	0.19	0.00
Japan	0.27	0.49	0.43	0.41	0.12	0.00
Kazakhstan	0.32	0.38	0.26	0.26	0.08	0.00
Macedonia, FYR	0.37	0.49	0.40	0.39	0.28	0.00
Mexico	0.07	0.34	0.30	0.30	0.30	0.00
Morocco	0.18	0.38	0.35	0.30	0.30	0.00
Pakistan	0.09	0.34	0.24	0.24	0.25	0.00
Philippines	0.33	0.50	0.53	0.40	0.25	0.00
Russia	0.16	0.31	0.28	0.28	0.05	0.00
Saudi Arabia	0.00	0.47	0.43	0.38	0.14	0.00
South Africa	0.71	0.41	0.31	0.31	0.17	0.00
Tanzania	0.05	0.19	0.13	0.13	0.61	0.00
Turkey	0.32	0.35	0.29	0.29	0.14	0.00
United Arab Emirates	0.03	0.42	0.40	0.39	0.08	0.00
United Kingdom	0.11	0.21	0.18	0.18	0.20	0.00
United States	0.17	0.31	0.32	0.29	0.28	0.00
Vietnam	0.48	0.59	0.39	0.39	0.16	0.00

Source: IMF staff calculations.
Note: Other policies are scaled such that they impose the same CO_2 price on emissions affected by each policy.

D. International-Level Mitigation

Two key issues for carbon pricing at the multilateral level are discussed below—coordination over pricing of domestic, and international transport, and fuels.

Carbon Price Floors

41. At an international level, the Paris mitigation process might be reinforced with a carbon price floor arrangement among willing (ideally large-emitting) countries. This arrangement would guarantee a minimum effort level among participants and provide some reassurance against losses in international competitiveness.[60] Parties need to agree on one central parameter—the common floor price. Coordination over price *floors* rather than price *levels* provides some flexibility to accommodate dispersion in prices implied by countries' mitigation pledges.

42. Provisions in the Paris Agreement might encourage broad participation in a price floor agreement. By recognizing internationally transferred mitigation outcomes (ITMOs) across national governments, one interpretation of the Paris Agreement[61] is that countries needing prices lower than the floor price to meet their mitigation pledges could benefit from setting the floor price and selling ITMOs at this price to other countries (for whom the floor price would be insufficient to meet their pledge). For example, calculations from the above tool suggest that India would gain external revenues of approximately 0.6 percent of GDP in 2030 from joining a price floor of US$35 per tonne and selling ITMOs.[62]

43. Price floor requirements could accommodate both carbon taxes and ETSs and participants may have a self-interest in agreeing on a robust price floor. ETSs could be accommodated through: (i) scaling emissions caps (as in Canada—see below) such that expected emissions prices at least equal the floor requirement; (ii) combining it with a variable tax (as in the U.K.) equal to any gap between the required floor and the ETS price; or (iii) using minimum price auctions (as in regional U.S. schemes) with the auction price equal to the international floor. Individual participants may support a robust floor price (e.g., one designed to meet NDC pledges at the global level) as this reduces the emissions of other participants, thereby conferring collective benefits for all.[63]

44. Focusing the arrangement on increases in 'effective' carbon prices provides flexibility and accounts for changes in energy taxes. Domestic carbon pricing may provide exemptions or favorable rates to selective emissions sources (see above) and its effectiveness might also be offset (or enhanced) by changes in pre-existing energy taxes. Effective carbon prices account for direct carbon pricing and energy taxes.[64] Focusing the arrangement on these prices allows countries flexibility in meeting the requirement (e.g., through setting higher carbon prices for covered sources to compensate for exemptions). To some extent, pre-existing energy taxes may be motivated by domestic environmental or fiscal considerations, varying with country circumstances, so there is little basis for equating effective carbon prices across countries. Instead, the agreement could focus on a

[60] The agreement may also help non-participants, and participants for whom the minimum price is not binding, raise carbon prices, as demonstrated in a broader environmental context (e.g., Kanbur and others 1995).

[61] UNFCCC (2016), Article 6.2.

[62] Further incentives—more powerful than for BTAs—might be provided through general trade sanctions imposed by a club of carbon pricing countries on those without carbon pricing (e.g., Nordhaus 2015), though this raises some of the same WTO- and Paris-related complexities as for BCAs.

[63] See Cramton and others (2016) and Weitzman (2015).

[64] Specifically, the effective tax is the carbon tax that would have the same impact on economy wide emissions as the combined effect from any carbon pricing schemes and pre-existing energy taxes.

required *increase* in countries' effective carbon prices (e.g., of US$35 per tonne of CO_2 by 2030) relative to a historical baseline.

45. Tracking effective carbon prices is manageable analytically (though conventions would need to be agreed upon). They are calculated here by: (i) expressing energy taxes on a CO_2-equivalent basis (i.e., dividing them by the relevant CO_2 emissions factor); and (ii) weighting the energy taxes, and any direct carbon pricing, by their relative effectiveness at reducing CO_2 emissions compared with an (equivalently-scaled) comprehensive carbon price (i.e., using analogous fractions to those in Table 5), and then aggregating across fuel products.[65] The results (see Figure 7 for selected countries) suggest considerable dispersion in effective carbon prices: they vary from zero to about US$30 per tonne of CO_2 in most cases, and substantially more than that in countries (Costa Rica and Tanzania) where road fuels are both highly taxed and account for nearly all economywide emissions.

46. Carbon price floor arrangements have precedents from both a climate and international tax perspective. Under federal requirements introduced in Canada in 2016, provinces and territories are required to phase in a minimum carbon price, rising to CA$50 (US$38) per tonne by 2022.[66] More broadly, some progress has been made in combating excessive competition for internationally mobile tax bases through tax floor arrangements, for example, for indirect taxes in the European Union.

47. Success in multilateral fora more generally provides some grounds for optimism. For example, the 1987 Montreal Protocol successfully scaled back ozone-depleting substances and an amendment to it—the 2016 Kigali Agreement—is phasing out the most important F-gases.[67] Indeed, it is conceivable that coalitions of countries willing to price carbon emissions may emerge under existing international arrangements. For example, the trans-Pacific, US-Mexico-Canada, and other trade agreements contain chapters requiring enforcement of environmental laws, while the 2018 EU-Japan trade deal committed its signatories to uphold the Paris Agreement.

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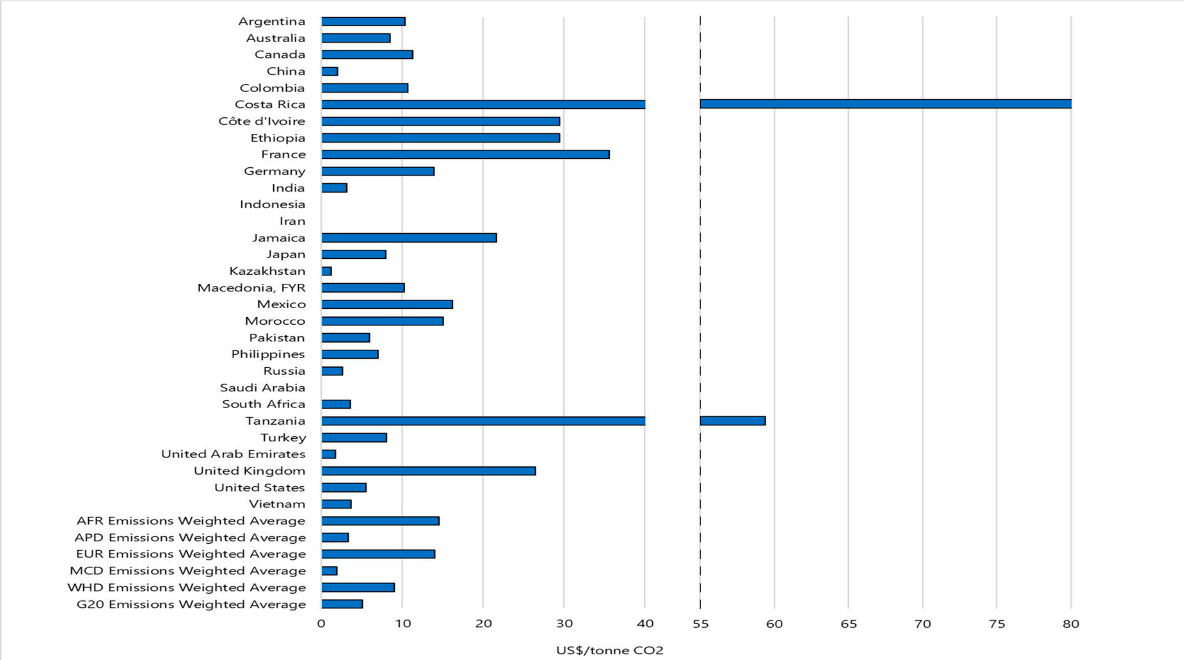
[65] OECD (2018) calculate effective carbon prices in 2018 for 42 (mostly advanced) countries using detailed national tax data, but weighting fuel taxes by the fuel's emissions share rather than the relative effectiveness of the fuel tax at reducing nationwide emissions (this approach, for example, would yield an effective carbon price of US$22 per tonne for the United States in 2030 rather than US$6 as calculated above). Including the carbon price equivalents from quantity-based regulations (e.g., for energy efficiency or renewables) in the effective carbon price would be challenging, as the implicit emissions prices are not observed.

[66] The enforcement mechanism is a federal 'carbon pricing backstop' imposing a carbon tax (which started in 2019 at CAN US$30 per tonne) in the event of non-compliance (Ontario and Saskatchewan have mounted legal challenges to the backstop). See, for example, Government of Canada (2018a and b), Parry and Mylonas (2018).

[67] See Mulye (2017) and, on further examples of successful international cooperation in non-environmental areas, Krogstrup and Obstfeld (2018).

Figure 7. Effective Carbon Prices, Selected Countries 2030



Source: IMF staff calculations.
Note: The effective carbon price is taken as zero for countries that currently subsidize energy.

International Transport Fuels

48. **United Nations agencies for international transportation (emissions from which are excluded from NDCs) have announced mitigation objectives, but meaningful policy action is not imminent.** The International Civil Aviation Organization (ICAO) is requiring airlines to purchase international emission offsets for any CO_2 emissions exceeding 2020 levels, but the scheme is not mandatory until 2026, lacks full coverage,[68] and considerable uncertainty surrounds future offset prices. Also, the International Maritime Organization (IMO) announced in April 2018 a commitment to cut emissions by 50 percent below 2008 levels by 2050, but specific policies for implementation are yet to be determined. International aviation and maritime fuels accounted for 1.4 and 2.6 percent of global CO_2 emissions in 2012 respectively and, without mitigation, these emissions are projected to grow steadily.[69] The fuels are exempt from excises (routinely applied to road fuels) and subject to broader preferential tax treatment.[70]

[68] Small island developing states, low-income countries, landlocked developing countries, and states with small shares in global aviation emissions, are all exempted from the scheme (ICAO 2018a).

[69] CO_2 shares are calculated from ICAO (2018b) and IMO (2014), Table 1. Parry and others (2018b), Figure 1, project BAU emissions growth for maritime of 31 percent between 2020 and 2040.

[70] Keen and others (2013).

49. A carbon tax on international transportation fuels of US$75 per tonne of CO_2 in 2030 would reduce CO_2 emissions from aviation and maritime by an estimated 10 and 15 percent below BAU levels respectively and raise annual revenues of around US$120 billion.[71] Taxes promote the full range of mitigation responses (e.g., increasing new and used vehicle efficiency, speed and other operational changes, shifting to fleets with larger vehicles and higher load factors, shifting to cleaner fuels, and reducing transportation demand).

50. There are workable solutions for the design issues, though complementary R&D programs would be needed. On administration, taxes could be collected from plane and ship operators (based on recently introduced emissions reporting requirements). Revenues could be viewed as a natural source of international climate finance, given that the tax bases are largely used in international airspace or waters. ICAO and IMO argue for retention of revenues to support R&D effort in the industries, though the funds at stake (from meaningful pricing) seem far more than could be efficiently absorbed. A way forward in this case might be a revenue-neutral feebate imposing a sliding scale of taxes on operators with above-average emissions intensity and vice-versa for operators with below-average emissions intensity. Compensation schemes, for instance, for small island developing states vulnerable to higher tourism or shipping costs, might be needed, but should be practical, not least because the burden of taxes is generally small in relation to countries' GDP (and especially so under feebates). Carbon pricing would need to be accompanied by R&D programs to develop alternative fuel technologies (e.g., batteries, biofuels, liquified natural gas, and hydrogen) if the deep emissions reductions ultimately envisioned for these sectors are to be achieved.

ADAPTATION STRATEGIES

51. Adaptation requires action across a wide range of areas. The Paris Agreement focuses on "enhancing adaptive capacity, strengthening resilience, and reducing vulnerability to climate change with a view to contributing to sustainable development and ensuring an adequate adaptation response".[72] This requires building systems and processes, enhancing analysis, monitoring and evaluation systems, in addition to policy actions countering climate change impacts. These actions will vary in content and priority across countries (e.g., with geographical setting and level of development), but might include: improving the efficiency of energy and water usage; strengthening regulations (e.g., building codes); upgrading flood defenses; climate-proofing public infrastructure; strengthening health and social protection systems; and developing drought-tolerant crops.

52. Adapting to climate change can be costly, particularly in small islands and low-income countries. Annual financing needs for adaptation investments in developing countries have been

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[71] For a CO_2 tax rising US$7.5 per tonne per year from 2021 onwards. Calculations are based on Parry and others (2018b) for maritime and staff calculations for aviation using a similar model with parameters based on Keen and others (2013).

[72] UNFCCC (2016), Article 7.1.

put at US$140-300 billion in 2030 and US$280-500 billion by 2050, compared with international adaptation finance in 2014 of around US$23 billion.[73] For small island states, adapting to climate change and natural disasters, for example, in Fiji is estimated to require physical investments of around 100 percent of GDP over the next 10 years, which implies almost doubling currently budgeted plans.[74] Initial Climate Change Policy Assessments undertaken by the Fund and World Bank, suggest that annual public investment needs to meet adaptation strategy requirements are around 2-3 percent of GDP. Additional pressures will also arise on social spending (e.g., health care, and social safety nets). This will be challenging in countries with constrained fiscal space but finding space for small cost-effective investments can still enhance resilience.

53. Further mobilization of official and private financing for adaptation is, therefore, essential. Additional contributions to climate finance agencies will be crucial and implementation will also help to moderate climate-related migration into donor countries. The measures outlined below to build fiscal management institutions in climate-vulnerable states should help ease their access to project and other finance, including well-governed Public Private Partnerships. Technical assistance from development partners has also proved to be valuable in easing access to these funds.[75] Revenue measures to promote energy efficiency, such as those described in the previous sections, are also important in climate-vulnerable states and can provide valuable additional fiscal space for adaptation investments.

54. Resilience building needs to go well beyond physical, climate-proofing investments—effective fiscal institutions are critical. A parallel paper[76] emphasizes that effective Disaster Resilience Strategies (DRS) require: (i) physical resilience; (ii) financial resilience; and (iii) emergency response systems. Critical components of a successful DRS are that: it is embedded within a sustainable macro-fiscal framework (requiring mobilization of sustainable financing); available options to transfer risk away from the budget are fully exploited; climate resilience is built into investment planning; and fiscal institutions are strong enough to effectively implement the DRS. As the other elements are covered in the parallel paper (and go well beyond fiscal aspects), the focus here is on the last element—supplementing the recommendations of the parallel paper by drawing on recent capacity development work.

55. Resilience building in Small Developing States (SDSs) and LICs is hampered by significant capacity gaps. These countries are particularly vulnerable to climate change and natural disasters and it is critically important that they invest in resilience.[77] Climate Change Policy Assessments (CCPAs) provide insights on specific ways in which capacity constraints impact on

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[73] UNEP (2016).

[74] WBG (2017).

[75] For instance, effective working partnerships between GiZ and the Grenada Ministry of Climate Resilience have helped two successful applications to the Green Climate Fund.

[76] IMF (2019).

[77] IMF (2016), Marto and others (2017, 2018), Bonato and others (2018a).

resilience building. The countries covered have different strengths and weaknesses, but share similar priority needs, especially strengthening public financial management systems and matching financing with investment objectives (Box 5).

Box 5. Climate Change Policy Assessments (CCPAs): Experience to Date

These reports, introduced on a pilot basis in 2017[1] and jointly conducted by the Fund and the World Bank, provide an overarching assessment of countries' climate strategies—as articulated in their NDCs and other government documents—focusing on SDSs. CCPAs are intended to help countries build coherent macro frameworks for responding to climate change, which could improve prospects for attracting external finance and put future revisions to NDCs on a sound footing. Key themes emerging in the assessments undertaken so far for Seychelles, St. Lucia, and Belize, include:

General preparedness. All three countries had high degrees of preparedness with climate issues prominent in the policy debate, though greater integrations of strategies would be required.

Mitigation. Although SDSs' contribution to global climate change is negligible, all three countries had plans to progress on their NDC mitigation pledges.

Adaptation. Priorities for adaptation were generally less well articulated than for mitigation. Nevertheless, all three countries allocated significant amounts to adaptation in their public investment plans.

Financing. Financing for addressing climate change was challenging due to high debt levels and fiscal constraints. Greater use of grant and private financing was viewed as essential in all three cases.

Risk Management. Risk management was generally focused on emergency planning—all three countries fell short on risk transfer through insurance and adequate budgetary contingencies.

National Processes. Public Investment Management systems were the key weakness in all three countries, including insufficient legal frameworks for public-private partnerships and project selection and costing.

Priority Needs. These included: attracting private investment for mitigation and adaptation; channeling more public funds towards resilience (e.g., through better access to external finance); and strengthening public financial management systems, particularly public investment management.

[1] Following consideration by an IMF Board paper on SDSs resilience to natural disasters and climate change and the Fund's role (IMF 2016).

56. **Financing for resilience-building should be fully integrated into fiscal policy frameworks.** The framework should be consistent with fiscal and debt sustainability while allowing room for investment in physical resilience and building fiscal buffers—including through reducing debt and building savings funds (see below)—to respond to shocks, especially from natural disasters. The optimal size of fiscal buffers depends on: the expected fiscal costs of climate/disaster risks; the extent to which risks have been transferred through insurance; and prospects for emergency borrowing (e.g., through state-contingent instruments like catastrophe bonds). The opportunity costs of buffers also need careful consideration, including by balancing the benefits of increased investment in resilient infrastructure with the need to have buffers available to meet the costs of natural disasters that cannot be offset through prior risk reduction.

57. **This financing requires building capacity in fiscal and debt sustainability analyses.** These analyses should regularly integrate: (i) probabilistic assessments of the frequency and severity of natural disasters and slow-onset climate-related damages (accounting for how damages are

diminished through climate-proofing investment); (ii) comprehensive financing strategies for ex ante fiscal buffers and ex post post-disaster expenditures; (iii) national budget financing (required beyond external finance) of physical adaptation and mitigation investments; and (iv) potentially positive impacts on growth from external finance. CCPAs have effectively developed these analyses to inform fiscal policy making—for instance, integrating the growth dividend of increased resilience investment into the long-term framework in the St. Lucia CCPA[78] showed how fiscal space could be increased. Given the uncertainties surrounding forecasting, however, scenario analysis and assessing policy responses to tail-risks, are important.

58. Robust medium-term fiscal frameworks are critical for building buffers and enabling adaptation investments. The best approach is to adopt formal fiscal responsibility frameworks anchored around a credible fiscal rule providing sufficient space for resilience expenditure while preserving fiscal sustainability and building buffers.[79] Fiscal rules need to target a fiscal balance that builds buffers and borrowing space when natural disasters are absent.[80] Supplementary rules that, for instance, moderate current expenditure growth may also be adopted, to ensure room for resilience investments. Escape clauses should allow for larger fiscal deficits as part of the response to natural disasters. Automatic correction mechanisms will also be required to ensure that fiscal policy returns to a sustainable path. Fiscal responsibility frameworks also normally include a requirement for a fiscal risk statement. In climate-vulnerable countries, these should analyze possible climate change impacts and natural disaster risks and, insofar as possible, quantify them. This approach has been taken in countries like New Zealand, the Philippines and Indonesia but is not well-established in SDSs and LICs.

59. Savings funds can ringfence buffers for responding to natural disasters. These self-insurance funds are particularly useful for financing relief and immediate reconstruction following a disaster. In principle, if access to immediate financing were available, for instance through mechanisms such as the World Bank's Catastrophe Deferred Drawdown Operations, such saving funds would be unnecessary. However, for many climate-vulnerable countries this is not yet the case, hence the increasing priority given to building these funds.[81] The target size of savings funds should be set to at least cover the immediate fiscal costs of successive natural disasters that cannot be covered by normal budgetary contingency appropriations, and they can be built through the adoption of a fiscal rule/policy target ensuring savings in good years. One approach is to establish a specific natural disaster contingency in the budget framework—if this contingency is not called upon, the unused funds can be automatically placed in the natural disaster savings fund. If savings

[78] Bonato and others (2018b).

[79] IMF (2018).

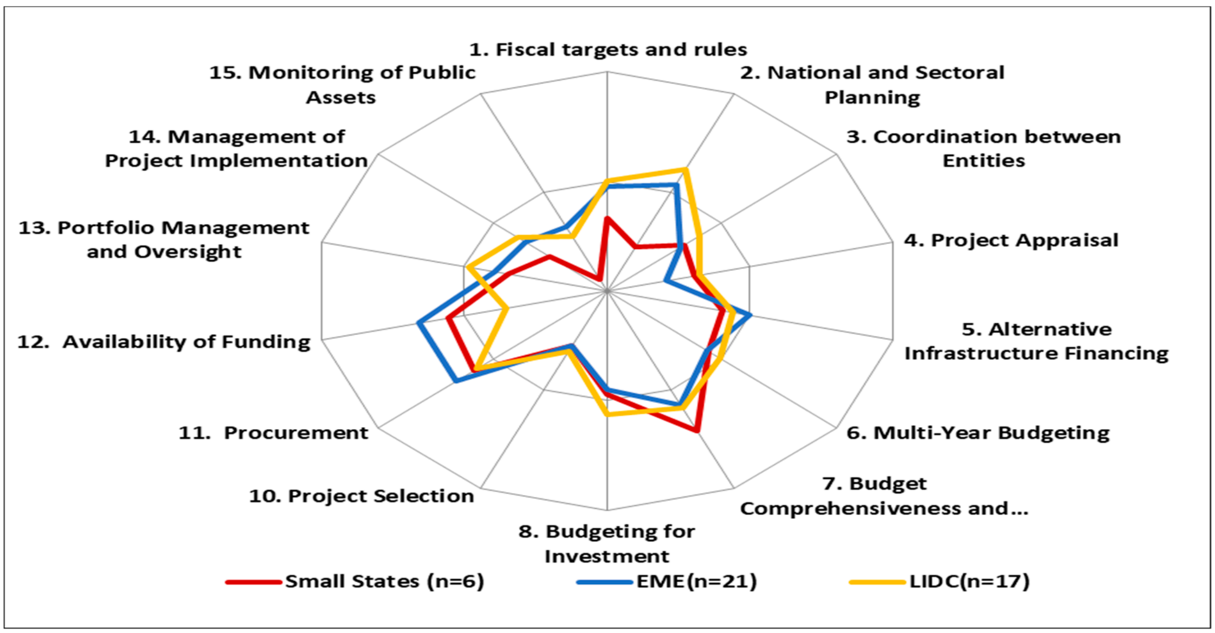
[80] This approach underlies the fiscal responsibility framework in Grenada, where in the initial stages buffers were built by reducing debt to sustainable levels. Grenada is now reviewing (with Fund assistance) the provisions of its fiscal rule, to ensure that it remains consistent with fiscal sustainability while creating appropriate incentives for resilience investments.

[81] IMF capacity development advice has recently been provided to both Dominica and St. Kitts and Nevis on establishing this type of fund.

funds become large enough, they can be used as an additional budgetary financing source for resilience investments or for debt reduction.

60. Savings funds should be fully integrated with the medium-term fiscal framework and annual budget. This will, however, place additional requirements on already stretched public financial management systems (Figure 10). Nevertheless, it is important to carefully design the financial management, governance structure and procedures of these funds to avoid undermining fiscal discipline and transparency. Funds should be fully consolidated with budget information; follow normal government accounting standards; clear disbursement rules should be established (e.g., funds should only be tapped in the event of large fiscal impacts); and they should ideally be subject to fiscal responsibility legislation (e.g., requiring escape clauses to be triggered for the fund to be drawn on). The financial investment strategy of the fund should maintain a high degree of liquidity, given the potential urgency of relief expenditures (e.g. the fund's assets may be best kept offshore in liquid foreign assets because domestic financial markets may be under stress after disasters, hampering asset sales in the disaster's aftermath).

Figure 8. Average Effectiveness of Small State PIM Systems



Source: IMF (2015).

61. Public investment management (PIM) systems need to be strengthened to enable the right investments to be made in the right way Having effective infrastructure governance systems is particularly important for countries vulnerable to climate change, with constrained fiscal space and large investment requirements. It is essential in these situations for PIM systems to ensure effective prioritization of resilience investments and maximize investment efficiency. The IMF's Public

Investment Management Assessment (PIMA) tool[82] allows assessment of the strength and effectiveness of infrastructure governance systems. Experience with implementing the PIMA tool in SDSs has been relatively limited, with full assessments undertaken only for Kiribati, Guyana and Timor-Leste. However, when combined with the light assessments undertaken in the context of CCPAs, some clear conclusions emerge (see Figure 8). Critical areas of weakness are in allocation (especially in project selection and appraisal) and in project management and monitoring. Reforms to be prioritized in addressing these weaknesses would focus on: (i) strengthening fiscal institutions to facilitate medium-term planning for public investment; (ii) building the capacity to undertake rigorous project appraisal and selection; and (iii) establishing appropriate mechanisms to oversee project implementation and facilitate the reporting of government assets.

ROLE OF THE FUND

62. Climate change is potentially macro-critical and the Fund has a role in providing analysis of (and guidance on) energy pricing and macro-fiscal policies consistent with countries' climate strategies submitted for the Paris Agreement. The Fund:

- *Is unique among UN agencies:* given its focus on macro and fiscal policies, universal membership, and regular interactions with finance ministries;
- *Adds value at the country level* (using tools described above)—in delivering macro projections and their emissions implications; evaluating the fiscal, domestic environmental, and economic impacts of mitigation policies; and assessing broader energy price reform;
- *Could analyze progress on NDCs* (again with the above tools)—through consistent, cross-country comparisons of mitigation pledges; likely progress under existing policy commitments; and tracking of effective carbon prices;
- *Can provide advice on macroeconomic and financial policy consistent with climate considerations*—for example, in developing policy frameworks to mobilize needed climate investments and in assessing risks to the financial system; and,
- *Can draw on others with appropriate expertise as needed*—for example, the World Bank (on tracking pricing schemes), the UN Environment Programme (on gaps between current pledges and temperature goals), and the UN Framework Convention on Climate Change (on climate finance flows).

63. The Fund can also emphasize the opportunities from green and climate-resilient economies. Low-carbon transitions can be consistent with strong growth, given: the productivity gains from emerging energy-efficient and renewable technologies; the local health benefits of diminished fossil fuel combustion; the broader fiscal reform, debt reduction, or investment in SDG

[82] IMF (2015). The PIMA identifies 15 desirable criteria for sound decision-making at the planning, allocation, and implementation stage and ranks countries based on whether these criteria are fully, partially, or not met.

goals potentially funded from carbon pricing; as well as reduced economic risks from slowing climate change. Finally, building climate resilience can boost macro performance through limiting expected GDP losses and attracting external finance.

64. Demand for support from the Fund, including capacity development, policy development, program work, and surveillance seems likely to increase in coming years. Future analytical work could include evaluation of potential revisions to mitigation pledges to inform international dialogue; case studies on carbon pricing/broader fiscal reform packages to address political economy challenges; implications of global mitigation for resource-rich countries and their fiscal regimes; and macro policies for mobilizing climate investment needs. Meanwhile, macro-fiscal frameworks fully integrating (near-term) natural disaster and (longer-term) climate risks are being applied to a broadening range of vulnerable countries. Within the areas of its expertise, the Fund might periodically take stock of progress towards delivering on the Paris commitments and emerging issues. At the same time, bilateral surveillance could integrate (at low resource cost) standardized analyses of mitigation policies that can be regularly updated for multilateral surveillance purposes using the tools set out in this paper.

ISSUES FOR DISCUSSION

65. Directors may wish to discuss the following issues:

- What role do Directors see for carbon pricing in meeting countries' Paris pledges? What role do they see for other mitigation instruments, such as regulations and feebates?
- Do Directors have views on how best to address the political economy challenges in raising momentum for carbon pricing and meeting Paris commitments more generally?
- Do Directors see merit in the suggestion of a carbon price floor at the international level?
- Do Directors believe the macro and fiscal implications of countries' Paris mitigation pledges should feature in bilateral policy discussions?
- Do Directors have views on the desirability and form of mitigation policy in low-income countries?
- Do Directors believe the Fund could usefully take stock of countries' progress on their Paris commitments using the kind of methodologies set out in this paper?
- What are Directors' views on how the Fund can best promote climate resilience in vulnerable countries?

Appendix I. Climate Strategies in NDCs[1]

Appendix Table 1. AFR Countries: Paris Mitigation Contributions and CO_2 Emissions Data

Country	Paris Mitigation Contribution[a]	2030 BAU		
		Share of Global CO_2	Tonnes CO_2/$ 1000 Real GDP	Tonnes CO_2 per Capita
Angola	Reduce GHGs 35% (50%) below BAU in 2030	0.04	0.13	0.4
Benin	Reduce GHGs 3.5% (17.9%) below BAU in 2030	0.02	0.43	0.5
Botswana	Reduce GHGs 15% below 2010 by 2030	0.02	0.32	3.1
Cameroon	Reduce GHGs (32%) below 2010 by 2035	0.02	0.12	0.2
Congo, Democratic Republic of the	Reduce GHGs (17%) below BAU in 2030	0.01	0.04	0.0
Congo, Republic of	Reduce GHGs (48%) below BAU in 2025; (55%) in 2035	0.01	0.26	0.4
Côte d'Ivoire	Reduce GHGs 28% below BAU in 2030	0.05	0.23	0.6
Eritrea	Reduce GHGs 39.2% (80.6%) below 2010 by 2030	0.00	0.06	0.1
Ethiopia	Reduce GHGs (64%) below BAU in 2030	0.04	0.10	0.1
Gabon	Reduce GHGs (50%) below BAU in 2025	0.01	0.16	1.5
Ghana	Reduce GHGs 15% (45%) below BAU in 2030	0.04	0.17	0.4
Kenya	Reduce GHGs (30%) below BAU in 2030	0.05	0.13	0.3
Mauritius	Reduce GHGs (30%) below BAU in 2030	0.01	0.22	3.3
Mozambique	Reduce GHGs 76.5 million tonnes by 2030	0.03	0.31	0.3
Namibia	Reduce GHGs (89%) below BAU in 2030	0.01	0.23	1.6
Niger	Reduce GHGs 3.5% (34.6%) below BAU in 2030	0.01	0.23	0.1
Nigeria	Reduce GHGs 20% (45%) below BAU in 2030	0.22	0.13	0.3
Senegal	Reduce GHGs 13% (31%) below BAU in 2030	0.03	0.22	0.4
South Africa	Reduce GHGs 398-614 million tonnes in 2025 and 2030	0.99	0.97	5.6
South Sudan	No target	0.00	0.30	0.0
Tanzania	Reduce GHGs 10-20% below BAU by 2030	0.04	0.15	0.2
Togo	Reduce GHGs 11.14% (20%) below BAU in 2030	0.01	0.30	0.3
Zambia	Reduce GHGs 25% (47%) below BAU in 2030	0.01	0.11	0.2
Zimbabwe	Reduce per capita GHGs (33%) below BAU in 2030	0.03	0.39	0.6
AFR Simple Average		**0.07**	**0.24**	**0.9**
AFR 2030 Emissions Weighted Average		**0.62**	**0.64**	**3.5**
AFR 2030 Energy Use Weighted Average		**0.25**	**0.28**	**1.2**
AFR 2030 GDP Weighted Average		**0.26**	**0.30**	**1.4**

Source: UNFCCC (2018b), IMF staff calculations.
Notes:. [a] Some countries have specified both conditional and unconditional pledges, where the former are contingent on external finance and other support—in these cases the conditional pledges are in parentheses. CO_2 refers to fossil fuel emissions only.

[1] For purposes of the Mitigation Analysis (see Appendix D): i) CO_2 reduction targets for fossil fuels are taken to be proportional to those for total GHGs; ii) where both conditional and unconditional targets are specified, the average of the two is used to compute a single, representative percent reduction in emissions; iii) for countries with sizeable forestry sectors (e.g. Brazil, Indonesia), it is assumed that forestry emissions are twice as responsive to carbon pricing as energy sector emissions (e.g. if forestry and energy emissions each account for 50% of total emissions, two-thirds of the emissions reductions are assumed to come from the forestry sector and the remaining one third from the energy sector). Thus, in the case of Brazil, the percent reduction in fossil fuel CO_2 emissions is assumed to be one-third of the percent reduction stated in the corresponding NDC; iv) for countries with emissions intensity targets (e.g., China, India), the CO_2 emissions in 2030 when those targets are met are compared with the model's BAU projection to infer the percent CO_2 reduction.

Appendix Table 2. APD Countries: Paris Mitigation Contributions and CO_2 Emissions Data

Country	Paris Mitigation Contribution[a]	2030 BAU		
		Share of Global CO_2	Tonnes CO_2/$ 1000 Real GDP	Tonnes CO_2 per Capita
Australia	Reduce GHGs 26-28% below 2005 by 2030	1.12	0.26	14.3
Bangladesh	Reduce GHGs 5% (20%) below BAU in 2030	0.34	0.24	0.7
Brunei Darussalam	Reduce GHG/GDP 45% below 2005 by 2030	0.02	0.51	18.2
Cambodia	Reduce GHGs (27%) below BAU by 2030	0.03	0.30	0.7
China	Reduce CO2/GDP 60-65% below 2005 by 2030	33.06	0.58	9.1
Hong Kong SAR	No specific target	0.13	0.11	6.3
India	Reduce GHG/GDP 33-35% below 2005 by 2030	9.18	0.64	2.3
Indonesia	Reduce GHGs 29% (41%) below BAU in 2030	1.52	0.37	1.9
Japan	Reduce GHGs 25.4% below 2005 by 2030	2.76	0.23	9.0
Korea	Reduce GHGs 37% below BAU by 2030	1.57	0.32	11.3
Malaysia	Reduce GHG/GDP 35% (45%) below 2005 by 2030	0.76	0.55	7.9
Mongolia	Reduce GHGs (14%) below BAU in 2030	0.07	1.08	6.9
Myanmar	No specific target	0.09	0.25	0.6
Nepal	No specific target	0.03	0.25	0.3
New Zealand	Reduce GHGs 30% below 2005 by 2030	0.08	0.13	5.5
Philippines	Reduce GHGs (70%) by 2030 relative to BAU of 2000-2030	0.43	0.26	1.2
Singapore	Reduce GHG/GDP 36% below 2005 by 2030	0.13	0.12	8.0
Sri Lanka	Reduce GHGs 4% (20%) in energy sector and 3% (10%) in other sectors below BAU by 2030	0.07	0.19	1.1
Thailand	Reduce GHGs 20% (25%) below BAU by 2030	0.74	0.45	4.2
Vietnam	Reduce GHGs 8% (25%) below BAU in 2030	0.69	0.60	2.6
APD Simple Average		**2.64**	**0.37**	**5.6**
APD 2030 Emissions Weighted Average		**22.59**	**0.54**	**7.5**
APD 2030 Energy Use Weighted Average		**19.93**	**0.53**	**7.0**
APD 2030 GDP Weighted Average		**19.19**	**0.49**	**7.7**

Source: UNFCCC (2018b), IMF staff calculations.

Notes: [a] Some countries have specified both conditional and unconditional pledges, where the former are contingent on external finance and other support—in these cases the conditional pledges are in parentheses. CO_2 refers to fossil fuel emissions only.

Appendix Table 3. EUR Countries: Paris Mitigation Contributions and CO_2 Emissions Data

Country	Paris Mitigation Contribution[a]	Share of Global CO_2	2030 BAU Tonnes CO_2/$ 1000 Real GDP	2030 BAU Tonnes CO_2 per Capita
Albania	Reduce GHGs 11.5% below BAU in 2030	0.01	0.20	1.5
Austria	Reduce GHGs 40% below 1990 by 2030	0.16	0.13	6.6
Belarus	Reduce GHGs 28% below 1990 by 2030	0.14	0.90	6.4
Belgium	Reduce GHGs 40% below 1990 by 2030	0.23	0.17	7.5
Bosnia and Herzegovina	Reduce GHGs 2% (3%) below 1990 by 2030	0.07	0.93	7.5
Bulgaria	Reduce GHGs 40% below 1990 by 2030	0.11	0.57	6.9
Croatia	Reduce GHGs 40% below 1990 by 2030	0.04	0.25	4.5
Cyprus	Reduce GHGs 40% below 1990 by 2030	0.02	0.23	7.2
Czech Republic	Reduce GHGs 40% below 1990 by 2030	0.28	0.35	10.4
Denmark	Reduce GHGs 40% below 1990 by 2030	0.07	0.07	4.5
Finland	Reduce GHGs 40% below 1990 by 2030	0.11	0.16	7.7
France	Reduce GHGs 40% below 1990 by 2030	0.73	0.10	4.2
Germany	Reduce GHGs 40% below 1990 by 2030	1.76	0.17	8.4
Greece	Reduce GHGs 40% below 1990 by 2030	0.16	0.28	5.9
Hungary	Reduce GHGs 40% below 1990 by 2030	0.13	0.27	5.3
Iceland	Reduce GHGs 40% below 1990 by 2030	0.01	0.07	5.5
Ireland	Reduce GHGs 40% below 1990 by 2030	0.11	0.09	7.6
Israel	Reduce GHGs 26% below 2005 by 2030	0.19	0.17	6.8
Italy	Reduce GHGs 40% below 1990 by 2030	0.76	0.15	5.0
Kosovo	No specific target	0.03	1.03	5.7
Latvia	Reduce GHGs 40% below 1990 by 2030	0.02	0.18	4.1
Lithuania	Reduce GHGs 40% below 1990 by 2030	0.03	0.19	4.9
Luxembourg	Reduce GHGs 40% below 1990 by 2030	0.02	0.11	11.8
Macedonia, FYR	Reduce GHGs 30% (36%) below BAU in 2030	0.02	0.47	3.5
Malta	Reduce GHGs 40% below 1990 by 2030	0.00	0.08	3.3
Moldova	Reduce GHGs 64% (67%) below 1990 by 2030	0.02	0.64	2.8
Montenegro, Rep. of	Reduce GHGs 30% below 1990 by 2030	0.01	0.32	3.5
Netherlands	Reduce GHGs 40% below 1990 by 2030	0.42	0.17	9.3
Norway	Reduce GHGs 40% below 1990 by 2030	0.09	0.08	5.9
Poland	Reduce GHGs 40% below 1990 by 2030	0.86	0.46	9.0
Portugal	Reduce GHGs 40% below 1990 by 2030	0.11	0.18	4.5
Romania	Reduce GHGs 40% below 1990 by 2030	0.21	0.26	4.2
Russia	Reduce GHGs 25-30% below 1990 by 2030	3.44	0.88	9.5
Serbia	Reduce GHGs 9.8% below 1990 by 2030	0.14	0.77	8.1
Slovak Republic	Reduce GHGs 40% below 1990 by 2030	0.09	0.26	6.5
Slovenia	Reduce GHGs 40% below 1990 by 2030	0.04	0.23	7.1
Spain	Reduce GHGs 40% below 1990 by 2030	0.61	0.16	5.3
Sweden	Reduce GHGs 40% below 1990 by 2030	0.10	0.06	3.3
Switzerland	Reduce GHGs 50% below 1990 by 2030	0.10	0.05	4.1
Turkey	Reduce GHGs 21% below BAU in 2030	0.97	0.43	4.0
Ukraine	Reduce GHGs 40% below 1990 by 2030	0.57	1.30	5.6
United Kingdom	Reduce GHGs 40% below 1990 by 2030	0.95	0.13	5.3
EUR Simple Average		**0.33**	**0.33**	**6.0**
EUR 2030 Emissions Weighted Average		**1.43**	**0.45**	**7.2**
EUR 2030 Energy Use Weighted Average		**1.38**	**0.42**	**7.0**
EUR 2030 GDP Weighted Average		**0.94**	**0.23**	**6.4**

Source: UNFCCC (2018b), IMF staff calculations.

Notes: [a] Some countries have specified both conditional and unconditional pledges, where the former are contingent on external finance and other support—in these cases the conditional pledges are in parentheses. CO_2 refers to fossil fuel emissions only.

Appendix Table 4. MCD Countries: Paris Mitigation Contributions and CO_2 Emissions Data

Country	Paris Mitigation Contribution[a]	2030 BAU Share of Global CO_2	2030 BAU Tonnes CO_2/$ 1000 Real GDP	2030 BAU Tonnes CO_2 per Capita
Algeria	Reduce GHGs 7% (22%) below BAU in 2030	0.25	0.54	1.9
Armenia	GHGs to not exceed 5.4 tonnes per capita for the period 2015-2030	0.02	0.41	2.4
Azerbaijan	Reduce GHGs 35% below 1990 by 2030	0.08	0.65	2.8
Bahrain	No specific target	0.07	0.62	14.8
Egypt	No specific target	0.67	0.55	2.1
Georgia	Reduce GHGs 15% (25%) below BAU in 2030	0.03	0.45	3.4
Iran	Reduce GHGs 4% (12%) below BAU in 2030	1.37	1.54	5.8
Iraq	Reduce GHGs 1% (14%) below BAU in 2020	0.30	0.44	2.2
Jordan	Reduce GHGs 1.5% (12.5%) below BAU in 2030	0.07	0.49	2.3
Kazakhstan	Reduce GHGs 15% (25%) below 1990 by 2030	0.68	0.96	12.0
Kuwait	No specific target	0.20	0.45	12.2
Kyrgyz Republic	Reduce GHGs 11.49-13.75% (29-30.89%) below BAU in 2030	0.02	0.90	1.1
Lebanon	Reduce GHGs 15% (30%) below BAU in 2030	0.05	0.31	4.1
Libya	No specific target	0.13	0.80	7.0
Morocco	Reduce GHGs 13% (32%) below BAU in 2030	0.17	0.40	1.7
Oman	Reduce GHGs 2% below BAU in 2030	0.19	0.92	12.2
Pakistan	Reduce GHGs (20%) below BAU in 2030	0.48	0.49	0.8
Qatar	No specific target	0.23	0.41	31.9
Saudi Arabia	Reduce GHGs 130 million tonnes below BAU by 2030	1.20	0.58	11.2
Sudan	Renewable energy in power sector at 20% by 2030	0.04	0.58	0.3
Tajikistan	Reduce GHGs 10-20% (25-35%) below 1990 by 2030	0.01	0.53	0.5
Tunisia	Reduce GHG/GDP 13% (41%) below 2010 by 2030	0.07	0.53	2.2
Turkmenistan	No specific target	0.26	1.30	15.7
United Arab Emirates	Clean energy from 0.2% to 24% of energy consumption by 2021	0.56	0.43	14.6
Uzbekistan	Reduce GHG/GDP (10%) below 2010 by 2030	0.36	1.84	3.9
Yemen	Reduce GHGs 1% (14%) below BAU in 2030	0.03	0.20	0.3
MCD Simple Average		**0.29**	**0.67**	**6.5**
MCD 2030 Emissions Weighted Average		**0.70**	**0.84**	**8.1**
MCD 2030 Energy Use Weighted Average		**0.68**	**0.81**	**7.9**
MCD 2030 GDP Weighted Average		**0.61**	**0.65**	**8.4**

Source: UNFCCC (2018b), IMF staff calculations.
Notes: [a] Some countries have specified both conditional and unconditional pledges, where the former are contingent on external finance and other support—in these cases the conditional pledges are in parentheses. CO_2 refers to fossil fuel emissions only.

Appendix Table 5. WHD Countries: Paris Mitigation Contributions and CO_2 Emissions Data

Country	Paris Mitigation Contribution[a]	2030 BAU Share of Global CO_2	2030 BAU Tonnes CO_2/$ 1000 Real GDP	2030 BAU Tonnes CO_2 per Capita
Argentina	Reduce GHGs 15% (30%) below BAU in 2030	0.53	0.40	4.1
Bolivia	No specific target	0.07	0.44	2.0
Brazil	Reduce GHGs 37% below 2005 by 2025	1.07	0.20	1.9
Canada	Reduce GHGs 30% below 2005 by 2030	1.46	0.28	13.8
Chile	Reduce GHG/GDP 30% (35-45%) below 2007 by 2030	0.24	0.26	4.5
Colombia	Reduce GHGs 20% (30%) below BAU by 2030	0.25	0.23	1.8
Costa Rica	Reduce GHGs 44% below BAU by 2030	0.02	0.11	1.5
Dominican Republic	Reduce GHGs (25%) below 2010 by 2030	0.07	0.23	2.4
Ecuador	Reduce GHGs 20.4-25% (37.5-45.8%) below BAU in 2025	0.08	0.29	1.5
El Salvador	No specific target	0.02	0.22	1.0
Guatemala	Reduce GHGs 11.2% (22.6%) below BAU in 2030	0.04	0.17	0.8
Haiti	Reduce GHGs 5% (26%) below BAU by 2030	0.01	0.30	0.3
Honduras	Reduce GHGs 15% below BAU by 2030	0.03	0.36	1.0
Jamaica	Reduce GHGs 7.8% (10%) below BAU by 2030	0.02	0.41	2.3
Mexico	Reduce GHGs 25% (40%) below BAU in 2030	1.21	0.33	3.4
Nicaragua	Renewables in power sector to 60% by 2030	0.01	0.30	0.7
Panama	Forestry target only	0.03	0.11	2.4
Paraguay	Reduce GHGs 10% (20%) below BAU in 2030	0.02	0.13	0.9
Peru	Reduce GHGs 20% (30%) below BAU in 2030	0.17	0.21	1.8
Suriname	Clean energy above 25% of energy consumption by 2025	0.01	0.43	3.2
Trinidad and Tobago	Reduce GHGs 30% (45%) below BAU in 2025 (public transport sector only)	0.06	0.81	15.1
United States	Reduce GHGs 26-28% below 2005 by 2025	12.32	0.23	13.7
Uruguay	Reduce GHG/GDP 25% (40%) below 1990 by 2030	0.02	0.09	1.9
WHD Simple Average		**0.77**	**0.28**	**3.6**
WHD 2030 Emissions Weighted Average		**8.84**	**0.25**	**11.3**
WHD 2030 Energy Use Weighted Average		**8.21**	**0.25**	**10.7**
WHD 2030 GDP Weighted Average		**9.17**	**0.24**	**11.4**

Source: UNFCCC (2018b), IMF staff calculations.

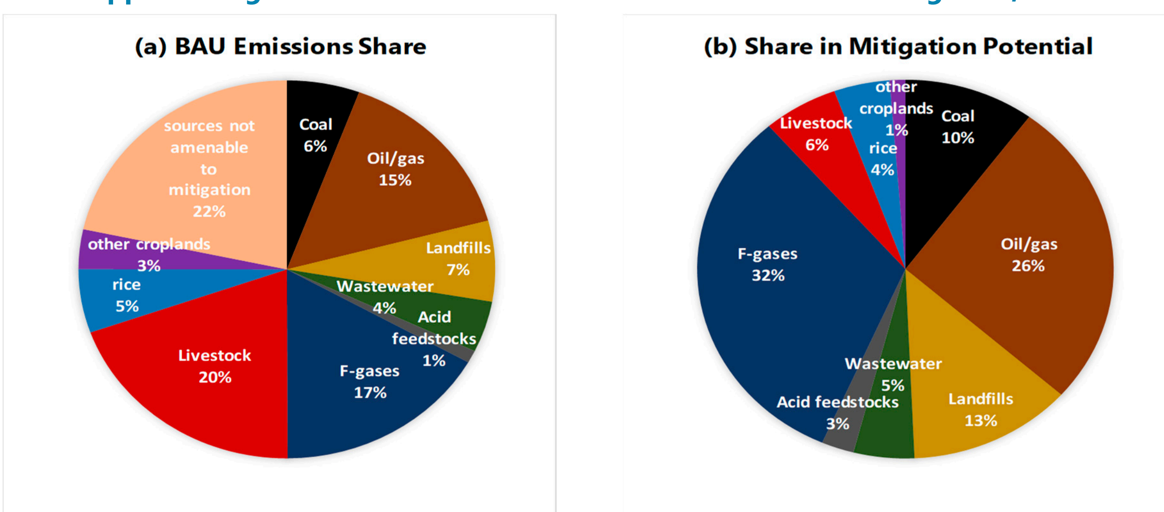
Notes: [a] Some countries have specified both conditional and unconditional pledges, where the former are contingent on external finance and other support—in these cases the conditional pledges are in parentheses. CO_2 refers to fossil fuel emissions only.

Appendix II. Mitigating Other Sources of GHGs

This Appendix discusses sources of GHGs beyond fossil fuel CO_2 and forestry emissions, the potential for mitigating them, and the practicality of taxing them. The discussion covers (approximately in declining order of practicality from an emissions tax perspective) CO_2 emissions from use of clinker in cement production; fluorinated gases (F-gases); nitrogen oxides from acid feedstocks; methane from fuel extraction; methane from landfills and wastewater systems; and non-CO_2 GHGs from agriculture.

Non-CO_2 GHGs are more potent than CO_2 (per unit weight) at trapping heat and, once emitted, methane, nitrogen oxides, and F-gases have expected atmospheric lifespans of around 12, 120, and hundreds of years respectively, compared with 100 years for CO_2.[1] When expressed in terms of the amount of CO_2 that produces the same amount of warming over a century, methane, nitrous oxide, and hydrofluorocarbons (HFC-23)—the main F-gas—have CO_2 equivalents of 25, 298, and 14,800 tonnes respectively.[2] Sources of projected non-CO_2 GHGs in 2030 and their potential contribution to cost-effective mitigation are summarized in Appendix Figure 1 and summarized below.

Appendix Figure 1. Sources of Non-CO_2 BAU Emissions and Mitigation, 2030



Source: EPA (2014).

Note: Total BAU emissions from non-CO_2 GHGs in 2030 are approximately 15 billion tonnes. In panel (a) other sources not amenable to mitigation are mostly from small-scale farm operations. In panel (b), mitigation potential (in most cases) is for a US$100 carbon price in 2030 reducing total emissions by 31 percent.

[1] EPA (2014), section I.2.

[2] IPCC (2007). Fuel combustion also produces methane and nitrous oxide but they are not discussed here as their CO_2 equivalent is small relative to the direct CO_2 emissions from combustion.

CO_2 Emissions from Cement Production

Production of clinker—currently the main component of cement—involves heating limestone which releases CO_2 emissions. Globally, these emissions are projected to stabilize at current levels of approximately 2 billion tonnes a year.[3] There are a variety of potential future possibilities for mitigating these emissions such as improving production efficiency, blending limestone with other materials (e.g., coal fly ash, blast finance sludge), installing on-site CCS technologies, pumping CO_2 into mixed concrete, and using captured CO_2 to produce cement. In principle, these responses can be promoted by taxes on clinker production, which can be monitored (along with its lime content) and a tax imposed in proportion to clinker emissions factors,[4] with potential rebates for use of CCS or direct absorption of CO_2 into cement. One study suggests that a US$65 per tonne CO_2 tax would reduce emissions by 30 to 70 percent below BAU levels in 2050, depending on the availability of CCS technologies.[5]

F-Gases

F-gases, accounting for 17 percent of projected BAU non-CO_2 GHGs in 2030 (Appendix Figure 1), were largely developed in response to the phase out of ozone-depleting chemicals under the Montreal Protocol. By far the most important—accounting for around 95 percent of the total—is hydrofluorocarbons (HFCs). Although F-gases are ozone friendly, they can reside in the atmosphere for centuries. HFCs are mainly used as refrigerants or in foams, aerosols, and fire extinguishers. Unlike other GHGs in the Paris Agreement, HFCs have other international negotiations—under the 2016 Kigali Agreement, advanced countries are required to reduce use of HFCs by 85 percent (relative to 2011-2013 levels) by 2036 and developing countries by 80-85 percent by 2045-2047. Some countries have implemented taxes on HFCs (in proportion to the global warming potential of the gas), and in some cases other F-gases[6], including Denmark, Norway, Poland, Slovenia, Spain, with tax rates equivalent to around US$5-40 per tonne of CO_2 equivalent.[7]

Nitric and Adipic Acid

The process used to produce nitric acid (commonly used as feedstock for fertilizers) and adipic acid (commonly used as a feedstock for synthetic fibers like nylon) generates nitrous oxides which account for 1 percent of projected BAU non-CO_2 GHGs in 2030 (Figure A1). Abatement possibilities

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[3] IEA/CSI (2018), van Ruijven and others (2016), Figure 9.

[4] See IPCC (1996) for comprehensive guidance on emissions factors.

[5] van Ruijven and others (2016), Figure 9.

[6] Other F-gases include sulfur hexafluoride (about 3 percent of F-gas emissions), used as an insulation gas in high-voltage switchgear and production of magnesium, and perfluorocarbons (2 percent) used in the electronics sector, for example, for cleaning silicon wafers (nitrogen trifluoride, is used in the cleaning of electronics, but it accounts for a negligible fraction of F-gas emissions).

[7] See Brack (2015) and Sastre (2016).

include, for example, thermal destruction and catalytic decomposition applied to the tail gas streams—emissions could be reduced by an estimated 79 percent in 2030 with a US$50 carbon equivalent price.[8] Taxes on acid manufactures could be applied based on default emission rates with rebates provided to entities demonstrating emissions mitigation.

Fuel Extraction

Oil and Gas. Upstream GHG emissions from oil and gas extractive operations fall into two main categories. First, is flaring or venting of natural gas, primarily from oil reservoirs (all of which contain a certain amount of gas either dissolved or capped over the deposit). The gas must be separated before oil enters the pipeline and flaring/venting avoids treatment costs, though venting is less common for safety reasons. Flaring reduces GHGs as it reduces the share of emissions released as methane rather than CO_2. Second is fugitive emissions which are unintentional methane leaks primarily from natural gas wells, processors, pipes, and storage sites.

Estimates from satellite images suggest flaring from oil and gas wells contributes about 0.5 percent to global GHGs, with the larges sources including Russia (25 percent), Nigeria (11 percent), Iran (8 percent), and Iraq (7 percent).[9] Fugitive and venting emissions are difficult to detect as measurement facilities are not widespread—but studies (based on assumed emissions factors) project (Appendix Figure 1) they will account for around 16 percent of global non-CO_2 GHGs in 2030, with the huge bulk (about 90 percent) from fugitive sources.[10]

Possibilities for mitigating emissions include reinjecting gas (after compressing it) for enhanced oil recovery or storage (though the feasibility of this varies with the sedimentary rock); using methane for on-site or regional power generation; and compressing the gas, or liquifying it, for sale—globally these measures could reduce BAU emissions from field operations in 2030 under a US$100 CO_2 price by an estimated 60 percent.[11]

If fugitive and venting emissions could be monitored on a continuous basis, an emissions tax would be the ideal instrument—monitoring technologies are advancing though currently provide only discrete measurements at a limited number of sites.[12] One possibility for the interim might be to tax fuel suppliers based on a default leakage rate but allow rebates to firms that are able to demonstrate lower leakage/venting rates through mitigation and installing their own continuous emission monitoring systems. CO_2 emissions from flaring are feasible to tax (as, for example, in Norway) because they are measurable, though safeguards may be needed to avoid creating perverse incentives for more venting.

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[8] EPA (2014).

[9] CL (2013).

[10] See also ERA (2015).

[11] EPA (2014).

[12] Metering technologies include satellites, aircraft, drones and remote sensing from vehicles.

Coal. Underground coal mining operations raise similar issues, though here the main emissions source is venting, accounting for a projected 6 percent of global BAU non-CO_2 GHGs in 2030. Potential abatement measures include recovery for pipeline injection, power generation, process heating, flaring, and catalytic or thermal oxidation of ventilation air methane—and globally these measures could reduce BAU emissions in 2030 under a US$100 CO_2 price by an estimated 60 percent.[13] Again, tax rates could be based on default emission rates with appropriate rebates for entities demonstrating methane recovery.

Landfills and Wastewater

Landfills produce methane through the bacterial decomposition of organic waste and this accounts for 7 percent of projected BAU non-CO_2 GHGs in 2030 (Figure A1). Abatement measures include capturing the methane for flaring, for use in energy, and diverting waste for recycling and re-use—and emissions could be reduced by an estimated 60 percent in 2030 with a US$100 carbon equivalent price.[14] Given that landfills are predominantly managed by the public sector, and the limited range of mitigation responses, a regulatory approach may be more suitable than emissions taxation.

Domestic and industrial wastewater treatment activities can lead to venting and fugitive methane emissions when organic material decomposes and account for 4 percent of projected BAU non-CO2 GHGs in 2030 (Figure A1). Most developed countries use aerobic wastewater treatment systems to minimize methane emissions, but many developing countries rely on systems such as septic tanks, latrines, open sewers, and lagoons. Besides switching to aerobic treatment plants, emissions can also be reduced through upgrading infrastructure and equipment—emissions could be reduced by an estimated 36 percent in 2030 with a US$100 carbon equivalent price.[15] Again however, these responses may be best induced through the public-sector planning process rather than emissions taxation.

Agriculture

Livestock. Cow and sheep operations generate methane emissions as a by-product of digestive processes in animals and nitrous oxide emissions result from nitrification and denitrification of manure—these emissions sources account for 20 percent of BAU non-CO_2 GHGs in 2030 (Appendix Figure 1). Options for reducing methane emissions include, for example, improved feed conversion efficiency, antibiotics, vaccines, changing diet, and intensive pasture management, while nitrogen oxide emissions might be reduced through small digesters and covered lagoons—emissions could

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[13] EPA (2014).

[14] EPA (2014).

[15] EPA (2014).

be reduced by an estimated 10 percent in 2030 with a US$30 carbon equivalent price though there is limited scope for further abatement opportunities.[16] Pricing livestock emissions is administratively challenging however, for example, a tax could be imposed per head of cattle or sheep (perhaps with reduced rates for lower emitting animal types and where there was proof of emissions-reducing diets), but this would be administratively complicated.

Rice. Rice cultivation is a source of methane and nitrous oxide emissions and flooding of paddy fields causes further emissions from decomposition of organic material—combined emissions account for 6 percent of projected BAU non-CO_2 GHGs in 2030 (Appendix Figure 1). Abatement options include, for example, changing tillage practices, direct seeding, and shifting to dry-land production and emissions could be reduced by an estimated 28 percent in 2030 with a US$30 carbon equivalent price though again there is limited scope for further abatement opportunities.[17]

Other cropland. Land management (e.g., tillage, fertilizer use) in production of crops like barley, maize, sorghum, soybeans, and wheat influences results in nitrous oxide emissions and methane fluxes—these emissions sources account for 3 percent of BAU non-CO_2 GHGs in 2030 (Appendix Figure 1). Abatement possibilities include, for example, no-till cultivation, changing fertilizer use, and crop residue incorporation—emissions could be reduced by an estimated 12 percent in 2030 with a US$30 carbon equivalent price.[18]

[16] EPA (2014).

[17] EPA (2014).

[18] EPA (2014).

Appendix III. Methodology for Analyzing Mitigation Policies

Analytical Model

The spreadsheet model distinguishes five fossil fuels, namely coal, natural gas, gasoline, road diesel, and other oil products (used in power generation, petrochemicals, home heating, non-road vehicles, etc.). The model projects, out to 2030, annual use of fossil and non-fossil fuel use in three sectors—power generation, road transport, and an 'other energy' sector, where the latter represents an aggregation of direct energy use by households, firms, and non-road transport. A discrete time-period model is used where t = 0… $\bar{t}$ denotes a year (though the focus is on 2030). Fossil fuels are first discussed, followed by fuel use by sector.

Fossil Fuels

Coal, natural gas, gasoline, road diesel and other oil products are denoted by i = *COAL*, *NGAS*, *GAS*, *DIES*, and *OIL* respectively. The user fuel price at time t, denoted p_t^i, is:

(1) $p_t^i = \tau_t^i + \hat{p}_t^i$

τ_t^i is the tax or subsidy (if negative) on fuel i reflecting (a) the combined effect of any pre-existing excises, favorable treatment under general sales tax for household fuels, and distortions from regulated or monopoly pricing and (b) any carbon charge. For most countries, τ_t^i is large for road fuels and zero for coal and gas (or a small positive for the latter two fuels in countries covered by the EU ETS). $\hat{p}_t^i$ is the pre-tax fuel price or supply cost (the international commodity price adjusted for processing/distribution margins). For fuel products used in multiple sectors, pre-tax prices and taxes are taken to be the same for all fuel users (for non-road oil products taxes are zero, except for EU countries to the extent they are covered by the ETS).

Power Sector

Residential, commercial, and industrial electricity consumption is aggregated into one economy-wide demand for electricity in year t, denoted Y_t^E, and determined by:

(2) $Y_t^E = \left(\frac{U_t^E}{U_0^E} \cdot \frac{h_t^E}{h_0^E}\right) \cdot Y_0^E, \quad \frac{U_t^E}{U_0^E} = \left(\frac{GDP_t}{GDP_0}\right)^{v^E} \cdot \left(\frac{h_t^E p_t^E}{h_0^E p_0^E}\right)^{\eta^{UE}}, \quad \frac{h_t^E}{h_0^E} = (1+\alpha^E)^{-t} \cdot \left(\frac{p_t^E}{p_0^E}\right)^{\eta^{hE}}$

U_t^E is usage of electricity-consuming products or capital (i.e., the stock of electricity-using capital times its average intensity of use). h_t^E is the electricity consumption rate (e.g., kWh per unit of capital usage), the inverse of energy efficiency. Product use increases with gross domestic product (GDP_t) according to v^E, the (constant) income elasticity of demand for electricity-using products. Product use also varies inversely with proportionate changes in unit electricity costs—the electricity consumption rate times p_t^E, the user electricity price. $\eta^{UE} < 0$ is the (constant) elasticity of demand for use of electricity-consuming products with respect to unit energy costs.[1] The electricity consumption rate declines (given other factors) at a fixed annual rate of $\alpha^E \geq 0$, reflecting autonomous energy efficiency improvements (e.g., due to gradual retirement of older, less efficient capital). Higher electricity prices further increase energy efficiency, implicitly through adoption of more efficient technologies: η^{hE} is the elasticity of the energy consumption rate with respect to energy prices. Note that (2) can be implemented with U_0^E and h_0^E normalized to unity (absolute values for these parameters are not needed).

Power generation fuels potentially include coal, natural gas, oil, nuclear, hydro, biomass and (non-hydro, non-biomass) renewables (principally wind and solar), where the latter are denoted by i = *NUC*, *HYD*, *BIO*, and *REN*. To accommodate flexible assumptions for the degree of substitution among fuels, the share of fuel i in generation, denoted θ_t^{Ei}, is defined:

$$(3)\ \theta_t^{Ei} = \theta_0^{Ei}\left\{\left(\frac{g_t^i}{g_0^i}\right)^{\tilde{\varepsilon}^{Ei}} + \sum_{j\neq i}\theta_0^{Ej}\left[1-\left(\frac{g_t^j}{g_0^j}\right)^{\tilde{\varepsilon}^{Ej}}\right]\Big/\sum_{l\neq j}\theta_0^{El}\right\}$$

where *i*, *j*, *l* = *COAL*, *NGAS*, *OIL*, *NUC*, *HYD*, *BIO*, *REN*. g_t^i is the full cost of generating a unit of electricity using fuel i (fuel, labor, capital, transmission/distribution costs). $\tilde{\varepsilon}^{Ei} < 0$ is the conditional (indicated by ~) own-price elasticity of generation from fuel i with respect to generation cost. Conditional here means the elasticity reflects the percent reduction in use of fuel i due to switching from that fuel to other generation fuels, per one-percent increase in generation cost for fuel i, holding total electricity generation fixed. Generation cost elasticities are larger than corresponding fuel price elasticities as an incremental increase in fuel and non-fuel generation costs has a bigger impact than an incremental increase in fuel costs alone.

From (3) fuel i's generation share decreases in own generation cost. It also increases in the generation cost of fuel $j \neq i$, where the increase in fuel i's generation share is the reduced share for fuel j (i.e., θ_0^{Ej} times the term in square brackets) multiplied by the (initial) share of fuel i in generation from all fuel alternatives to j (i.e., $\theta_0^{Ei}/\sum_{l\neq j}\theta_0^{El}$).

Use of fossil fuel i in power generation at time t, denoted F_t^{Ei}, is given by:

$$(4)\ F_t^{Ei} = \frac{\theta_t^{Ei}\cdot Y_t^E}{\rho_t^{Ei}}$$

Fuel use equals the generation share times total electricity output—assumed equal to total electricity demand—and divided by ρ_t^{Ei}, the productivity of fuel use or electricity generated per unit of F_t^{Ei}.

Unit generation costs are determined by:

[1] Improvements in energy efficiency reduce unit electricity costs, thereby increasing use of electricity-consuming products. However, this 'rebound effect' is not too large (for electricity or other energy-using products) in the model—increased energy demand offsets roughly 10 percent of the energy savings from higher energy efficiency.

(5) $g_t^{Ei} = \frac{p_t^i + k_t^{Ei}}{\rho_t^{Ei}}$, *i=COAL, NGAS, OIL;* $g_t^{Ei} = \frac{k_t^{Ei}}{\rho_t^{Ei}}$, *i=NUC, HYD, BIO, REN*;

$\rho_t^{Ei} = (1+\alpha^{\rho i})^t \rho_0^{Ei}$

where k_t^{Ei} is non-fossil fuel costs per unit. Unit generation costs decline with rising productivity (which, for a given generation type, is assumed to reduce fossil-fuel and non-fuel costs by the same proportion). Productivity of generation by fuel i increases at rate $\alpha^{\rho i} \geq 0$ per year (again, for example, due to retirement of older, less efficient plants).

Finally:

(6) $p_t^E = \sum_i \theta_t^{Ei} \cdot g_t^{Ei} + \tau_t^E$

The user price of electricity is the generation shares times unit generation costs summed over fuels (pre-existing electricity taxes are taken to be zero).

Road Transport Sector

Analogous to (1), gasoline and road diesel fuel demand in period *t*, denoted F_t^{Ti} , where *i* = *GAS*, *DIES* is gasoline and diesel respectively, is:

(7) $F_t^{Ti} = \left(\frac{U_t^{Ti}}{U_0^{Ti}} \cdot \frac{h_t^{Ti}}{h_0^{Ti}}\right) F_0^{Ti}$; $\frac{U_t^{Ti}}{U_0^{Ti}} = \left(\frac{GDP_t}{GDP_0}\right)^{\upsilon^{Ti}} \cdot \left(\frac{h_t^{Ti} p_t^i}{h_0^{Ti} p_0^i}\right)^{\eta^{UTi}}$; $\frac{h_t^{Ti}}{h_0^{Ti}} = (1+\alpha^{hTi})^{-t} \cdot \left(\frac{p_t^i}{p_0^i}\right)^{\eta^{hTi}}$

U_t^{Ti} is kilometers (km) driven by vehicles with fuel type i and h_t^{Ti} is average fuel use per vehicle km (the inverse of fuel economy). km driven in vehicle type i increases with GDP, according to the income elasticity of demand υ^{Ti}, and varies inversely with proportionate changes in fuel costs per km $h_t^{Ti} p_t^i$, where $\eta^{UTi} < 0$ is the elasticity of vehicle km driven with respect to per km fuel costs.[2] $\alpha^{Ti} \geq 0$ is an annual reduction in the fuel consumption rate due to autonomous technological change that improves fuel economy. Higher fuel prices also reduce fuel consumption rates according to the elasticity of the fuel consumption rate $\eta^{hTi} \leq 0$—this encompasses both improvements in petroleum vehicles (better engine efficiency, lighter weight materials, shifting to smaller vehicles, etc.) as well as shifting to electric and hybrid vehicles.

[2] The model abstracts from formal substitution between use of gasoline and diesel vehicles given that carbon pricing tends to increase user prices for gasoline and diesel in roughly the same proportion (and for many countries, heavy vehicles—which do not really compete with light-duty, gasoline vehicles—account for most diesel consumption).

Other Energy Sector

The other energy sector disaggregates small fuel users (households, low-emitting firms) from large (industrial) users (e.g., steel, aluminum, cement, refining, chemicals, construction, domestic aviation), denoted by q = *LARGE*, *SMALL* respectively, to distinguish ETSs which often (e.g., in the EU) only cover the latter.[3] Use of fuel i in the other energy sector, by group q, at time t, denoted F_t^{Oqi}, is:

(8) $$F_t^{Oqi} = \left(\frac{U_t^{Oqi}}{U_0^{Oqi}} \cdot \frac{h_t^{Oqi}}{h_0^{Oqi}}\right) F_0^{Oqi}; \qquad \frac{U_t^{Oqi}}{U_0^{Oqi}} = \left(\frac{GDP_t}{GDP_0}\right)^{\upsilon^{Oi}} \cdot \left(\frac{h_t^{Oqi} p_t^i}{h_0^{Oqi} p_0^i}\right)^{\eta^{UOi}}; \qquad \frac{h_t^{Oqi}}{h_0^{Oqi}} = (1+\alpha^{Oi})^{-t} \cdot \left(\frac{p_t^i}{p_0^i}\right)^{\eta^{hOi}}$$

where i = *COAL*, *NGAS*, *OIL*, *BIO*, and *REN*. The interpretation for (8) is analogous to that for (2) and (7) with U_t^{Oqi} and h_t^{Oqi} denoting respectively, use of products requiring fuel i at time t by group q and its fuel consumption rate. Parameters υ^{Oi}, η^{UOi}, η^{hOi}, and α^{Oi} have analogous interpretations to previous notation and are taken to be the same across large and small users.

Modelling Policies

The carbon tax is modelled by incorporating into the tax for fuel i a charge of $\tau_t^{CO2} \cdot \mu^{CO2i}$, for i = *COAL*, *NGAS*, *GAS*, *DIES*, and *OIL*, where τ_t^{CO2} is a uniform tax on CO_2 emissions in period t and μ^{CO2i} is fuel i's CO_2 emissions factor (positive for fossil fuels and zero for renewables, hydro, biomass, and nuclear).[4] The ETS is modelled in the same way, but with charges applying only to fuels used by power generators and large users in the other energy sector. The coal tax is the same policy as the carbon tax, but with charges applying only to coal use, and similarly the road fuel tax applies the carbon charges to road fuels only. The electricity tax, denoted τ_t^E, increases electricity prices by the same amount as they increase in the carbon tax scenario. The electricity emissions tax is the same policy as the ETS but with charges applied to power generation fuels only (not large industrial users). The energy efficiency policy applies a 'virtual' carbon charge to fuel prices in the equations governing energy efficiency, but not to fuel prices in the equations governing the usage of energy-consuming products.[5]

Metrics for Comparing Policies

CO_2 emissions. CO_2 emissions from fossil fuel use at time t are:

(9) $$\sum_{ji} F_t^{ji} \cdot \mu^{CO2i}$$

[3] ETSs can be applied (and are at the regional level in California and Canada) midstream to cover road and heating fuels, though this may overlap with existing administration for collecting fuel excises.

[4] There can be significant variation in CO_2 emissions factors among different coal types, but this is less of an issue when (as here) emission rates are defined per unit of energy.

[5] See, for example, Parry, Evans, and Oates (2014).

where $j = E, T, O$ denotes the electricity, road transport and other energy sector respectively. CO_2 reduction targets for fossil fuels are taken to be proportional to those (listed in Appendix I) for total GHGs. For (usually emerging and developing) countries with both conditional and unconditional targets, the average of the two is used to compute a representative percent reduction in emissions. For tropical countries (e.g. Brazil, Indonesia) an adjustment is made to account for the disproportionately large contribution expected from forestry (see Appendix I). For countries with emissions intensity targets (e.g., China, India), the CO_2 emissions in 2030 when those targets are met are compared with our BAU projection to infer the percent CO_2 reduction

Revenue. Revenue from fuel and electricity taxes is:

(10) $$\sum_{ji} F_t^{ji} \cdot \tau_t^i + Y_t^E \cdot \tau_t^E$$

Deaths from fossil fuel air pollution. At time *t* these are given by:

(11) $$\sum_{ij} F_t^{ji} \cdot m_t^{ji}$$

m_t^{ji} is mortality per unit of (fossil) fuel i used in sector *j*, which may differ by sector due to differing use of air emissions control technologies and local population exposure to emissions.

Economic welfare gains. The economic costs and net welfare gains of policies are calculated using applications and extensions of long-established formulas in the public finance literature[6] based, for simplicity, on second order approximations.[7] The information required to apply these formulas includes the size of price distortions in fuel and electricity markets (i.e., the difference between social and private costs due to any domestic environmental costs net of any fuel taxes), any induced quantity changes in markets affected by these distortions (an output from the model), and any new source of distortions created by carbon policies.[8]

The economic welfare gains (excluding the global climate benefits) from a carbon tax in period *t* are computed using:

(12) $$\sum_{ji} \left(\Gamma_t^{ji} - \frac{\mu^{CO2i} \cdot \tau_t^{CO2}}{2} \right) \cdot \left(-\Delta F_t^{ji} \right)$$

(13) $$\Gamma_t^{ji} = VMORT_t \cdot m_t^{ji} - \hat{\tau}_t^i, \text{ for } j \neq T,\ i = COAL, NGAS, OIL$$

$$\Gamma_t^{Ti} = VMORT_t \cdot m_t^{Ti} + \left(\frac{\eta^{UTi}}{\eta^{hTi} + \eta^{UTi}} \right) \cdot \beta_t^{Ti} - \hat{\tau}_t^i$$

(14) $$\Delta F_t^{ji} = F_t^{ji} - \hat{F}_t^{ji}$$

[6] See, for example, Harberger (1964).

[7] That is, taking fuel and electricity demand curves to be linear over the range of policy-induced fuel changes.

[8] Induced quantity changes in markets with no price distortions have no implications for economic welfare.

where a ^ denotes a BAU value and Γ_t^{ji} is the price distortion in a fuel market.

In (13), Γ_t^{ji} consists, for non-road fossil fuels, of local air pollution costs, equal to premature mortalities per unit of fuel use times $VMORT_t$, the value per premature mortality—Γ_t^{ji} is defined net of any pre-existing fuel taxes but these are modest at most for non-road fuels.[9] For road fuels, there is an additional environmental cost equal to the external costs of traffic congestion, accidents, and road damage expressed per unit of fuel use, β_t^{Ti}. The latter is multiplied by the term in parentheses, which amounts to the fraction of the induced change in fuel use due to changes in vehicle km driven as opposed to (long run) improvements in fuel economy.[10]

In (14), ΔF_t^{ji} is the change in fuel use, relative to its BAU level $\hat{F}_t^{ji}$.

From equation (12), the welfare change from the tax increase for a fossil fuel in a sector consists of: (i) the reduction in use of a fuel product in a particular sector times the pre-existing price distortion associated with that product/sector and aggregated over fuels/sectors, less (ii) the 'Harberger triangle', equal to the reduction in fuel use times one-half of the tax increase, where the latter is the product of the fuel's CO_2 emissions factor and the CO_2 price at time *t*.

The above formula is also used to calculate the net welfare change from the ETS, coal tax, road fuel taxes, and energy efficiency policies, where the charges apply to fuel use (or virtually to energy efficiency) and sectors as described above.

Parameterization

Fossil Fuels

Supply prices for coal, natural gas, gasoline, diesel, and oil products for 2016-2018 by country are from the IMF[11] and reflect international reference prices of the finished product (e.g., gasoline) adjusted, where appropriate, using standard (absolute) markups for transport and distribution costs. The international (crude) component of these prices is projected forward using actual and projected international energy prices obtained by averaging over projections in IMF (2018)[12] and EIA (2018), Tables 12, 13 and 15.

For electricity (generally a non-traded good), the supply cost for 2016-2018 in the IMF database is the domestic production cost or cost-recovery price, with costs evaluated at international reference

[9] Local air pollution causes a range of other impacts beyond mortality (morbidity, impaired visibility, building corrosion, crop damage, lake acidification, etc.) but previous studies suggest their combined costs tend to be modest relative to mortality costs (e.g., US EPA 2011, WBG/SEPAC 2007).

[10] See Parry and others (2014b), Ch. 5.

[11] See www.imf.org/external/np/fad/subsidies/data/subsidiestemplate.xlsx.

[12] These projections go to 2023 and are extrapolated to 2030.

prices. Electricity prices are projected forward using (A6), and changes in fuel prices and generation shares in a future year relative to 2016 levels.

For all countries, 2016-2018 prices to fuel users are available from the IMF and the difference between these prices and supply prices, after the latter (for household fuels) have been marked up for general sales taxes, gives the estimated fuel tax (or subsidy). Pre-existing fuel taxes are taken as constant (in real terms) from 2019 onwards in the BAU while any subsidies (primarily for natural gas in Argentina and road fuels in Saudi Arabia) are assumed to phase out progressively by 2030.

Power Sector Electricity Consumption

This is obtained for 2016 from IEA (2018c) focusing on domestic generation.

Income elasticity of demand for electricity-using products. Empirical studies for different countries suggest a range for this elasticity of around 0.5-1.5.[13] A baseline value of 0.75 is used (aside from India where a value of 0.9 is used to make an adjustment for the progressive expansion in grid access among lower income households).

Price elasticities for electricity. A simple average across the 26 estimates of long-run electricity demand elasticities reported for different countries in Jamil and Ahmad (2011), Table 1, is about -0.5, and nearly all estimates lie within a range of about -0.15 to -1.0.[14] A study for China suggests an elasticity of -0.35 to -0.5.[15] Evidence for the United States suggests the long-run price elasticity for electricity demand is around -0.4, with about half the response reflecting reduced use of electricity-consuming products and half improvements in energy efficiency.[16] Values of -0.25 are assumed for both the usage and energy consumption rate elasticities for all countries, implying a total electricity demand elasticity of -0.5.

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[13] For example, Jamil and Ahmad (2011), Table 1, report 26 estimates of long-run income elasticities for electricity from 17 studies, almost all of them lying within the above range. Many energy-climate models assume an income elasticity of unity (Webster et al. 2008, Table 1), though a review for industrializing countries suggests an elasticity of around 0.6 (Huntington and others 2017).

[14] See Madlener and others (2011) for further discussion and Webster and others (2008), Table 1, for a summary of energy demand elasticities assumed in energy climate models, most of which are between -0.3 and -0.7. A meta-analysis by Labandeira and others (2017) of studies from around the world reports a mean long-run price elasticity for electricity of -0.4. A review of a limited number of studies for China, India, and Mexico by Huntington and others (2017) puts the long run electricity demand elasticity at -0.46. Studies for residential electricity demand in the United States suggest a long-run elasticity of around -0.3 to -0.8 (Alberini and Filippini 2011), pp. 889 and 895.

[15] Zhou and Teng (2013).

[16] For example, Myers and others (2009), Parry, Evans and Oates (2014), Sanstad and McMahon (2008).

Annual rate of efficiency improvement for electricity-using products. This parameter (which is of moderate significance for the BAU) is taken to be 1 percent a year.[17]

Generation shares. These are obtained from IEA (2018c) by the electricity produced from each fuel type divided by total electricity generation.

Own-price elasticities for generation fuels (conditional on total electricity output). Empirical studies tend to suggest that coal is only moderately price responsive. For example, one survey of eight studies for various advanced countries, China, and India put the coal price elasticity at -0.15 to -0.6.[18] And for the United States, simulations from a variant of the US Department of Energy's National Energy Modeling System (NEMS) model suggested a coal price elasticity of around -0.15 (with fuel switching rather than reduced electricity demand accounting for over 80 percent of the response).[19] Other studies suggest somewhat larger responsiveness however, for example, EIA (2014) estimate a US$34 per tonne carbon tax raising coal prices by about 150 percent reduces US coal use by 32 percent in 2040, while an US$85 per tonne carbon tax reduces coal use 90 percent). And a study for China reports coal price elasticities of -0.3 to -0.7.[20] Our judgment is that the rapid (and continued future) decline in the costs of renewable energy will likely increase the price responsiveness of coal use relative to previous estimates, and could induce significant technological innovation[21], and a coal price elasticity of -0.7 is assumed here for all countries.[22] The same elasticity is assumed for other fossil generation fuels. The elasticities in equation (A3) are defined with respect to generation costs rather than fuel costs and can be obtained by dividing the fuel price elasticity by the share of fuel costs in generation costs, which for coal generation is taken to be 0.25 (see below).

Fossil fuel consumption and productivity. Consumption of coal, natural gas, and oil used in power generation is taken from IEA (2018c) for 2016. Electricity generated from a fossil fuel, divided by input of that fuel, gives the productivity of the fuel.

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[17] Typical assumptions in other models are between about 0.5 and 1 percent (e.g., Webster and others 2008, Table 1, Cao and others 2013, pp. 389-90). Significantly higher values for energy products in general seem unlikely—for example, Nordhaus (2018) puts the annual rate of decline in the CO_2 intensity of GDP at 1.5 percent (in the absence of new policies) which reflects not only improving energy efficiency but other factors (e.g., below-unity income elasticities, shifting towards low-carbon fuels).

[18] Trüby and Paulus (2012), Table 5.

[19] See Krupnick and others (2010). This simulation was for a carbon price which also raises natural gas prices, thereby dampening some of the reduction in coal use.

[20] Burke and Liao (2015).

[21] For example, Fried (2018) estimates that induced innovation increases the price-responsiveness of US CO_2 emissions by about a fifth.

[22] The degree of substitution among fossil and non-fossil generation sources is, however, limited in practice, for example, due to the intermittency of renewables, their location away from population centers, and public opposition to nuclear power.

Annual rate of autonomous productivity improvement. Productivity improvements at power plants reflect improvements in technical efficiency and gradual retirement of older, less efficient plants. For coal, annual average productivity growth is taken to be 0.5 percent based approximately on IEA (2015), Figure 2.16. For natural gas, nuclear, and hydro, there is likely a bit more room for productivity improvements and baseline annual growth rate of 1 percent is assumed. For renewables, a productivity growth rate of 5 percent is used (i.e., costs halve every 15 years).

Non-fuel generation costs. For coal and oil plants, non-fuel generation costs are taken to be three times 2014 fuel costs and for natural gas plants (which have low capital costs) non-fuel generation costs are taken to be 50 percent of fuel costs. Generation costs for nuclear, biofuels, and renewables (implicitly including any subsidies) in 2016 are taken to be 100 percent of those for coal, and for hydro 90 percent of those for coal.[23]

Road Transport Sector

Fuel use. Consumption of road gasoline and diesel in 2016 is taken from IEA (2018c).

Income elasticity of demand for vehicle km. Estimates of this parameter for advanced countries are typically between about 0.35 and 0.8, although a few estimates exceed unity (Parry and Small 2005). A value of 0.6 is used here, aside from China and India, where values of 0.8 are assumed, given the greater potential of higher income to affect vehicle ownership rates.[24]

Fuel price elasticities. Numerous studies have estimated road fuel (especially gasoline) price elasticities for different countries and some studies decompose the contribution of reduced vehicle km from long-run improvements in average fleet fuel efficiency. Based on this literature, a value of -0.25 is used for each of these elasticities and for both gasoline and diesel—the total price elasticities for each fuel are therefore -0.5.[25]

[23] EIA (2015), Table 1.

[24] Studies tend to suggest somewhat higher income elasticities for industrializing countries, for example, a review by Huntington and others (2017), Figure 7, suggests an income elasticity for gasoline of around unity (0.8 in China but well above unity for India).

[25] There is significant variation among studies however: for example, Sterner (2007) reports globally averaged (long-run) gasoline price elasticities of around –0.7, Huntington and others (2017) suggest an elasticity of -0.6 for industrializing countries, while individual country estimates in Dahl (2012) are closer to about –0.25 on average and a meta-analysis by Havranek and others (2012) of international studies puts the long run gasoline price elasticity at -0.3 (see Charap and others 2013 for further discussion). The responsiveness of fuel efficiency to taxation will be dampened in the presence of binding fuel economy regulations on new vehicles in some countries, though an adjustment is not made for this given the difficulty of gauging how binding these regulations are and the preference here for clean comparisons between fuel efficiency policies and other mitigation policies.

Annual rate of autonomous decline in vehicle fuel consumption rates (from technological improvements). As for electricity, this parameter is set at 1 percent a year (and implicitly encompasses progressive penetration of electric and hybrid vehicles).

Other Energy Sector

Fuel use. We assume 75 percent of fuel consumption by industry is by large firms that would be covered by the ETS.[26]

Income and price elasticities for other energy products. Evidence on income and price elasticities for fuels used in the industrial and residential sectors is more limited. Income elasticities of 0.5 are assumed for products using coal, oil, and biomass, and 1.0 for products using natural gas[27] and renewables. Price elasticities for fuels used in the other energy sector are taken to be the same as for electricity and road fuels.

Annual rate of autonomous productivity improvements. These are assumed to follow those for the same fuel as used in the power sector.
Miscellaneous

Real GDP growth. Projected real GDP out to 2023 is from IMF (2018) and annual real GDP growth between 2024 and 2030 is assumed equal the projected growth rate for 2023.

CO_2 emissions factors. These are calculated by dividing, for 2016, CO_2 emissions by fuel use from IEA (2018b) by fuel use (from IEA 2018c).

Mortality rates from fuel combustion. The major pollutant from power plant coal combustion causing premature mortality is $PM_{2.5}$, fine particulate matter with diameter up to 2.5 micrometers, which is small enough to penetrate the lungs and bloodstream. $PM_{2.5}$ can be produced directly during fuel combustion and is also formed indirectly from chemical reactions in the atmosphere involving sulfur dioxide (SO_2) and nitrogen oxide (NO_x) emissions. Air pollution emissions, mortality, and damage estimates by country are taken from Parry and others (2014), as updated in Coady and others (2018). Air emission rates from power plant coal combustion are assumed to converge linearly from the industry average in 2015 to the emission rate from plants with control technologies by 2030. A linear upward adjustment in the annual mortality rate is made for China and India (growing at 1.3 and 2.6 percent a year respectively) to account for (steadily) rising urban population exposure.[28] For large industrial coal users, the same mortality rates as for coal power plants in each year is assumed while

[26] This fraction will depend on the threshold emissions level determining whether entities are covered by pricing schemes, which depends in part on administrative considerations.

[27] Burke and Yang (2016) put the income elasticity for natural gas at about unity, based on a meta-analysis for 44 countries.

[28] See Parry and others (2016, 2017).

for small-scale coal users, mortality rates in 2015 are assumed equal to the industry average for coal plant emissions.

Annual change in urban population. 2017 growth rates in urban population (assumed to stay constant at this level each year during the period 2018-2030) are from WBG (2019).

Comparison with other models. Broadly speaking, the relation between carbon prices and proportionate emissions reductions is consistent with other recent studies.[29]

[29] Crudely expressing results in terms of the carbon price divided by the percent CO_2 reductions (for a carbon tax of around US$70 per tonne in 2030), in Aldy and others (2016), Table 1, this ratio is 1.9, 2.4, 2.9 and 3.1 for different US models (compared with 2.6 here); for China 1.5, 1.7, and 2.3 (1.7 here); for Japan 2.1, 5.4, and 14.2 (3.6 here); and for the EU 1.8, 3.0, 3.6 and 5.5 (compared with 2.5 to 5.4 for EU countries here). And averaging across several US models, the ratio is approximately 2.8 in Barron and others (2018), Figure 1, and for the global economy approximately 2.7 in Nordhaus (2018) (compared with 2.1 here).

Appendix IV. Full Country-Level Mitigation Analysis

Appendix Table 1. AFR Countries: Change in BAU CO_2 Emissions, 2017-2030
(In percent)

Country	GDP	CO2 to Primary Energy	Primary Energy Use to GDP	CO2 Net Change
Angola	53	-6	-35	-6
Benin	120	14	-48	31
Botswana	88	8	-36	28
Cameroon	90	1	-44	7
Congo, Democratic Republic of the	78	10	-41	16
Congo, Republic of	8	-15	-16	-23
Côte d'Ivoire	132	12	-51	26
Eritrea	71	4	-39	9
Ethiopia	162	24	-57	39
Gabon	71	2	-39	6
Ghana	95	6	-42	19
Kenya	116	6	-47	22
Mauritius	67	1	-30	17
Mozambique	180	15	-58	35
Namibia	51	-1	-32	2
Niger	112	21	-47	35
Nigeria	36	-3	-26	-2
Senegal	130	8	-50	25
South Africa	25	1	-20	1
South Sudan	-54	-21	34	-51
Tanzania	124	14	-51	25
Togo	96	11	-45	20
Zambia	76	-2	-42	0
Zimbabwe	84	-14	-44	-10
AFR Simple Average	**84**	**4**	**-38**	**11**
AFR 2030 Emissions Weighted Average	**50**	**2**	**-28**	**5**
AFR 2030 Energy Use Weighted Average	**77**	**5**	**-37**	**11**
AFR 2030 GDP Weighted Average	**71**	**3**	**-35**	**9**

Source: IMF staff spreadsheet model

Appendix Table 2. APD Countries: Change in BAU CO_2 Emissions, 2017-2030

(In percent)

Country	GDP	CO2 to Primary Energy Use	Primary Energy Use to GDP	CO2 Net Change
Australia	41	2	-26	7
Bangladesh	142	11	-42	54
Brunei Darussalam	73	-2	-22	34
Cambodia	118	13	-48	28
China	108	1	-32	43
Hong Kong SAR	49	8	-30	13
India	162	14	-41	75
Indonesia	96	5	-41	22
Japan	8	2	-20	-12
Korea	41	1	-25	6
Malaysia	84	3	-31	30
Mongolia	104	3	-32	44
Myanmar	143	13	-50	36
Nepal	76	9	-39	17
New Zealand	42	-1	-27	2
Philippines	135	5	-42	43
Singapore	41	0	-31	-3
Sri Lanka	84	28	-29	68
Thailand	60	-3	-30	9
Vietnam	127	9	-42	44
APD Simple Average	**87**	**6**	**-34**	**28**
APD 2030 Emissions Weighted Average	**108**	**4**	**-33**	**42**
APD 2030 Energy Use Weighted Average	**108**	**4**	**-34**	**42**
APD 2030 GDP Weighted Average	**96**	**4**	**-32**	**36**

Source: IMF staff spreadsheet model.

Appendix Table 3. EUR Countries: Change in BAU CO_2 Emissions, 2017-2030

(In percent)

Country	GDP	CO2 to primary	Primary Energy Use to	CO2 net change
Albania	65	-4	-29	11
Austria	23	-2	-22	-5
Belarus	34	0	-30	-6
Belgium	21	-1	-23	-7
Bosnia and Herzegovina	64	3	-28	22
Bulgaria	45	0	-25	8
Croatia	33	-1	-25	-1
Cyprus	42	-3	-31	-6
Czech Republic	40	1	-23	9
Denmark	26	-10	-32	-23
Finland	19	-2	-20	-7
France	23	-5	-20	-6
Germany	19	-1	-23	-9
Greece	21	0	-24	-8
Hungary	37	-1	-24	3
Iceland	41	-4	-24	2
Ireland	48	0	-29	5
Israel	49	5	-25	16
Italy	10	-2	-22	-15
Kosovo	67	7	-28	28
Latvia	48	-3	-30	0
Lithuania	34	0	-27	-3
Luxembourg	50	-1	-29	6
Macedonia, FYR	49	2	-28	10
Malta	58	-1	-35	2
Moldova	62	2	-32	13
Montenegro, Rep. of	48	-1	-28	6
Netherlands	30	2	-25	-1
Norway	27	-3	-22	-4
Poland	47	2	-24	13
Portugal	21	-2	-24	-11
Romania	51	1	-27	10
Russia	19	0	-27	-13
Serbia	66	3	-28	24
Slovak Republic	58	-2	-26	14
Slovenia	37	-1	-24	4
Spain	26	-1	-26	-7
Sweden	29	-2	-23	-3
Switzerland	26	-1	-22	-4
Turkey	37	1	-23	6
Ukraine	53	-1	-25	14
United Kingdom	23	-1	-24	-7
EUR Simple Average	**39**	**-1**	**-26**	**2**
EUR 2030 Emissions Weighted Average	**28**	**0**	**-25**	**-4**
EUR 2030 Energy Use Weighted Averag	**27**	**-1**	**-24**	**-5**
EUR 2030 GDP Weighted Average	**26**	**-1**	**-24**	**-5**

Source: IMF staff spreadsheet model.

Appendix Table 4. MCD Countries: Change in BAU CO_2 Emissions, 2017-2030

(In percent)

Country	GDP	CO2 to Primary Energy Use	Primary Energy Use to GDP	CO2 Net Change
Algeria	14	0	-37	0
Armenia	80	3	-33	24
Azerbaijan	33	0	-34	0
Bahrain	40	0	-39	-15
Egypt	110	-2	-42	19
Georgia	93	-1	-33	28
Iran	20	0	-30	-17
Iraq	40	0	-38	-14
Jordan	45	0	-33	-4
Kazakhstan	68	-2	-32	12
Kuwait	50	-1	-48	-23
Kyrgyz Republic	48	-6	-33	-7
Lebanon	38	-1	-38	-16
Libya	45	-1	-50	-27
Morocco	71	2	-34	16
Oman	29	-1	-22	0
Pakistan	54	1	-31	7
Qatar	42	-1	-27	3
Saudi Arabia	33	0	-36	-15
Sudan	-4	-17	-6	-25
Tajikistan	73	-6	-31	13
Tunisia	63	0	-36	4
Turkmenistan	106	0	-41	22
United Arab Emirates	47	1	-31	2
Uzbekistan	108	0	-30	45
Yemen	143	1	-50	22
MCD Simple Average	**57**	**-1**	**-34**	**2**
MCD 2030 Emissions Weighted Average	**52**	**-1**	**-34**	**0**
MCD 2030 Energy Use Weighted Average	**51**	**-1**	**-34**	**0**
MCD 2030 GDP Weighted Average	**53**	**0**	**-35**	**-1**

Source: IMF staff spreadsheet model.

Appendix Table 5. WHD Countries: Change in BAU CO_2 Emissions, 2017-2030

(In percent)

Country	GDP	CO2 to Primary Energy Use	Primary Energy Use to GDP	CO2 Net Change
Argentina	34	-1	-21	4
Bolivia	63	2	-29	18
Brazil	32	-3	-23	-1
Canada	25	-1	-21	-2
Chile	49	0	-28	8
Colombia	57	1	-29	12
Costa Rica	55	1	-32	6
Dominican Republic	93	1	-42	14
Ecuador	23	-5	-31	-19
El Salvador	33	-6	-30	-11
Guatemala	56	-3	-33	2
Haiti	45	-13	-32	-14
Honduras	60	-3	-35	1
Jamaica	30	-8	-25	-11
Mexico	44	0	-26	7
Nicaragua	46	-7	-35	-12
Panama	102	-1	-42	17
Paraguay	68	-1	-31	14
Peru	67	1	-29	20
Suriname	42	-5	-32	-9
Trinidad and Tobago	27	-3	-18	0
United States	24	-1	-21	-3
Uruguay	47	0	-30	3
WHD Simple Average	**49**	**-2**	**-29**	**2**
WHD 2030 Emissions Weighted Average	**28**	**-1**	**-22**	**-1**
WHD 2030 Energy Use Weighted Average	**29**	**-1**	**-22**	**-1**
WHD 2030 GDP Weighted Average	**28**	**-1**	**-22**	**-1**

Source: IMF staff spreadsheet model.

Appendix Table 6. AFR Countries: Reduction in CO_2 Emissions from Carbon Taxes, 2030

(In percent, below BAU)

Country	US$35 Carbon Tax	US$70 Carbon Tax	Paris Pledge
Angola	7	12	43
Benin	5	9	12
Botswana	25	33	69
Cameroon	5	10	39
Congo, Democratic Republic of the	4	7	8
Congo, Republic of	6	10	24
Côte d'Ivoire	9	16	28
Eritrea	6	10	72
Ethiopia	8	13	32
Gabon	6	12	25
Ghana	5	10	30
Kenya	7	12	15
Mauritius	14	22	15
Mozambique	7	12	0
Namibia	6	11	45
Niger	7	12	19
Nigeria	8	13	33
Senegal	9	14	22
South Africa	30	42	10
South Sudan	6	11	0
Tanzania	7	12	15
Togo	5	8	16
Zambia	9	15	36
Zimbabwe	40	52	17
AFR Simple Average	**10**	**16**	**26**
AFR 2030 Emissions Weighted Average	**22**	**31**	**18**
AFR 2030 Energy Use Weighted Average	**12**	**18**	**24**
AFR 2030 GDP Weighted Average	**12**	**19**	**25**

Source: IMF staff spreadsheet model.

Appendix Table 7. APD Countries: Reduction in CO_2 Emissions from Carbon Taxes, 2030

(In percent, below BAU)

Country	US$35 Carbon Tax	US$70 Carbon Tax	Paris Pledge
Australia	20	29	38
Bangladesh	8	14	13
Brunei Darussalam	6	11	49
Cambodia	16	25	14
China	30	42	8
Hong Kong SAR	20	28	0
India	29	40	0
Indonesia	16	24	15
Japan	14	22	20
Korea	17	26	37
Malaysia	14	21	0
Mongolia	37	50	7
Myanmar	10	17	0
Nepal	12	19	0
New Zealand	9	14	27
Philippines	20	29	35
Singapore	4	8	0
Sri Lanka	13	20	9
Thailand	9	16	23
Vietnam	21	31	17
APD Simple Average	**16**	**24**	**15**
APD 2030 Emissions Weighted Average	**27**	**38**	**9**
APD 2030 Energy Use Weighted Average	**26**	**37**	**9**
APD 2030 GDP Weighted Average	**25**	**35**	**11**

Source: IMF staff spreadsheet model.

Appendix Table 8. EUR Countries: Reduction in CO_2 Emissions from Carbon Taxes, 2030

(In percent, below BAU)

Country	US$35 Carbon Tax	US$70 Carbon Tax	Paris Pledge
Albania	6	10	12
Austria	9	15	47
Belarus	8	15	0
Belgium	8	14	30
Bosnia and Herzegovina	31	44	8
Bulgaria	23	34	1
Croatia	9	16	27
Cyprus	6	11	65
Czech Republic	24	35	19
Denmark	14	21	0
Finland	17	25	27
France	7	13	28
Germany	16	25	18
Greece	16	24	31
Hungary	11	18	21
Iceland	8	13	49
Ireland	12	20	56
Israel	14	21	43
Italy	10	16	22
Kosovo	36	49	0
Latvia	9	15	0
Lithuania	6	10	0
Luxembourg	5	10	33
Macedonia, FYR	23	33	33
Malta	2	3	13
Moldova	8	14	0
Montenegro, Rep. of	27	38	36
Netherlands	12	20	46
Norway	8	14	54
Poland	27	38	39
Portugal	11	18	49
Romania	15	24	0
Russia	11	18	0
Serbia	32	44	0
Slovak Republic	14	21	9
Slovenia	15	23	45
Spain	11	17	50
Sweden	7	11	18
Switzerland	5	9	49
Turkey	17	26	21
Ukraine	19	30	0
United Kingdom	10	17	11
EUR Simple Average	**14**	**21**	**24**
EUR 2030 Emissions Weighted Average	**14**	**22**	**18**
EUR 2030 Energy Use Weighted Average	**13**	**20**	**19**
EUR 2030 GDP Weighted Average	**12**	**19**	**25**

Source: IMF staff spreadsheet model.

Appendix Table 9. MCD Countries: Reduction in CO_2 Emissions from Carbon Taxes, 2030

(In percent, below BAU)

Country	US$35 Carbon Tax	US$70 Carbon Tax	Paris Pledge
Algeria	7	13	15
Armenia	9	16	0
Azerbaijan	8	15	0
Bahrain	7	13	0
Egypt	7	12	0
Georgia	9	15	20
Iran	9	15	8
Iraq	6	11	8
Jordan	8	13	11
Kazakhstan	17	26	28
Kuwait	8	14	0
Kyrgyz Republic	15	24	21
Lebanon	6	11	23
Libya	9	15	0
Morocco	15	23	23
Oman	8	14	2
Pakistan	10	17	10
Qatar	7	13	0
Saudi Arabia	6	11	28
Sudan	7	13	0
Tajikistan	18	27	0
Tunisia	7	13	0
Turkmenistan	10	17	0
United Arab Emirates	8	14	28
Uzbekistan	11	19	0
Yemen	8	14	7
MCD Simple Average	**9**	**16**	**9**
MCD 2030 Emissions Weighted Average	**9**	**15**	**13**
MCD 2030 Energy Use Weighted Average	**9**	**15**	**12**
MCD 2030 GDP Weighted Average	**8**	**15**	**14**

Source: IMF staff spreadsheet model.

Appendix Table 10. WHD Countries: Reduction in CO_2 Emissions from Carbon Taxes, 2030

(In percent, below BAU)

Country	US$35 Carbon Tax	US$70 Carbon Tax	Paris Pledge
Argentina	14	23	23
Bolivia	16	24	0
Brazil	11	17	34
Canada	14	22	34
Chile	17	26	13
Colombia	16	24	25
Costa Rica	6	10	44
Dominican Republic	11	17	40
Ecuador	7	13	32
El Salvador	6	11	0
Guatemala	13	21	17
Haiti	6	11	16
Honduras	8	14	15
Jamaica	7	13	9
Mexico	12	20	33
Nicaragua	7	12	20
Panama	5	9	0
Paraguay	4	7	15
Peru	15	23	25
Suriname	10	17	26
Trinidad and Tobago	8	15	4
United States	18	27	15
Uruguay	5	9	0
WHD Simple Average	**10**	**17**	**19**
WHD 2030 Emissions Weighted Average	**16**	**25**	**19**
WHD 2030 Energy Use Weighted Average	**16**	**24**	**20**
WHD 2030 GDP Weighted Average	**16**	**25**	**19**

Source: IMF staff spreadsheet model.

Appendix Table 11. AFR Countries: Impact of US$35 Carbon Price on Energy Prices, 2030

Country	Coal		Natural Gas		Electricity		Gasoline	
	BAU Price, $/GJ	% Price Increase	BAU Price, $/GJ	% Price Increase	BAU Price, $/kWh	% Price Increase	BAU Price, $/liter	% Price Increase
Angola	3.1	106	7.3	26	0.19	3	0.8	11
Benin	3.1	109	7.3	26	0.28	9	1.1	9
Botswana	3.1	109	7.3	26	0.10	136	1.0	11
Cameroon	3.1	106	7.3	26	0.14	5	1.2	6
Congo, Democratic Republic of the	3.1	106	7.3	0	0.10	0	1.3	6
Congo, Republic of	3.1	106	7.3	27	0.13	7	1.1	7
Côte d'Ivoire	3.1	106	7.3	27	0.12	17	1.2	11
Eritrea	3.1	106	7.3	26	0.35	12	0.6	15
Ethiopia	3.1	109	7.3	26	0.10	0	1.0	8
Gabon	3.1	106	7.3	21	0.16	7	1.2	6
Ghana	3.1	106	7.3	20	0.11	8	0.8	10
Kenya	3.1	110	7.3	26	0.16	1	1.2	7
Mauritius	3.1	85	7.3	26	0.18	22	1.5	4
Mozambique	3.1	0	7.3	27	0.10	1	1.1	8
Namibia	3.1	106	7.3	26	0.11	0	1.1	9
Niger	3.1	115	7.3	26	0.20	34	1.1	9
Nigeria	3.1	95	7.3	25	0.13	11	0.7	11
Senegal	3.1	106	7.3	0	0.23	10	1.3	6
South Africa	3.1	93	7.3	10	0.08	54	1.2	8
South Sudan	3.1	106	7.3	26	0.43	12	1.7	5
Tanzania	3.1	111	7.3	26	0.11	13	1.1	8
Togo	3.1	106	7.3	26	0.11	0	1.1	8
Zambia	3.1	111	7.3	26	0.10	0	1.5	6
Zimbabwe	3.1	206	7.3	26	0.11	36	1.4	6
AFR Simple Average	**3.1**	**105.2**	**7.3**	**22.8**	**0.16**	**16.6**	**1.1**	**8.1**
AFR 2030 Emissions Weighted Average	**3.1**	**97.4**	**7.3**	**16.2**	**0.11**	**37.4**	**1.1**	**8.2**
AFR 2030 Energy Use Weighted Average	**3.1**	**100.4**	**7.3**	**21.0**	**0.12**	**16.1**	**1.0**	**8.6**
AFR 2030 GDP Weighted Average	**3.1**	**100.9**	**7.3**	**21.5**	**0.13**	**18.4**	**1.0**	**8.9**

Source: IMF staff spreadsheet model.

Appendix Table 12. APD Countries: Impact of US$35 Carbon Price on Energy Prices, 2030

Country	Coal		Natural Gas		Electricity		Gasoline	
	BAU Price, $/GJ	% Price Increase	BAU Price, $/GJ	% Price Increase	BAU Price, $/kWh	% Price Increase	BAU Price, $/liter	% Price Increase
Australia	3.1	119	9.7	20	0.12	44	1.3	7
Bangladesh	3.1	113	9.7	19	0.21	12	1.3	7
Brunei Darussalam	3.1	106	9.7	17	0.22	12	0.6	13
Cambodia	3.1	107	9.7	19	0.11	22	0.6	15
China	3.1	108	9.7	19	0.09	39	1.2	6
Hong Kong SAR	3.1	107	7.4	30	0.09	52	1.2	1
India	3.1	104	9.7	12	0.09	49	1.3	6
Indonesia	3.1	108	9.7	17	0.13	35	0.6	15
Japan	3.1	104	9.7	22	0.13	23	1.4	5
Korea	3.1	99	9.7	21	0.16	23	1.5	3
Malaysia	3.1	108	9.7	15	0.13	27	0.7	11
Mongolia	3.1	118	9.7	19	0.16	67	0.7	13
Myanmar	3.1	106	9.7	20	0.19	5	0.9	9
Nepal	3.1	106	9.7	19	0.10	0	1.1	8
New Zealand	3.1	126	7.4	19	0.12	2	1.5	5
Philippines	3.1	107	9.7	20	0.12	26	1.1	7
Singapore	3.1	107	9.7	20	0.13	14	1.6	1
Sri Lanka	3.1	93	9.7	19	0.18	19	1.2	7
Thailand	3.1	90	9.7	19	0.15	15	1.0	5
Vietnam	3.1	109	9.7	20	0.12	19	1.0	7
APD Simple Average	**3.1**	**107**	**9.5**	**19**	**0.14**	**25**	**1.1**	**8**
APD 2030 Emissions Weighted Average	**3.1**	**107**	**9.7**	**18**	**0.10**	**38**	**1.2**	**6**
APD 2030 Energy Use Weighted Average	**3.1**	**106**	**9.7**	**18**	**0.11**	**37**	**1.2**	**6**
APD 2030 GDP Weighted Average	**3.1**	**107**	**9.6**	**18**	**0.11**	**36**	**1.2**	**6**

Source: IMF staff spreadsheet model.

Appendix Table 13. EUR Countries: Impact of US$35 Carbon Price on Energy Prices, 2030

Country	Coal		Natural Gas		Electricty		Gasoline	
	BAU Price, $/GJ	% Price Increase	BAU Price, $/GJ	% Price Increase	BAU Price, $/kWh	% Price Increase	BAU Price, $/liter	% Price Increase
Albania	3.1	106	7.3	33	0.11	0	1.6	5
Austria	3.7	94	7.6	25	0.12	4	1.6	5
Belarus	3.1	111	7.3	25	0.18	18	0.8	10
Belgium	3.7	89	7.6	24	0.12	5	1.8	3
Bosnia and Herzegovina	3.1	108	7.3	25	0.09	35	1.7	5
Bulgaria	3.7	94	7.6	21	0.11	20	1.4	6
Croatia	3.7	89	7.5	21	0.11	9	1.7	5
Cyprus	3.7	90	7.6	25	0.27	6	1.6	5
Czech Republic	3.7	91	7.6	25	0.11	26	1.5	5
Denmark	3.8	114	7.6	27	0.14	2	2.0	4
Finland	3.8	114	7.6	22	0.14	8	1.9	4
France	3.6	80	7.6	25	0.12	1	1.8	4
Germany	3.7	88	7.6	27	0.12	17	1.8	4
Greece	3.8	107	7.6	24	0.12	22	2.0	4
Hungary	3.7	89	7.6	25	0.12	10	1.5	5
Iceland	3.1	109	7.3	26	0.12	0	1.6	4
Ireland	3.8	105	7.6	25	0.11	18	1.8	4
Israel	3.1	113	7.3	28	0.09	35	1.8	4
Italy	3.7	91	7.6	25	0.13	12	2.0	4
Kosovo	3.7	97	7.6	25	0.09	59	1.4	7
Latvia	3.9	120	7.7	31	0.14	8	1.5	4
Lithuania	3.8	103	7.5	15	0.16	2	1.5	5
Luxembourg	3.6	87	7.6	26	0.15	2	1.6	5
Macedonia, FYR	3.1	117	7.3	26	0.10	30	1.5	5
Malta	3.7	90	7.6	25	0.26	1	1.7	1
Moldova	3.1	143	7.3	26	0.16	17	1.0	9
Montenegro, Rep. of	3.1	117	7.3	26	0.09	18	1.7	4
Netherlands	3.7	97	7.6	25	0.11	24	2.0	2
Norway	3.1	121	7.3	26	0.10	0	2.0	3
Poland	3.7	94	7.5	21	0.10	53	1.5	6
Portugal	3.7	89	7.6	25	0.13	10	1.9	4
Romania	3.7	98	7.6	24	0.12	13	1.3	7
Russia	3.1	77	7.3	24	0.15	13	0.9	6
Serbia	3.1	113	7.3	22	0.08	41	1.6	5
Slovak Republic	3.6	87	7.6	23	0.13	6	1.7	5
Slovenia	3.7	95	7.6	25	0.10	14	1.7	5
Spain	3.8	105	7.6	25	0.13	8	1.6	4
Sweden	3.5	67	7.6	23	0.13	0	1.9	3
Switzerland	3.1	119	7.3	27	0.11	0	1.7	5
Turkey	3.1	105	7.3	26	0.10	22	1.6	4
Ukraine	3.1	92	7.3	26	0.11	16	1.1	7
United Kingdom	3.9	116	7.6	26	0.13	11	1.8	4
EUR Simple Average	**3.5**	**101**	**7.5**	**24.9**	**0.13**	**15**	**1.6**	**4.8**
EUR 2030 Emissions Weighted Average	**3.5**	**92**	**7.5**	**24.9**	**0.12**	**16**	**1.5**	**4.8**
EUR 2030 Energy Use Weighted Average	**3.5**	**91**	**7.5**	**24.9**	**0.13**	**14**	**1.5**	**4.7**
EUR 2030 GDP Weighted Average	**3.6**	**96**	**7.5**	**25.3**	**0.12**	**13**	**1.7**	**4.2**

Source: IMF staff spreadsheet model.

Appendix Table 14. MCD Countries: Impact of US$35 Carbon Price on Energy Prices, 2030

Country	Coal		Natual Gas		Electricity		Gasoline	
	BAU Price, $/GJ	% Price Increase	BAU Price, $/GJ	% Price Increase	BAU Price, $/kWh	% Price Increase	BAU Price, $/liter	% Price Increase
Algeria	3.1	0	7.3	24	0.14	16	0.6	15
Armenia	3.1	0	7.3	25	0.11	5	0.9	8
Azerbaijan	3.1	106	7.3	25	0.14	20	0.6	12
Bahrain	3.1	106	7.3	24	0.19	17	0.6	9
Egypt	3.1	116	7.3	21	0.14	19	0.6	16
Georgia	3.1	104	7.3	22	0.10	2	1.0	8
Iran	3.1	136	7.3	25	0.16	22	0.6	13
Iraq	3.1	106	7.3	26	0.39	10	0.6	12
Jordan	3.1	110	7.3	27	0.14	25	1.2	7
Kazakhstan	3.1	95	7.3	25	0.11	38	0.6	14
Kuwait	3.1	106	7.3	27	0.21	13	0.6	13
Kyrgyz Republic	3.1	105	7.3	24	0.10	1	0.7	14
Lebanon	3.1	111	7.3	26	0.29	11	1.0	9
Libya	3.1	106	7.3	34	0.16	21	0.6	15
Morocco	3.1	103	7.3	27	0.11	35	1.3	7
Oman	3.1	106	7.3	25	0.13	19	0.7	15
Pakistan	3.1	109	7.3	24	0.17	8	0.9	11
Qatar	3.1	106	7.3	17	0.14	3	0.7	16
Saudi Arabia	3.1	106	7.3	25	0.23	18	0.6	13
Sudan	3.1	106	7.3	26	0.21	3	0.9	10
Tajikistan	3.1	107	7.3	0	0.10	1	1.0	8
Tunisia	3.1	106	7.3	27	0.12	18	1.0	8
Turkmenistan	3.1	106	7.3	27	0.27	5	0.6	14
United Arab Emirates	3.1	107	7.3	27	0.18	19	0.7	5
Uzbekistan	3.1	111	7.3	25	0.16	12	0.9	9
Yemen	3.1	108	7.3	27	0.23	11	0.8	13
MCD Simple Average	**3.1**	**100**	**7.3**	**24**	**0.17**	**14**	**0.8**	**11**
MCD 2030 Emissions Weighted Average	**3.1**	**108**	**7.3**	**25**	**0.18**	**19**	**0.7**	**12**
MCD 2030 Energy Use Weighted Average	**3.1**	**108**	**7.3**	**25**	**0.18**	**17**	**0.7**	**12**
MCD 2030 GDP Weighted Average	**3.1**	**104**	**7.3**	**25**	**0.19**	**17**	**0.7**	**12**

Source: IMF staff spreadsheet model.

Appendix Table 15. WHD Countries: Impact of US$35 Carbon Price on Energy Prices, 2030

Country	Coal		Natural Gas		Electricity		Gasoline	
	BAU Price, $/GJ	% Price Increase	BAU Price, $/GJ	% Price Increase	BAU Price, $/kWh	% Price Increase	BAU Price, $/liter	% Price Increase
Argentina	3.1	134	3.0	62	0.10	27	1.5	6
Bolivia	3.1	106	3.0	64	0.08	45	0.7	14
Brazil	3.1	101	3.0	61	0.12	4	1.4	6
Canada	3.1	113	3.0	60	0.11	6	1.1	8
Chile	3.1	110	3.0	56	0.11	24	1.3	7
Colombia	3.1	120	3.0	71	0.10	11	0.9	10
Costa Rica	3.1	128	3.0	63	0.12	0	1.2	7
Dominican Republic	3.1	109	3.0	67	0.18	18	1.3	7
Ecuador	3.1	106	3.0	65	0.17	5	0.7	13
El Salvador	3.1	106	3.0	63	0.18	3	1.0	9
Guatemala	3.1	94	3.0	63	0.16	14	0.7	13
Haiti	3.1	106	3.0	63	0.36	10	1.3	8
Honduras	3.1	107	3.0	63	0.20	5	1.1	10
Jamaica	3.1	93	3.0	63	0.30	6	1.1	7
Mexico	3.1	102	3.0	62	0.10	41	1.1	8
Nicaragua	3.1	106	3.0	63	0.20	3	1.1	9
Panama	3.1	102	3.0	63	0.14	3	0.9	4
Paraguay	3.1	106	3.0	63	0.12	0	1.3	8
Peru	3.1	176	3.0	64	0.09	20	1.1	7
Suriname	3.1	106	3.0	63	0.35	4	0.9	13
Trinidad and Tobago	3.1	106	3.0	27	0.07	16	0.7	9
United States	3.1	115	3.0	63	0.08	30	0.9	9
Uruguay	3.1	0	3.0	54	0.14	0	1.7	5
WHD Simple Average	**3.1**	**107**	**3.0**	**61**	**0.15**	**13**	**1.1**	**9**
WHD 2030 Emissions Weighted Average	**3.1**	**114**	**3.0**	**63**	**0.09**	**26**	**1.0**	**9**
WHD 2030 Energy Use Weighted Average	**3.1**	**113**	**3.0**	**63**	**0.09**	**24**	**1.0**	**8**
WHD 2030 GDP Weighted Average	**3.1**	**114**	**3.0**	**63**	**0.09**	**26**	**0.9**	**9**

Source: IMF staff spreadsheet model.

Appendix Table 16. AFR Countries: Revenue from Carbon Taxes (in Excess of BAU), 2030

(In percent of GDP)

Country	US$35 Carbon Tax	US$70 Carbon Tax
Angola	0.4	0.8
Benin	1.2	2.3
Botswana	0.8	1.3
Cameroon	0.4	0.7
Congo, Democratic Republic of the	0.1	0.2
Congo, Republic of	0.8	1.5
Côte d'Ivoire	0.7	1.3
Eritrea	0.2	0.3
Ethiopia	0.3	0.6
Gabon	0.5	0.9
Ghana	0.5	1.0
Kenya	0.4	0.7
Mauritius	0.6	1.1
Mozambique	0.9	1.7
Namibia	0.7	1.3
Niger	0.7	1.3
Nigeria	0.4	0.8
Senegal	0.7	1.2
South Africa	2.2	3.6
South Sudan	1.0	1.8
Tanzania	0.4	0.8
Togo	0.9	1.7
Zambia	0.3	0.6
Zimbabwe	0.8	1.2
AFR Simple Average	**0.7**	**1.2**
AFR 2030 Emissions Weighted Average	**1.5**	**2.5**
AFR 2030 Energy Use Weighted Average	**0.7**	**1.3**
AFR 2030 GDP Weighted Average	**0.8**	**1.4**

Source: IMF staff spreadsheet model.

Appendix Table 17. APD Countries: Revenue from Carbon Taxes (in Excess of BAU), 2030

(In percent of GDP)

Country	US$35 Carbon Tax	US$ 70 Carbon Tax
Australia	0.7	1.2
Bangladesh	0.8	1.5
Brunei Darussalam	1.7	3.2
Cambodia	0.9	1.6
China	1.4	2.3
Hong Kong SAR	0.3	0.5
India	1.5	2.5
Indonesia	1.1	2.0
Japan	0.6	1.1
Korea	1.1	1.9
Malaysia	1.7	3.0
Mongolia	2.3	3.7
Myanmar	0.8	1.4
Nepal	0.7	1.3
New Zealand	0.4	0.7
Philippines	0.7	1.2
Singapore	0.4	0.8
Sri Lanka	0.6	1.1
Thailand	1.4	2.6
Vietnam	1.7	3.0
APD Simple Average	**1.0**	**1.8**
APD 2030 Emissions Weighted Average	**1.3**	**2.3**
APD 2030 Energy Use Weighted Average	**1.3**	**2.2**
APD 2030 GDP Weighted Average	**1.2**	**2.1**

Source: IMF staff spreadsheet model.

Appendix Table 18. EUR Countries: Revenue from Carbon Taxes (in Excess of BAU), 2030

(In percent of GDP)

Country	US$35 Carbon Tax	US$70 Carbon Tax
Albania	0.6	1.1
Austria	0.4	0.7
Belarus	2.8	5.3
Belgium	0.6	1.0
Bosnia and Herzegovina	2.1	3.4
Bulgaria	1.5	2.5
Croatia	0.8	1.4
Cyprus	0.7	1.3
Czech Republic	0.9	1.5
Denmark	0.2	0.3
Finland	0.4	0.8
France	0.3	0.6
Germany	0.5	0.8
Greece	0.8	1.4
Hungary	0.9	1.5
Iceland	0.2	0.4
Ireland	0.3	0.5
Israel	0.5	0.9
Italy	0.5	0.8
Kosovo	2.0	3.2
Latvia	0.6	1.0
Lithuania	0.6	1.1
Luxembourg	0.3	0.6
Macedonia, FYR	1.2	2.0
Malta	0.3	0.6
Moldova	2.0	3.7
Montenegro, Rep. of	0.8	1.3
Netherlands	0.5	0.9
Norway	0.2	0.4
Poland	1.1	1.8
Portugal	0.5	1.0
Romania	0.8	1.3
Russia	2.7	4.9
Serbia	1.8	2.9
Slovak Republic	0.8	1.3
Slovenia	0.6	1.1
Spain	0.5	0.9
Sweden	0.2	0.4
Switzerland	0.1	0.3
Turkey	1.2	2.1
Ukraine	3.6	6.3
United Kingdom	0.4	0.7
EUR Simple Average	**0.9**	**1.6**
EUR 2030 Emissions Weighted Average	**1.3**	**2.3**
EUR 2030 Energy Use Weighted Average	**1.2**	**2.2**
EUR 2030 GDP Weighted Average	**0.7**	**1.2**

Source: IMF staff spreadsheet model.

Appendix Table 19. MCD Countries: Revenue from Carbon Taxes (in Excess of BAU), 2030

(In percent of GDP)

Country	US$35 Carbon Tax	US$70 Carbon Tax
Algeria	1.7	3.3
Armenia	1.3	2.4
Azerbaijan	2.1	3.9
Bahrain	2.0	3.8
Egypt	1.8	3.4
Georgia	1.3	2.5
Iran	4.9	9.1
Iraq	1.4	2.7
Jordan	1.5	2.8
Kazakhstan	2.8	4.9
Kuwait	1.5	2.7
Kyrgyz Republic	2.6	4.7
Lebanon	1.0	1.8
Libya	2.6	4.8
Morocco	1.1	2.0
Oman	2.9	5.5
Pakistan	1.5	2.8
Qatar	1.3	2.5
Saudi Arabia	1.9	3.6
Sudan	1.8	3.5
Tajikistan	1.5	2.6
Tunisia	1.7	3.1
Turkmenistan	4.1	7.5
United Arab Emirates	1.4	2.6
Uzbekistan	5.7	10.4
Yemen	0.6	1.2
MCD Simple Average	**2.1**	**3.8**
MCD 2030 Emissions Weighted Average	**2.7**	**4.9**
MCD 2030 Energy Use Weighted Average	**2.6**	**4.8**
MCD 2030 GDP Weighted Average	**2.1**	**3.8**

Source: IMF staff spreadsheet model.

Appendix Table 20. WHD Countries: Revenue from Carbon Taxes (in Excess of BAU), 2030
(In percent of GDP)

Country	US$35 Carbon Tax	US$70 Carbon Tax
Argentina	1.1	2.1
Bolivia	1.3	2.3
Brazil	0.6	1.0
Canada	0.8	1.5
Chile	0.7	1.3
Colombia	0.7	1.2
Costa Rica	0.3	0.6
Dominican Republic	0.7	1.3
Ecuador	0.9	1.8
El Salvador	0.7	1.3
Guatemala	0.5	0.9
Haiti	0.9	1.7
Honduras	1.1	2.0
Jamaica	1.3	2.4
Mexico	1.0	1.8
Nicaragua	0.9	1.7
Panama	0.4	0.7
Paraguay	0.4	0.7
Peru	0.6	1.1
Suriname	1.5	2.7
Trinidad and Tobago	2.6	4.8
United States	0.6	1.1
Uruguay	0.3	0.5
WHD Simple Average	**0.9**	**1.6**
WHD 2030 Emissions Weighted Average	**0.7**	**1.2**
WHD 2030 Energy Use Weighted Average	**0.7**	**1.2**
WHD 2030 GDP Weighted Average	**0.7**	**1.2**

Source: IMF staff spreadsheet model.

Appendix Table 21. AFR Countries: Welfare Gains and Economic Costs, 2030

(In percent of GDP)

Country	Welfare Gains	Economic Costs
Angola	0.2	0.1
Benin	-0.3	-0.2
Botswana	-0.2	0.1
Cameroon	0.1	0.0
Congo, Democratic Republic of the	0.0	0.0
Congo, Republic of	-0.1	0.0
Côte d'Ivoire	0.0	0.1
Eritrea	0.0	0.0
Ethiopia	0.1	0.0
Gabon	0.0	0.1
Ghana	0.1	0.1
Kenya	0.0	0.1
Mauritius	0.2	0.2
Mozambique	-0.1	0.1
Namibia	0.0	0.1
Niger	-0.1	0.0
Nigeria	0.2	0.1
Senegal	-0.1	0.0
South Africa	-0.6	0.9
South Sudan	-0.1	0.0
Tanzania	0.0	0.1
Togo	-0.2	-0.1
Zambia	0.0	-0.6
Zimbabwe	-0.7	-1.2
AFR Simple Average	**-0.1**	**0.0**
AFR 2030 Emissions Weighted Average	**-0.3**	**-0.5**
AFR 2030 Energy Use Weighted Average	**-0.1**	**-0.2**
AFR 2030 GDP Weighted Average	**0.0**	**-0.2**

Source: IMF staff spreadsheet model.

Appendix Table 22. APD Countries: Welfare Gains and Economic Costs, 2030

(In percent of GDP)

Country	Welfare Gains	Economic Costs
Australia	-0.1	0.2
Bangladesh	0.2	0.1
Brunei Darussalam	0.2	0.2
Cambodia	1.0	0.3
China	3.9	0.9
Hong Kong SAR	0.2	0.1
India	3.8	4.7
Indonesia	1.3	0.4
Japan	0.3	0.2
Korea	0.6	0.3
Malaysia	0.9	0.4
Mongolia	4.8	1.9
Myanmar	0.3	0.1
Nepal	0.1	0.2
New Zealand	0.0	0.0
Philippines	0.1	0.4
Singapore	1.2	0.0
Sri Lanka	1.0	0.1
Thailand	-0.9	-0.6
Vietnam	1.2	0.6
APD Simple Average	**1.0**	**-0.5**
APD 2030 Emissions Weighted Average	**3.2**	**-1.4**
APD 2030 Energy Use Weighted Average	**3.0**	**-1.5**
APD 2030 GDP Weighted Average	**2.7**	**-1.2**

Source: IMF staff spreadsheet model.

Appendix Table 23. EUR Countries: Welfare Gains and Economic Costs, 2030

(In percent of GDP)

Country	Welfare Gains	Economic Costs
Albania	0.2	0.1
Austria	0.0	0.1
Belarus	1.8	0.5
Belgium	0.1	0.1
Bosnia and Herzegovina	21.1	1.4
Bulgaria	2.5	0.7
Croatia	0.5	0.1
Cyprus	-0.1	0.0
Czech Republic	1.7	0.5
Denmark	0.0	0.1
Finland	0.0	0.1
France	0.1	0.0
Germany	0.2	0.2
Greece	0.2	0.3
Hungary	0.4	0.2
Iceland	0.0	0.0
Ireland	0.0	0.1
Israel	0.0	0.1
Italy	0.0	0.1
Kosovo	22.0	1.9
Latvia	0.2	0.1
Lithuania	0.4	0.1
Luxembourg	0.2	0.0
Macedonia, FYR	6.0	0.5
Malta	0.0	0.0
Moldova	0.3	0.3
Montenegro, Rep. of	6.9	0.4
Netherlands	0.0	0.1
Norway	0.1	0.2
Poland	1.0	0.7
Portugal	-0.1	0.1
Romania	1.2	0.2
Russia	4.5	0.6
Serbia	16.0	1.2
Slovak Republic	0.3	0.2
Slovenia	0.3	0.2
Spain	0.1	0.1
Sweden	0.0	0.0
Switzerland	0.0	0.0
Turkey	0.9	0.4
Ukraine	24.1	1.4
United Kingdom	0.0	0.1
EUR Simple Average	**2.7**	**-0.3**
EUR 2030 Emissions Weighted Average	**2.7**	**-0.4**
EUR 2030 Energy Use Weighted Average	**2.4**	**-0.3**
EUR 2030 GDP Weighted Average	**0.7**	**-0.2**

Source: IMF staff spreadsheet model.

Appendix Table 24. MCD Countries: Welfare Gains and Economic Costs, 2030

(In percent of GDP)

Country	Welfare Gains	Economic Costs
Algeria	0.2	0.3
Armenia	0.2	0.2
Azerbaijan	0.0	0.3
Bahrain	-0.1	0.2
Egypt	0.5	0.2
Georgia	1.5	0.2
Iran	0.0	0.8
Iraq	0.5	0.2
Jordan	-0.2	0.1
Kazakhstan	2.1	0.9
Kuwait	0.6	0.2
Kyrgyz Republic	0.1	0.8
Lebanon	0.4	0.5
Libya	-0.3	0.1
Morocco	0.3	0.3
Oman	-0.2	0.3
Pakistan	0.4	0.3
Qatar	0.1	0.2
Saudi Arabia	0.8	0.2
Sudan	-0.1	0.1
Tajikistan	0.0	0.5
Tunisia	0.4	0.3
Turkmenistan	1.3	-7.5
United Arab Emirates	0.0	-2.6
Uzbekistan	-0.4	-10.4
Yemen	-0.1	-1.2
MCD Simple Average	**0.3**	**0.6**
MCD 2030 Emissions Weighted Average	**0.5**	**0.6**
MCD 2030 Energy Use Weighted Average	**0.4**	**0.6**
MCD 2030 GDP Weighted Average	**0.5**	**0.3**

Source: IMF staff spreadsheet model.

Appendix Table 25. WHD Countries: Welfare Gains and Economic Costs, 2030

(In percent of GDP)

Country	Welfare Gains	Economic Costs
Argentina	0.1	0.3
Bolivia	0.0	0.4
Brazil	0.1	0.1
Canada	0.0	0.2
Chile	0.3	0.2
Colombia	0.3	0.2
Costa Rica	0.1	0.0
Dominican Republic	0.7	0.1
Ecuador	0.3	0.1
El Salvador	0.1	0.2
Guatemala	0.1	0.1
Haiti	-0.1	0.0
Honduras	0.1	0.2
Jamaica	0.2	0.2
Mexico	0.1	0.2
Nicaragua	0.0	0.2
Panama	0.4	0.0
Paraguay	0.0	0.0
Peru	0.0	0.2
Suriname	0.2	0.3
Trinidad and Tobago	0.8	0.4
United States	0.1	0.2
Uruguay	0.1	-0.5
WHD Simple Average	**0.2**	**-0.2**
WHD 2030 Emissions Weighted Average	**0.1**	**-0.2**
WHD 2030 Energy Use Weighted Average	**0.1**	**-0.2**
WHD 2030 GDP Weighted Average	**0.1**	**-0.2**

Source: IMF staff spreadsheet model.

Appendix Table 26. AFR Countries: CO_2 Reduction from Alternative Policies, 2030 (as a fraction of CO_2 reductions under US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Angola	0.00	0.32	0.02	0.27	0.24	0.38
Benin	0.22	0.28	0.03	0.21	0.61	0.41
Botswana	0.83	0.88	0.60	0.87	0.10	0.37
Cameroon	0.00	0.45	0.10	0.44	0.26	0.33
Congo, Democratic Republic of the	0.00	0.04	0.00	0.03	0.50	0.49
Congo, Republic of	0.00	0.24	0.04	0.24	0.35	0.40
Côte d'Ivoire	0.00	0.54	0.18	0.50	0.17	0.34
Eritrea	0.00	0.55	0.51	0.54	0.30	0.48
Ethiopia	0.31	0.37	0.00	0.24	0.22	0.38
Gabon	0.00	0.56	0.11	0.49	0.08	0.31
Ghana	0.00	0.38	0.11	0.34	0.30	0.39
Kenya	0.31	0.40	0.00	0.30	0.25	0.35
Mauritius	0.83	0.85	0.28	0.84	0.02	0.22
Mozambique	0.00	0.38	0.01	0.34	0.29	0.34
Namibia	0.06	0.14	0.00	0.11	0.33	0.44
Niger	0.40	0.48	0.30	0.46	0.37	0.42
Nigeria	0.00	0.35	0.08	0.32	0.26	0.38
Senegal	0.50	0.53	0.12	0.40	0.13	0.36
South Africa	0.96	0.73	0.25	0.71	0.02	0.27
South Sudan	0.00	0.18	0.16	0.17	0.40	0.49
Tanzania	0.22	0.45	0.09	0.37	0.34	0.36
Togo	0.00	0.09	0.00	0.07	0.56	0.47
Zambia	0.45	0.57	0.00	0.43	0.10	0.29
Zimbabwe	0.95	0.91	0.19	0.95	0.02	0.12
AFR Simple Average	**0.25**	**0.44**	**0.13**	**0.40**	**0.26**	**0.37**
AFR 2030 Emissions Weighted Average	**0.63**	**0.61**	**0.19**	**0.57**	**0.11**	**0.31**
AFR 2030 Energy Use Weighted Average	**0.28**	**0.43**	**0.10**	**0.39**	**0.23**	**0.36**
AFR 2030 GDP Weighted Average	**0.28**	**0.46**	**0.11**	**0.41**	**0.21**	**0.35**

Source: IMF staff spreadsheet model.

Appendix Table 27. APD Countries: CO_2 Reduction from Alternative Policies, 2030 (as a fraction of CO_2 reductions under US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output tax	Electricity CO2 tax	Road Fuel Taxes	Energy Efficiency Combination
Australia	0.77	0.83	0.36	0.84	0.03	0.26
Bangladesh	0.19	0.59	0.27	0.51	0.03	0.38
Brunei Darussalam	0.00	0.31	0.29	0.30	0.11	0.49
Cambodia	0.67	0.71	0.16	0.70	0.17	0.23
China	0.95	0.79	0.20	0.73	0.01	0.23
Hong Kong SAR	0.92	0.93	0.57	0.89	0.00	0.34
India	0.94	0.87	0.30	0.83	0.01	0.23
Indonesia	0.68	0.72	0.27	0.68	0.12	0.30
Japan	0.69	0.67	0.26	0.63	0.02	0.31
Korea	0.81	0.71	0.21	0.68	0.01	0.26
Malaysia	0.71	0.77	0.31	0.74	0.08	0.28
Mongolia	0.95	0.85	0.36	0.84	0.01	0.26
Myanmar	0.15	0.57	0.07	0.52	0.04	0.28
Nepal	0.65	0.49	0.00	0.33	0.16	0.34
New Zealand	0.44	0.43	0.01	0.35	0.11	0.33
Philippines	0.82	0.85	0.24	0.81	0.05	0.22
Singapore	0.14	0.84	0.57	0.79	0.00	0.39
Sri Lanka	0.66	0.71	0.23	0.70	0.12	0.26
Thailand	0.46	0.58	0.21	0.52	0.03	0.35
Vietnam	0.86	0.80	0.15	0.71	0.03	0.22
APD Simple Average	**0.62**	**0.70**	**0.25**	**0.65**	**0.06**	**0.30**
APD 2030 Emissions Weighted Average	**0.90**	**0.79**	**0.23**	**0.74**	**0.02**	**0.24**
APD 2030 Energy Use Weighted Averag	**0.87**	**0.78**	**0.23**	**0.74**	**0.02**	**0.25**
APD 2030 GDP Weighted Average	**0.86**	**0.77**	**0.24**	**0.73**	**0.02**	**0.25**

Source: IMF staff spreadsheet model.

Appendix Table 28. EUR Countries: CO_2 Reduction from Alternative Policies, 2030 (as a fraction of CO_2 reductions under US$70 carbon tax)

Country	Coal tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Albania	0.21	0.23	0.00	0.15	0.20	0.42
Austria	0.47	0.38	0.02	0.33	0.08	0.35
Belarus	0.16	0.41	0.30	0.38	0.07	0.46
Belgium	0.33	0.36	0.02	0.30	0.02	0.36
Bosnia and Herzegovina	0.95	0.84	0.23	0.83	0.01	0.20
Bulgaria	0.86	0.87	0.19	0.86	0.02	0.16
Croatia	0.44	0.54	0.07	0.52	0.09	0.28
Cyprus	0.00	0.57	0.15	0.56	0.09	0.29
Czech Republic	0.87	0.79	0.20	0.77	0.02	0.21
Denmark	0.58	0.66	0.00	0.66	0.04	0.17
Finland	0.78	0.80	0.07	0.77	0.03	0.15
France	0.24	0.28	0.00	0.24	0.08	0.38
Germany	0.72	0.71	0.13	0.68	0.02	0.22
Greece	0.72	0.81	0.23	0.81	0.03	0.21
Hungary	0.43	0.48	0.07	0.45	0.04	0.31
Iceland	0.58	0.46	0.00	0.30	0.06	0.35
Ireland	0.55	0.71	0.19	0.69	0.05	0.25
Israel	0.81	0.88	0.58	0.87	0.03	0.36
Italy	0.31	0.56	0.13	0.53	0.05	0.30
Kosovo	0.96	0.96	0.39	0.96	0.01	0.21
Latvia	0.07	0.63	0.11	0.60	0.06	0.25
Lithuania	0.24	0.19	0.00	0.14	0.15	0.43
Luxembourg	0.08	0.23	0.00	0.16	0.23	0.42
Macedonia, FYR	0.86	0.90	0.23	0.87	0.03	0.18
Malta	-0.01	0.12	0.02	0.12	0.02	0.45
Moldova	0.11	0.54	0.35	0.50	0.09	0.43
Montenegro, Rep. of	0.93	0.92	0.14	0.91	0.02	0.11
Netherlands	0.55	0.67	0.24	0.64	0.01	0.30
Norway	0.25	0.23	0.00	0.16	0.03	0.42
Poland	0.91	0.77	0.28	0.75	0.01	0.26
Portugal	0.55	0.72	0.11	0.70	0.05	0.21
Romania	0.64	0.71	0.12	0.68	0.05	0.22
Russia	0.38	0.46	0.14	0.44	0.01	0.35
Serbia	0.93	0.88	0.27	0.87	0.01	0.20
Slovak Republic	0.67	0.42	0.03	0.38	0.03	0.33
Slovenia	0.76	0.81	0.12	0.79	0.07	0.16
Spain	0.46	0.62	0.08	0.61	0.05	0.24
Sweden	0.49	0.28	0.00	0.23	0.06	0.39
Switzerland	0.06	0.17	0.00	0.12	0.15	0.44
Turkey	0.74	0.64	0.17	0.60	0.02	0.28
Ukraine	0.76	0.55	0.09	0.52	0.01	0.29
United Kingdom	0.33	0.55	0.10	0.54	0.04	0.28
EUR Simple Average	**0.52**	**0.58**	**0.13**	**0.55**	**0.05**	**0.29**
EUR 2030 Emissions Weighted Average	**0.53**	**0.57**	**0.14**	**0.55**	**0.03**	**0.30**
EUR 2030 Energy Use Weighted Average	**0.50**	**0.54**	**0.12**	**0.52**	**0.03**	**0.30**
EUR 2030 GDP Weighted Average	**0.48**	**0.55**	**0.11**	**0.52**	**0.04**	**0.30**

Source: IMF staff spreadsheet model.

Appendix Table 29. MCD Countries: CO_2 Reduction from Alternative Policies, 2030 (as a fraction of CO_2 reductions under US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Algeria	0.00	0.24	0.15	0.21	0.19	0.47
Armenia	0.00	0.32	0.05	0.30	0.03	0.37
Azerbaijan	0.00	0.43	0.26	0.40	0.08	0.43
Bahrain	0.00	0.57	0.49	0.54	0.03	0.47
Egypt	0.03	0.41	0.40	0.36	0.19	0.52
Georgia	0.29	0.34	0.01	0.27	0.14	0.37
Iran	0.04	0.35	0.20	0.31	0.06	0.44
Iraq	0.00	0.50	0.33	0.48	0.07	0.42
Jordan	0.12	0.60	0.47	0.55	0.14	0.46
Kazakhstan	0.69	0.59	0.22	0.54	0.03	0.34
Kuwait	0.00	0.38	0.13	0.30	0.09	0.42
Kyrgyz Republic	0.66	0.33	0.00	0.30	0.17	0.35
Lebanon	0.13	0.54	0.34	0.50	0.17	0.42
Libya	0.00	0.70	0.55	0.69	0.22	0.43
Morocco	0.68	0.76	0.31	0.75	0.07	0.28
Oman	0.00	0.44	0.19	0.35	0.11	0.42
Pakistan	0.30	0.53	0.08	0.42	0.13	0.33
Qatar	0.00	0.26	0.03	0.23	0.15	0.40
Saudi Arabia	0.00	0.51	0.41	0.45	0.11	0.48
Sudan	0.00	0.41	0.05	0.39	0.34	0.33
Tajikistan	0.83	0.20	0.00	0.19	0.06	0.40
Tunisia	0.00	0.52	0.29	0.47	0.14	0.41
Turkmenistan	0.00	0.33	0.05	0.31	0.05	0.37
United Arab Emirates	0.10	0.77	0.37	0.64	0.02	0.36
Uzbekistan	0.11	0.47	0.13	0.44	0.01	0.35
Yemen	0.10	0.46	0.16	0.41	0.24	0.37
MCD Simple Average	**0.2**	**0.5**	**0.2**	**0.4**	**0.1**	**0.4**
MCD 2030 Emissions Weighted Average	**0.1**	**0.5**	**0.3**	**0.4**	**0.1**	**0.4**
MCD 2030 Energy Use Weighted Average	**0.1**	**0.5**	**0.2**	**0.4**	**0.1**	**0.4**
MCD 2030 GDP Weighted Average	**0.1**	**0.5**	**0.3**	**0.4**	**0.1**	**0.4**

Source: IMF staff spreadsheet model.

Appendix Table 30. WHD Countries: CO_2 Reduction from Alternative Policies, 2030 (as a fraction of CO_2 reductions under US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Argentina	0.04	0.46	0.16	0.42	0.04	0.37
Bolivia	0.00	0.53	0.20	0.50	0.13	0.35
Brazil	0.34	0.46	0.02	0.39	0.10	0.32
Canada	0.26	0.40	0.03	0.37	0.07	0.33
Chile	0.67	0.78	0.20	0.75	0.07	0.22
Colombia	0.29	0.47	0.05	0.45	0.11	0.30
Costa Rica	0.23	0.19	0.00	0.13	0.43	0.43
Dominican Republic	0.43	0.68	0.27	0.62	0.06	0.32
Ecuador	0.00	0.35	0.06	0.33	0.27	0.36
El Salvador	0.00	0.37	0.03	0.33	0.34	0.35
Guatemala	0.61	0.62	0.10	0.61	0.20	0.25
Haiti	0.00	0.41	0.10	0.34	0.47	0.38
Honduras	0.13	0.64	0.09	0.60	0.26	0.25
Jamaica	0.08	0.59	0.09	0.52	0.10	0.29
Mexico	0.18	0.60	0.31	0.55	0.10	0.38
Nicaragua	0.00	0.45	0.04	0.41	0.29	0.31
Panama	0.36	0.47	0.03	0.45	0.08	0.29
Paraguay	0.00	0.04	0.00	0.03	0.88	0.49
Peru	0.17	0.63	0.14	0.64	0.07	0.25
Suriname	0.00	0.56	0.07	0.56	0.15	0.26
Trinidad and Tobago	0.00	0.14	0.07	0.12	0.04	0.47
United States	0.48	0.69	0.23	0.68	0.06	0.28
Uruguay	0.00	0.18	0.00	0.14	0.26	0.43
WHD Simple Average	**0.19**	**0.47**	**0.10**	**0.43**	**0.20**	**0.33**
WHD 2030 Emissions Weighted Average	**0.41**	**0.63**	**0.20**	**0.61**	**0.07**	**0.29**
WHD 2030 Energy Use Weighted Average	**0.40**	**0.61**	**0.18**	**0.59**	**0.08**	**0.30**
WHD 2030 GDP Weighted Average	**0.42**	**0.63**	**0.19**	**0.61**	**0.07**	**0.29**

Source: IMF staff spreadsheet model.

Appendix Table 31. AFR Countries: Revenue from Alternative Policies, 2030 (as a fraction of revenue from US$70 carbon tax)

Country	Coal tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Angola	0.00	0.17	0.13	0.13	0.33	-0.01
Benin	0.04	0.12	0.05	0.05	0.83	-0.03
Botswana	0.26	0.46	0.40	0.36	0.52	-0.01
Cameroon	0.00	0.27	0.25	0.24	0.46	-0.01
Congo, Democratic Republic of the	0.00	0.02	0.00	0.00	0.68	-0.01
Congo, Republic of	0.00	0.10	0.08	0.08	0.54	-0.01
Côte d'Ivoire	0.00	0.31	0.27	0.25	0.33	0.00
Eritrea	0.00	0.60	0.58	0.58	0.29	0.00
Ethiopia	0.07	0.21	0.00	0.00	0.40	-0.01
Gabon	0.00	0.44	0.24	0.23	0.17	0.00
Ghana	0.00	0.29	0.20	0.20	0.43	-0.01
Kenya	0.07	0.20	0.06	0.06	0.49	-0.01
Mauritius	0.28	0.45	0.46	0.40	0.16	0.00
Mozambique	0.00	0.13	0.09	0.08	0.50	-0.01
Namibia	0.00	0.07	0.00	0.00	0.49	-0.01
Niger	0.07	0.24	0.19	0.19	0.61	-0.01
Nigeria	0.00	0.13	0.13	0.12	0.45	0.00
Senegal	0.13	0.40	0.27	0.26	0.31	0.00
South Africa	0.71	0.41	0.40	0.31	0.17	0.00
South Sudan	0.00	0.21	0.20	0.20	0.46	-0.01
Tanzania	0.05	0.19	0.13	0.13	0.61	-0.01
Togo	0.00	0.06	0.00	0.00	0.70	-0.02
Zambia	0.11	0.34	0.01	0.01	0.31	0.00
Zimbabwe	0.48	0.55	0.39	0.39	0.29	0.00
AFR Simple Average	**0.10**	**0.27**	**0.19**	**0.18**	**0.44**	**-0.01**
AFR 2030 Emissions Weighted Average	**0.44**	**0.33**	**0.30**	**0.25**	**0.28**	**0.00**
AFR 2030 Energy Use Weighted Average	**0.15**	**0.22**	**0.16**	**0.14**	**0.41**	**-0.01**
AFR 2030 GDP Weighted Average	**0.16**	**0.24**	**0.18**	**0.16**	**0.39**	**0.00**

Source: IMF staff spreadsheet model.

Appendix Table 32. APD Countries: Revenue from Alternative Policies, 2030 (as a fraction of revenue from US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Australia	0.24	0.43	0.46	0.39	0.20	0.00
Bangladesh	0.04	0.47	0.44	0.43	0.05	0.00
Brunei Darussalam	0.00	0.38	0.35	0.35	0.12	0.00
Cambodia	0.18	0.27	0.25	0.21	0.48	-0.01
China	0.70	0.54	0.46	0.35	0.08	0.00
Hong Kong SAR	0.38	0.66	0.65	0.58	0.03	0.00
India	0.56	0.56	0.55	0.42	0.13	0.00
Indonesia	0.21	0.37	0.31	0.28	0.31	0.00
Japan	0.27	0.49	0.45	0.41	0.12	0.00
Korea	0.42	0.50	0.53	0.46	0.06	0.00
Malaysia	0.19	0.41	0.41	0.37	0.22	0.00
Mongolia	0.66	0.62	0.75	0.53	0.13	0.00
Myanmar	0.05	0.41	0.35	0.32	0.08	0.00
Nepal	0.25	0.19	0.00	0.00	0.44	-0.01
New Zealand	0.10	0.14	0.08	0.07	0.32	0.00
Philippines	0.33	0.50	0.41	0.40	0.25	0.00
Singapore	0.02	0.44	0.46	0.41	0.01	0.00
Sri Lanka	0.25	0.45	0.44	0.40	0.36	0.00
Thailand	0.14	0.39	0.32	0.31	0.12	0.00
Vietnam	0.48	0.59	0.48	0.39	0.16	0.00
APD Simple Average	**0.27**	**0.44**	**0.41**	**0.35**	**0.18**	**0.00**
APD 2030 Emissions Weighted Average	**0.59**	**0.53**	**0.47**	**0.37**	**0.11**	**0.00**
APD 2030 Energy Use Weighted Average	**0.56**	**0.52**	**0.47**	**0.37**	**0.11**	**0.00**
APD 2030 GDP Weighted Average	**0.53**	**0.52**	**0.46**	**0.37**	**0.11**	**0.00**

Source: IMF staff spreadsheet model.

Appendix Table 33. EUR Countries: Revenue from Alternative Policies, 2030 (as a fraction of revenue from US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Albania	0.04	0.09	0.00	0.00	0.44	0.00
Austria	0.19	0.13	0.10	0.10	0.30	0.00
Belarus	0.04	0.38	0.37	0.36	0.14	0.00
Belgium	0.15	0.13	0.08	0.08	0.12	0.00
Bosnia and Herzegovina	0.63	0.51	0.65	0.46	0.19	0.00
Bulgaria	0.42	0.44	0.54	0.41	0.19	0.00
Croatia	0.14	0.18	0.14	0.13	0.30	0.00
Cyprus	0.03	0.40	0.37	0.35	0.24	0.00
Czech Republic	0.49	0.38	0.43	0.34	0.17	0.00
Denmark	0.02	-0.01	-0.07	-0.06	0.31	0.00
Finland	0.28	0.33	0.27	0.23	0.22	0.00
France	0.12	0.08	0.05	0.05	0.26	0.00
Germany	0.28	0.24	0.24	0.20	0.17	0.00
Greece	0.22	0.38	0.38	0.33	0.20	0.00
Hungary	0.17	0.17	0.14	0.13	0.18	0.00
Iceland	0.15	0.15	0.00	0.00	0.26	0.00
Ireland	0.17	0.29	0.27	0.25	0.25	0.00
Israel	0.20	0.61	0.64	0.59	0.18	0.00
Italy	0.12	0.25	0.24	0.22	0.22	0.00
Kosovo	0.63	0.69	0.94	0.61	0.19	0.00
Latvia	0.06	0.27	0.27	0.25	0.25	0.00
Lithuania	0.10	0.05	0.02	0.02	0.33	0.00
Luxembourg	0.06	0.02	0.01	0.00	0.48	-0.01
Macedonia, FYR	0.37	0.49	0.50	0.39	0.28	0.00
Malta	0.07	0.06	0.06	0.06	0.06	0.00
Moldova	0.02	0.44	0.44	0.43	0.19	0.00
Montenegro, Rep. of	0.42	0.47	0.57	0.39	0.32	0.00
Netherlands	0.19	0.29	0.27	0.25	0.06	0.00
Norway	0.06	0.09	0.01	0.01	0.14	0.00
Poland	0.50	0.32	0.34	0.27	0.18	0.00
Portugal	0.17	0.27	0.27	0.24	0.25	0.00
Romania	0.24	0.30	0.29	0.25	0.22	0.00
Russia	0.16	0.31	0.30	0.28	0.05	0.00
Serbia	0.55	0.51	0.65	0.46	0.12	0.00
Slovak Republic	0.35	0.19	0.13	0.12	0.18	0.00
Slovenia	0.25	0.26	0.27	0.23	0.40	0.00
Spain	0.13	0.20	0.19	0.17	0.24	0.00
Sweden	0.20	0.11	0.04	0.04	0.26	0.00
Switzerland	0.01	0.04	0.01	0.01	0.36	0.00
Turkey	0.32	0.35	0.33	0.29	0.14	0.00
Ukraine	0.43	0.29	0.26	0.23	0.08	0.00
United Kingdom	0.11	0.21	0.19	0.18	0.20	0.00
EUR Simple Average	**0.22**	**0.27**	**0.27**	**0.22**	**0.22**	**0.00**
EUR 2030 Emissions Weighted Average	**0.23**	**0.27**	**0.26**	**0.23**	**0.15**	**0.00**
EUR 2030 Energy Use Weighted Average	**0.21**	**0.25**	**0.24**	**0.22**	**0.16**	**0.00**
EUR 2030 GDP Weighted Average	**0.19**	**0.22**	**0.20**	**0.18**	**0.20**	**0.00**

Source: IMF staff spreadsheet model.

Appendix Table 34. MCD Countries: Revenue from Alternative Policies, 2030
(as a fraction of revenue from US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Algeria	0.00	0.20	0.18	0.18	0.25	0.00
Armenia	0.00	0.18	0.18	0.17	0.09	0.00
Azerbaijan	0.00	0.29	0.29	0.29	0.15	0.00
Bahrain	0.00	0.52	0.53	0.52	0.06	0.00
Egypt	0.01	0.44	0.38	0.38	0.20	0.00
Georgia	0.09	0.14	0.07	0.06	0.33	0.00
Iran	0.01	0.22	0.21	0.21	0.10	0.00
Iraq	0.00	0.52	0.50	0.49	0.09	0.00
Jordan	0.03	0.47	0.40	0.40	0.28	0.00
Kazakhstan	0.32	0.38	0.28	0.26	0.08	0.00
Kuwait	0.00	0.21	0.19	0.19	0.13	0.00
Kyrgyz Republic	0.22	0.07	0.00	0.00	0.46	-0.01
Lebanon	0.03	0.52	0.50	0.49	0.26	0.00
Libya	0.00	0.60	0.59	0.57	0.32	-0.01
Morocco	0.18	0.38	0.34	0.30	0.30	0.00
Oman	0.00	0.22	0.22	0.21	0.15	0.00
Pakistan	0.09	0.34	0.25	0.24	0.25	0.00
Qatar	0.00	0.14	0.12	0.12	0.17	0.00
Saudi Arabia	0.00	0.47	0.39	0.38	0.14	0.00
Sudan	0.00	0.29	0.25	0.24	0.47	-0.01
Tajikistan	0.41	0.05	0.04	0.04	0.27	0.00
Tunisia	0.00	0.38	0.31	0.31	0.23	0.00
Turkmenistan	0.00	0.20	0.21	0.20	0.08	0.00
United Arab Emirates	0.03	0.42	0.39	0.39	0.08	0.00
Uzbekistan	0.03	0.29	0.28	0.28	0.03	0.00
Yemen	0.03	0.37	0.29	0.29	0.35	0.00
MCD Simple Average	**0.1**	**0.3**	**0.3**	**0.3**	**0.2**	**0.00**
MCD 2030 Emissions Weighted Average	**0.0**	**0.3**	**0.3**	**0.3**	**0.1**	**0.00**
MCD 2030 Energy Use Weighted Average	**0.0**	**0.3**	**0.3**	**0.3**	**0.2**	**0.00**
MCD 2030 GDP Weighted Average	**0.0**	**0.4**	**0.3**	**0.3**	**0.2**	**0.00**

Source: IMF staff spreadsheet model.

Appendix Table 35. WHD Countries: Revenue from Alternative Policies, 2030
(as a fraction of revenue from US$70 carbon tax)

Country	Coal Tax	ETS	Electricity Output Tax	Electricity CO2 Tax	Road Fuel Taxes	Energy Efficiency Combination
Argentina	0.01	0.27	0.24	0.22	0.16	0.00
Bolivia	0.00	0.17	0.17	0.15	0.36	-0.01
Brazil	0.11	0.18	0.10	0.09	0.35	0.00
Canada	0.08	0.15	0.13	0.12	0.25	0.00
Chile	0.22	0.42	0.35	0.30	0.29	0.00
Colombia	0.11	0.24	0.16	0.14	0.37	0.00
Costa Rica	0.04	0.10	0.01	0.01	0.68	-0.01
Dominican Republic	0.13	0.49	0.45	0.42	0.18	0.00
Ecuador	0.00	0.25	0.19	0.18	0.37	-0.01
El Salvador	0.00	0.25	0.14	0.14	0.49	-0.01
Guatemala	0.18	0.28	0.22	0.20	0.49	-0.01
Haiti	0.00	0.31	0.15	0.15	0.60	-0.02
Honduras	0.03	0.44	0.36	0.33	0.46	-0.01
Jamaica	0.02	0.47	0.28	0.27	0.20	0.00
Mexico	0.07	0.34	0.31	0.30	0.30	0.00
Nicaragua	0.00	0.29	0.19	0.18	0.47	0.00
Panama	0.04	0.17	0.11	0.11	0.19	-0.01
Paraguay	0.00	0.02	0.00	0.00	0.93	-0.03
Peru	0.05	0.29	0.24	0.22	0.32	0.00
Suriname	0.00	0.48	0.50	0.46	0.24	0.00
Trinidad and Tobago	0.00	0.10	0.09	0.09	0.09	0.00
United States	0.17	0.31	0.34	0.29	0.28	0.00
Uruguay	0.00	0.12	0.04	0.04	0.47	-0.01
WHD Simple Average	**0.05**	**0.27**	**0.21**	**0.19**	**0.37**	**-0.01**
WHD 2030 Emissions Weighted Average	**0.14**	**0.29**	**0.29**	**0.26**	**0.28**	**0.00**
WHD 2030 Energy Use Weighted Average	**0.14**	**0.28**	**0.28**	**0.25**	**0.29**	**0.00**
WHD 2030 GDP Weighted Average	**0.14**	**0.29**	**0.29**	**0.26**	**0.29**	**0.00**

Source: IMF staff spreadsheet model.

Appendix Table 36. AFR Countries: Effective Carbon Prices, 2030

(In USD$ per tonne CO_2)

Country	Diesel	Gasoline	Natural Gas	Coal	ETS	Total
Angola	0.0	3.4	0.0	0.0	0.0	3.4
Benin	42.4	54.3	0.0	0.0	0.0	96.7
Botswana	5.3	5.9	0.0	0.0	0.0	11.2
Cameroon	29.7	33.3	0.0	0.0	0.0	63.0
Congo, Democratic Republic of the	76.4	72.1	0.0	0.0	0.0	148.5
Congo, Republic of	32.7	23.4	0.0	0.0	0.0	56.0
Côte d'Ivoire	14.7	11.8	0.0	0.0	0.0	26.5
Eritrea	0.0	0.0	0.0	0.0	0.0	0.0
Ethiopia	21.7	7.8	0.0	0.0	0.0	29.4
Gabon	13.1	7.7	0.0	0.0	0.0	20.8
Ghana	33.0	12.4	0.0	0.0	0.0	45.4
Kenya	25.6	24.8	0.0	0.0	0.0	50.5
Mauritius	4.8	6.0	0.0	0.0	0.0	10.8
Mozambique	22.9	19.0	0.0	0.0	0.0	41.8
Namibia	23.3	28.4	0.0	0.0	0.0	51.7
Niger	34.9	19.8	0.0	0.0	0.0	54.6
Nigeria	2.6	9.7	0.0	0.0	0.0	12.3
Senegal	23.9	5.6	0.0	0.0	0.0	29.5
South Africa	1.5	2.1	0.0	0.0	0.0	3.6
South Sudan	0.0	13.2	0.0	0.0	0.0	13.2
Tanzania	35.0	24.4	0.0	0.0	0.0	59.4
Togo	62.7	37.3	0.0	0.0	0.0	100.0
Zambia	6.2	29.1	0.0	0.0	0.0	35.3
Zimbabwe	2.6	2.6	0.0	0.0	0.0	5.1
AFR Simple Average	**21.5**	**18.9**	**0.0**	**0.0**	**0.0**	**40.4**
AFR 2030 Emissions Weighted Average	**7.3**	**7.3**	**0.0**	**0.0**	**0.0**	**14.6**
AFR 2030 Energy Use Weighted Average	**16.6**	**15.8**	**0.0**	**0.0**	**0.0**	**32.4**
AFR 2030 GDP Weighted Average	**13.0**	**12.9**	**0.0**	**0.0**	**0.0**	**25.9**

Source: IMF staff spreadsheet model.

Appendix Table 37. APD Countries: Effective Carbon Prices, 2030

(In USD$ per tonne CO_2)

Country	Diesel	Gasoline	Natural Gas	Coal	ETS	Total
Australia	3.8	4.6	0.0	0.0	0.0	8.5
Bangladesh	2.9	1.1	0.0	0.0	0.0	3.9
Brunei Darussalam	0.0	0.0	0.0	0.0	0.0	0.0
Cambodia	0.0	0.0	0.0	0.0	0.0	0.0
China	0.9	1.1	0.0	0.0	0.0	2.0
Hong Kong SAR	1.2	0.3	0.0	0.0	0.0	1.5
India	2.0	1.2	0.0	0.0	0.0	3.1
Indonesia	0.0	0.0	0.0	0.0	0.0	0.0
Japan	2.6	5.4	0.0	0.0	0.0	7.9
Korea	2.4	1.6	0.0	0.0	14.9	18.9
Malaysia	0.9	2.2	0.0	0.0	0.0	3.0
Mongolia	0.0	0.4	0.0	0.0	0.0	0.5
Myanmar	0.0	4.5	0.0	0.0	0.0	4.5
Nepal	11.7	6.8	0.0	0.0	0.0	18.6
New Zealand	10.2	22.0	0.0	0.0	6.5	38.7
Philippines	3.3	3.7	0.0	0.0	0.0	7.0
Singapore	1.4	1.4	0.0	0.0	0.0	2.7
Sri Lanka	10.9	11.1	0.0	0.0	0.0	22.0
Thailand	4.6	3.1	0.0	0.0	0.0	7.6
Vietnam	1.5	2.2	0.0	0.0	0.0	3.7
APD Simple Average	**3.0**	**3.6**	**0.0**	**0.0**	**1.1**	**7.7**
APD 2030 Emissions Weighted Average	**1.4**	**1.5**	**0.0**	**0.0**	**0.5**	**3.3**
APD 2030 Energy Use Weighted Average	**1.5**	**1.6**	**0.0**	**0.0**	**0.6**	**3.7**
APD 2030 GDP Weighted Average	**1.6**	**2.0**	**0.0**	**0.0**	**0.7**	**4.3**

Source: IMF staff spreadsheet model.

Appendix Table 38. EUR Countries: Effective Carbon Prices, 2030

(In USD$ per tonne CO_2)

Country	Diesel	Gasoline	Natural Gas	Coal	ETS	Total
Albania	70.9	11.9	0.0	0.0	0.0	82.9
Austria	18.7	5.5	1.8	2.8	0.0	28.6
Belarus	3.3	1.8	0.0	0.0	0.0	5.1
Belgium	10.8	1.3	2.6	1.9	0.0	16.6
Bosnia and Herzegovina	4.8	1.1	0.0	0.0	0.0	5.9
Bulgaria	4.2	1.1	0.4	5.1	0.0	10.7
Croatia	17.9	8.7	1.5	2.6	0.0	30.7
Cyprus	12.5	18.5	0.0	0.0	0.0	31.0
Czech Republic	3.6	1.4	0.5	5.2	0.0	10.7
Denmark	9.9	7.2	1.3	3.5	0.0	21.8
Finland	7.7	2.8	0.3	4.6	0.0	15.4
France	27.3	4.3	2.5	1.4	0.0	35.6
Germany	5.5	3.1	1.0	4.3	0.0	13.9
Greece	4.0	6.7	0.3	4.3	0.0	15.3
Hungary	8.6	5.2	2.5	2.6	0.0	18.8
Iceland	21.2	16.7	0.0	0.0	0.0	37.9
Ireland	13.1	4.9	1.2	3.2	0.0	22.4
Israel	7.8	9.2	0.0	0.0	0.0	17.0
Italy	16.6	6.1	2.7	1.8	0.0	27.3
Kosovo	2.7	0.6	0.0	5.7	0.0	9.0
Latvia	17.4	5.3	4.0	0.4	0.0	27.1
Lithuania	34.8	5.2	1.5	1.4	0.0	42.9
Luxembourg	48.3	10.9	2.4	0.5	0.0	62.1
Macedonia, FYR	8.1	2.1	0.0	0.0	0.0	10.2
Malta	9.2	4.8	0.0	0.0	0.0	13.9
Moldova	12.5	4.2	0.0	0.0	0.0	16.7
Montenegro, Rep. of	9.5	2.2	0.0	0.0	0.0	11.7
Netherlands	2.7	2.4	1.8	3.3	0.0	10.2
Norway	16.6	5.8	0.0	0.0	0.0	22.5
Poland	2.8	0.8	0.2	5.4	0.0	9.2
Portugal	13.5	4.0	1.2	3.3	0.0	22.0
Romania	6.1	2.4	1.3	3.8	0.0	13.6
Russia	0.7	1.9	0.0	0.0	0.0	2.6
Serbia	2.8	0.9	0.0	0.0	0.0	3.7
Slovak Republic	6.7	3.0	1.3	4.0	0.0	14.9
Slovenia	17.5	6.0	0.6	4.5	0.0	28.5
Spain	14.0	3.2	1.5	2.7	0.0	21.4
Sweden	16.1	13.4	0.4	2.9	0.0	32.8
Switzerland	40.0	31.5	0.0	0.0	0.0	71.5
Turkey	7.1	1.0	0.0	0.0	0.0	8.0
Ukraine	1.5	1.3	0.0	0.0	0.0	2.8
United Kingdom	14.3	7.4	2.8	1.9	0.0	26.5
EUR Simple Average	**16.2**	**6.1**	**1.1**	**2.2**	**0.0**	**25.6**
EUR 2030 Emissions Weighted Average	**7.8**	**3.4**	**0.9**	**1.9**	**0.0**	**14.0**
EUR 2030 Energy Use Weighted Average	**9.1**	**3.7**	**1.0**	**1.9**	**0.0**	**15.7**
EUR 2030 GDP Weighted Average	**12.8**	**5.3**	**1.4**	**2.4**	**0.0**	**21.9**

Source: IMF staff spreadsheet model.

Appendix Table 39. MCD Countries: Effective Carbon Prices, 2030

(In USD per tonne CO_2)

Country	Diesel	Gasoline	Natural Gas	Coal	ETS	Total
Algeria	0.0	0.0	0.0	0.0	0.0	0.0
Armenia	1.4	3.3	0.0	0.0	0.0	4.7
Azerbaijan	0.0	0.0	0.0	0.0	0.0	0.0
Bahrain	0.0	0.0	0.0	0.0	0.0	0.0
Egypt	0.0	0.0	0.0	0.0	0.0	0.0
Georgia	10.7	12.7	0.0	0.0	0.0	23.4
Iran	0.0	0.0	0.0	0.0	0.0	0.0
Iraq	0.5	0.0	0.0	0.0	0.0	0.5
Jordan	9.3	15.8	0.0	0.0	0.0	25.1
Kazakhstan	0.0	0.0	0.0	0.0	1.2	1.2
Kuwait	0.0	0.0	0.0	0.0	0.0	0.0
Kyrgyz Republic	0.6	4.0	0.0	0.0	0.0	4.6
Lebanon	0.2	25.4	0.0	0.0	0.0	25.7
Libya	0.0	0.0	0.0	0.0	0.0	0.0
Morocco	12.6	2.5	0.0	0.0	0.0	15.0
Oman	1.1	1.9	0.0	0.0	0.0	3.0
Pakistan	1.0	4.9	0.0	0.0	0.0	5.9
Qatar	0.0	0.7	0.0	0.0	0.0	0.7
Saudi Arabia	0.0	0.0	0.0	0.0	0.0	0.0
Sudan	0.0	13.5	0.0	0.0	0.0	13.5
Tajikistan	3.9	4.1	0.0	0.0	0.0	8.1
Tunisia	7.5	5.8	0.0	0.0	0.0	13.3
Turkmenistan	0.0	0.0	0.0	0.0	0.0	0.0
United Arab Emirates	1.0	0.8	0.0	0.0	0.0	1.8
Uzbekistan	0.3	1.0	0.0	0.0	0.0	1.3
Yemen	0.9	10.5	0.0	0.0	0.0	11.4
MCD Simple Average	**2.0**	**4.1**	**0.0**	**0.0**	**0.0**	**6.1**
MCD 2030 Emissions Weighted Average	**0.7**	**1.1**	**0.0**	**0.0**	**0.1**	**1.9**
MCD 2030 Energy Use Weighted Average	**0.7**	**1.5**	**0.0**	**0.0**	**0.1**	**2.2**
MCD 2030 GDP Weighted Average	**1.0**	**1.6**	**0.0**	**0.0**	**0.1**	**2.7**

Source: IMF staff spreadsheet model.

Appendix Table 40. WHD Countries: Effective Carbon Prices, 2030

(In USD$ per tonne CO_2)

Country	Diesel	Gasoline	Natural Gas	Coal	ETS	Total
Argentina	5.1	5.1	0.0	0.0	0.0	10.3
Bolivia	0.6	0.0	0.0	0.0	0.0	0.6
Brazil	15.9	12.2	0.0	0.0	0.0	28.2
Canada	3.8	7.5	0.0	0.0	0.0	11.3
Chile	4.7	5.7	0.0	0.0	0.0	10.4
Colombia	5.7	4.9	0.0	0.0	0.0	10.6
Costa Rica	39.0	46.5	0.0	0.0	0.0	85.4
Dominican Republic	4.8	8.5	0.0	0.0	0.0	13.3
Ecuador	0.0	0.0	0.0	0.0	0.0	0.0
El Salvador	18.1	22.0	0.0	0.0	0.0	40.0
Guatemala	0.0	0.0	0.0	0.0	0.0	0.0
Haiti	25.4	30.4	0.0	0.0	0.0	55.8
Honduras	16.4	16.8	0.0	0.0	0.0	33.2
Jamaica	3.4	14.3	0.0	0.0	0.0	17.7
Mexico	5.2	11.1	0.0	0.0	0.0	16.2
Nicaragua	20.0	22.2	0.0	0.0	0.0	42.3
Panama	6.9	10.6	0.0	0.0	0.0	17.4
Paraguay	124.8	55.7	0.0	0.0	0.0	180.5
Peru	16.1	4.1	0.0	0.0	0.0	20.2
Suriname	-0.1	10.1	0.0	0.0	0.0	10.0
Trinidad and Tobago	0.0	0.4	0.0	0.0	0.0	0.4
United States	1.8	3.6	0.0	0.0	0.0	5.5
Uruguay	47.7	51.1	0.0	0.0	0.0	98.8
WHD Simple Average	**15.9**	**14.9**	**0.0**	**0.0**	**0.0**	**30.8**
WHD 2030 Emissions Weighted Average	**3.7**	**5.3**	**0.0**	**0.0**	**0.0**	**9.0**
WHD 2030 Energy Use Weighted Average	**4.8**	**5.9**	**0.0**	**0.0**	**0.0**	**10.7**
WHD 2030 GDP Weighted Average	**4.0**	**5.4**	**0.0**	**0.0**	**0.0**	**9.4**

Source: IMF staff spreadsheet model.

References

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous, 2012, "The Environment and Directed Technical Change," *American Economic Review*, Vol. 102, pp. 131–166.

Alberini, Anna, and Massimo Filippini, 2011, "Response of Residential Electricity Demand to Price: The Effect of Measurement Error," *Energy Economics*, Vol. 33, pp. 889-895.

Aldy, Joseph and others, 2016, "Economic Tools to Promote Transparency and Comparability in the Paris Agreement," *Nature Climate Change*, Vol. 6, pp. 1,000–1,004.

Ares, Elena, and Jeanne Delebarre, 2016, The Carbon Price Floor, Briefing paper No. CBP05927, House of Commons Library (London, United Kingdom).

Barron, Alexander R, Allen A. Fawcett, Marc A.C. Hafstead, James R. McFarland, and Adele Morris, 2018, "Policy Insights from the EMF 32 Study on US Carbon Tax Scenarios," *Climate Change Economics*, Vol. 9, pp. 1-47.

Bento, Antonio M., Mark R. Jacobsen, and Antung A. Liu, 2018, "Environmental Policy in the Presence of an Informal Sector," *Journal of Environmental Economics and Management*, Vol. 90, pp. 61-77.

Böhringer, Christophe, Jared C. Carbone, and Thomas F. Rutherford, 2012, "Unilateral Climate Policy Design: Efficiency and Equity Implications of Alternative Instruments to Reduce Carbon Leakage," *Energy Economics*, Vol. 34 (Supplement 2), pp. S208–S217.

Bonato, Leo, Alessandro Cantelmo, Giovanni Melina, and Gonzalo Salinas, 2018a, "Policy Trade-Offs in Building Resilience to Natural Disasters." Selected Issues Paper, SM/18 (Washington: International Monetary Fund).

________, and others, 2018b, *St. Lucia: Climate Change Policy Assessment* (Washington: International Monetary Fund).

Bovenberg, A. Lans and Ruud A. de Mooij, 1994, "Environmental Levies and Distortionary Taxation," *American Economic Review*, Vol. 84, pp. 1,085-1,089.

Brack, Duncan, 2015, *National Legislation on Hydrofluorocarbons* (Washington: Institute for Governance and Sustainable Development).

Breeden, Sarah, 2018, "The Shared Response to Climate Change: Turning Momentum into Action" May 14 (Bank of England, London).

Bunch, David S., David L. Greene, Timothy Lipman, Dr. Elliot Martin and Dr. Susan Shaheen, 2011, Potential Design, Implementation, and Benefits of a Feebate Program for New Passenger Vehicles in California, pp. 59-61, prepared for the State of California Air Resources Board and the California Environmental Protection Agency.

Burke, Marshall, Solomon M. Hsiang, and Edward Miguel, 2015, "Global Non-Linear Effect of Temperature on Economic Production," *Nature*, Vol. 527, pp. 235–39.

Burke, Paul J. and Hua Liao, 2015, "Is the Price Elasticity of Demand for Coal in China Increasing?" CCEP Working Paper 1506, Crawford School of Public Policy, Australian National University.

Burniaux, Jean-Marc, Jean Chateau, Jean and Romain Duval, 2013, "Is There a Case for Carbon-Based Border Tax Adjustment? An applied General Equilibrium Analysis," *Applied Economics*, Vol. 45, pp. 2231-2240.

Calder, Jack, 2015, "Administration of a U.S. Carbon Tax," In *Implementing a U.S. Carbon Tax: Challenges and Debates*, edited by I. Parry, A. Morris, and R. Williams (New York: Routledge).

Cambridge Econometrics, 2013, The Effectiveness of CO_2-Based 'Feebate' Systems in the European Passenger Vehicle Market Context: An Analysis of the Netherlands and the UK," Report for the International Council on Clean Transportation (Cambridge, United Kingdom).

Carl, Jeremy, and David Fedor, 2016, "Tracking Global Carbon Revenues: A Survey of Carbon Taxes versus Cap-and-Trade in the Real World," *Energy Policy*, Vol. 96, pp. 50-77.

CAT, 2018, *CAT Emissions Gaps*, Climate Action Tracker, Available at: https://climateactiontracker.org/global/cat-emissions-gaps.

CL, 2013, *Associated Petroleum Gas Flaring Study for Russia, Kazakhstan, Turkmenistan and Azerbaijan,* Carbon Limits (Oslo, Norway).

Clements, Benedict, and David Coady, Stefania Fabrizio, Sanjeev Gupta, Trevor Alleyne, and Carlos Sdralevich, editors, 2013, *Energy Subsidy Reform: Lessons and Implications* (Washington: International Monetary Fund).

Coady, David, Ian W.H. Parry, Louis Sears, and Baoping Shang, 2015, "How Large Are Global Energy Subsidies," IMF Working Paper No. 15/105 (Washington: International Monetary Fund).

________, Ian W.H. Parry, Nghia-Piotr Le, and Baoping Shang, 2019, "Global Fossil Fuel Subsidies Remain Large: An Update Based on Country-Level Estimates," Working Paper, forthcoming (Washington: International Monetary Fund).

Cohen, Gail, Joao Jalles, Prakash Loungani and Ricardo Marto, 2017, "Emissions and Growth: Trends and Cycles in a Globalized World," Working Paper 17/191 (Washington: International Monetary Fund).

Cramton, Peter, David MacKay, Axel Ockenfels, and Steven Stoft (eds.), 2017, *Global Carbon Pricing: The Path to Climate Cooperation*, pp. 13-30 (Cambridge: MIT Press).

Dechezleprêtre, Antoine, and David Popp, 2017, "Fiscal and Regulatory Instruments for Clean Technology Development in the European Union." In Ian Parry, Karen Pittel and Herman Vollebergh (eds.), *Energy Tax and Regulatory Policy in Europe: Reform Priorities*, pp. 167-214 (Cambridge: MIT Press).

Dixit, Avinash K. and Robert S. Pindyck, 1994, *Investment under Uncertainty*. (Princeton: Princeton University Press).

Dorband, Ira Irina, Michael Jakob, Matthias Kalkukl, and Jan Christoph Steckel, 2019, "Poverty and Distributional Effects of Carbon Pricing in Low- and Middle-Income Countries—A Global Comparative Analysis." *World Development*, Vol. 115, pp. 246-257.

EIA, 2018, *Annual Energy Outlook*, United States Energy Information Administration, Washington, DC.

EPA, 2014, *Global Mitigation of Non-*CO_2 *Greenhouse Gases: 2010-2030*, United States Environmental Protection Agency, Washington, DC.

ERA, 2015, *Flaring and Venting of Associated Gas: Current Developments and Impacts of Marginal Oil*, Energy Research Architecture.

Fabrizio, Stefania, Alexei Goumilevski and Kangni Kpodar, 2016, "A New Tool for Distributional Incidence Analysis: An Application to Fuel Subsidy Reform," International Monetary Fund, Washington, DC.

Farid, Mai, Michael Keen, Michael Papaioannou, Ian Parry, Catherine Pattillo, and Anna Ter-Martirosyan, 2016, *After Paris: Fiscal, Macroeconomic, and Financial Implications of Climate Change*, Staff Discussion Note 16/01, IMF, Washington, DC.

Favero, Alice, Robert Mendelsohn, Brent Sohngen, 2017," Using Forests for Climate Mitigation: Sequester Carbon or Produce Woody Biomass?" *Climatic Change*, Vol. 144, pp. 195-206.

Fawcett, Allen A., Leon C. Clarke, and John Weyant, 2015, "Carbon taxes to Achieve Emissions Targets: Insights from EMF 24," In I. Parry, A. Morris and R. Williams, *Implementing a US Carbon Tax: Challenges and Debates*, Routledge.

Fischer, Carolyn, Richard Morgenstern and Nathan Richardson, 2015, "Carbon Taxes and Energy-Intensive Trade-Exposed Industries: Impacts and Options," In *Implementing a U.S. Carbon Tax: Challenges and Debates*, edited by I. Parry, A. Morris, and R. Williams. New York: Routledge.

Flachsland, Christian, Michael Pahle, Dallas Burtraw, Ottmar Edenhofer, Milan Elkerbout, Carolyn Fischer, Oliver Tietjen, and Lars Zetterberg, 2018, *Five Myths About a European Union Emissions Trading System Carbon Price Floor*, Resources for the Future, Washington, DC.

Fried, Stephie, 2018, "Climate Policy and Innovation: A Quantitative Macroeconomic Analysis." *American Economic Journal: Macroeconomics*, Vol. 10, pp. 90-118.

Fullerton, Don, and Garth Heutel, 2011, "Analytical General Equilibrium Effects of Energy Policy on Output and Factor Prices," *The B.E. Journal of Economic Analysis and Policy*, Vol. 10, pp. 1–26.

GIZ, 2016, *(I)NDC Adaptation Components and NAP*, Climate Change Policy Brief, Deutsche Gesellschaft für Internationale Zusammenarbeit (Bonn, Germany).

Gaspar, Vitor, David Amaglobeli, Mercedes Garcia-Escribano, Delphine Prady, and Mauricio Soto, 2019, Fiscal Policy and Development: Human, Social, and Physical Investment for the SDGs, IMF Staff Discussion Note 19/03 (Washington: International Monetary Fund).

Goulder, Lawrence H., Dallas Burtraw and Roberton C. Williams, 1999, "The Cost-Effectiveness of Alternative Instruments for Environmental Protection in a Second-Best Setting," *Journal of Public Economics*, Vol. 72, pp. 329-360.

Government of Canada, 2018a, *Guidance on the Pan-Canadian Carbon Pollution Pricing Benchmark*. Available at: www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework/guidance-carbon-pollution-pricing-benchmark.html.

________, 2018b, *Legislative and Regulatory Proposals Relating to the Greenhouse Gas Pollution Pricing Act and Explanatory Notes,* Available at: https://www.fin.gc.ca/drleg-apl/2018/ggpp-tpcges-eng.asp.

Government of India, 2015, *Climate Change Finance, Analysis of a Recent OECD Report: Some Credible Facts Needed,* Discussion paper, Department of Economic Affairs, Ministry of Finance (New Delhi, India).

Harberger, Arnold C., 1996, "The Measurement of Waste," *American Economic Review*, Vol. 54, pp. 58-76.

Horowitz, John, Julie-Anne Cronin, Hannah Hawkins, Laura Konda and Alex Yuskavage, 2017, "Methodology for Analyzing a Carbon Tax," Working paper 115 (Washington: US Department of the Treasury).

Huntington, Hillard G., James B. Barrios, and Vipin Arora, 2017, "Review of Key International Demand Elasticities for Major Industrializing Economies," Working paper, Stanford Energy Modelling Forum (Stanford: Stanford University).

ICAO, 2018a, *What is CORSIA and how does it work?,* International Civil Aviation Organization, Montreal, Available at: www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ2.aspx.

________, 2018b, *Environmental Trends*. International Civil Aviation Organization, Montreal, Available at: www.icao.int/environmental-protection/Pages/Environmental-Trends.aspx.

International Energy Agency, 2018a, *Policies and Measures Databases*, International Energy Agency (Paris, France).

________, 2018b, *CO_2 Emissions from Fuel Combustion Highlights* International Energy Agency (Paris, France). Available at: www.iea.org/policiesandmeasures.

________, 2018c, *World Energy Balances,* International Energy Agency (Paris, France).

________ and CSI, 2018, *Low-Carbon Transition in the Cement Industry,* International Energy Agency and Cement Sustainability Initiative (Paris, France).

International Finance Corporation, 2016, *Climate Investment Opportunities in Emerging Markets,* (Washington).

International Monetary Fund, 2008a, *The Fiscal Implications of Climate Change* (Washington).

________, 2008b, "Climate Change and the Global Economy," In *World Economic Outlook*, (Washington).

________, 2015a, *The Managing Director's Statement on the Role of the Fund in Addressing Climate Change* (Washington).

________, 2015b, *Making Public Investment More Efficient* (Washington).

________, 2016, *Small State's Resilience to natural Disasters and Climate Change—Role for the IMF*, (Washington).

________, 2017, *World Economic Outlook, October 2017*, Seeking Sustainable Growth: Short-Term Recovery, Long-Term Challenges (Washington).

________, 2018, *World Economic Outlook*. (Washington). Available at: https://www.imf.org/external/pubs/ft/weo/2018/02/weodata/index.aspx

________, 2019, *Building Resilience in Countries Vulnerable to Natural Disasters* (Washington).

________, Organization for Economic Cooperation and Development, World Bank, and United Nations, 2015, *Options for Low Income Countries' Effective and Efficient Use of Tax Incentives for Investment: A Report to the G-20 Development Working Group* https://www.imf.org/external/np/g20/pdf/101515.pdf

International Maritime Organization, 2014, *Third IMO Greenhouse Gas Study* (London, United Kingdom).

Intergovernmental Panel on Climate Change, 1996. *IPCC Guidelines for National Greenhouse Gas Inventories*, Three volumes: Vol. 1, Reporting Instructions; Vol. 2, Workbook; Vol. 3, Reference Manual (Paris: Intergovernmental Panel on Climate Change, United Nations Environmental Programme, Organization for Economic Co-Operation and Development, International Energy Agency).

________, 2007, *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press).

________, 2014, *Climate Change 2014: Mitigation of Climate Change,* Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press).

________, 2018, *Global Warming of 1.5ºC* (Switzerland).

Jamaludin, Fazurin Ricardo Marto, Hidetaka Nishizawa and Irene Huan Zhang, 2018. *Fiscal Anchors: Options/Trade-Offs*. Selected Issues Paper, 18/73. (Washington: International Monetary Fund).

Jamil, Faisal and Eatzaz Ahmad 2011, "Income and Price Elasticities of Electricity Demand: Aggregate and Sector-Wise Analyses," *Energy Policy*, Vol. 39, pp. 5,519-527.

Kanbur, Ravi, Michael Keen, and S. Van Wijnbergen, 1995, "Industrial Competitiveness, Environmental Regulation, and Foreign Direct Investment," In I. Goldin and L. A. Winters (eds.) *The Economics of Sustainable Development*, CEPR and Cambridge University Press, pp. 289-302.

Keen, Michael, and Christos Kotsogiannis, 2014, "Coordinating Climate and Trade Policies: Pareto Efficiency and the Role of Border Tax Adjustments," *Journal of International Economics*, Vol. 94, pp. 119–28.

Keen, Michael, Ian W.H. Parry, and Jon Strand, 2013, "Ships, Planes, and Taxes: Charging for International Aviation and Maritime Emissions," *Economic Policy*, Vol. 28, pp. 701–49.

Kriegler, Elmar, and others, 2015, "Diagnostic Indicators for Integrated Assessment Models of Climate Policy," *Technological Forecasting and Social Change*, Vol. 90, pp. 45-61.

Krogstrup, Signe and Maurice Obstfeld, 2018, "A Planet at Risk Requires Multilateral Action." IMFBlog, available at: https://blogs.imf.org/2018/12/03/a-planet-at-risk-requires-multilateral-action.

Krupnick, Alan J., Ian W.H. Parry, Margaret Walls, Tony Knowles and Kristin Hayes, 2010, *Toward a New National Energy Policy: Assessing the Options* (Washington: Resources for the Future and National Energy Policy Institute).

Labandeira, Xavier, Jose M. Labeaga, and Xiral Lopez-Otero, 2017, "A Meta-Analysis on the Price Elasticity of Energy Demand," *Energy Policy*, Vol. 102, pp. 549-568.

Le Quéré, Corinne, Robbie M. Andrew, Pierre Friedlingstein, Stephen Sitch, Julia Pongratz, Manning, Andrew C., Jan Ivar Korsbakken, and others, 2018, "Global Carbon Budget 2017," *Earth System Science Data*, Vol. 10, pp. 405–48.

Liu, Weifeng, Warwick J. Mckibbin, Adele C. Morris and Peter J. Wilcoxen, 2019, "Global Economic and Environmental Outcomes of the Paris Agreement," Climate and Energy Economics Discussion Paper (Washington: Brookings Institution).

Madlener, Reinhard, Ronald Bernstein and Miguel Ángel Alva González, 2011, "Econometric Estimation of Energy Demand Elasticities," E.ON Energy Research Center, Series 3, Issue 8 (Aachen: Aachen University).

Marto, Ricardo, Chris Papageorgiou and Vladimir Klyuev, 2017. "Building Resilience to Natural Disasters: An Application to Small Developing States." Working paper 17/223 (Washington: International Monetary Fund).

Mendelsohn, Robert, Roger Sedjo, and Brent Sohngen, 2012, "Forest Carbon Sequestration." In I. Parry, R. de Mooij, and M. Keen (eds.), *Fiscal Policy to Mitigate Climate Change: A Guide for Policymakers*, pp. 89-102 (Washington: International Monetary Fund).

Metcalf, Gilbert E. and David Weisbach, 2009, "The Design of a Carbon Tax," *Harvard Environmental Law Review*, Vol 3, pp. 499-556.

Morris, Adele, 2016, *Build a Better Future for Coal Workers and Their Communities*, Climate and Energy Economics Project (Washington: Brookings Institution).

Mulye, Manjiri, 2017, "Kigali Agreement: Simplified," Cearias.com. Available at: www.clearias.com/kigali-agreement.

Munich Re, 2017, *Topics Geo: Natural Catastrophes 2017* (Munich Re: Munich).

Myers, Erica, Karen L. Palmer, and Anthony Paul, 2009, "A Partial Adjustment Models of U.S. Electricity Demand by Region, Season and Sector," Discussion Paper 08-50, Resources for the Future, Washington, DC.

National Academy of Sciences, 2018, *Rapid Climate Change Special Feature*, Proceedings of the National Academy of Sciences, Vol. 15.

National Aeronautics and Space Administration, 2018, *Global Land-Ocean Temperature Index*. US Department of Commerce. Available at: https://climate.nasa.gov/vital-signs/global-temperature.

Newell, Richard, 2015, "The Role of Energy Technology Policy Alongside Carbon Pricing," In *Implementing a U.S. Carbon Tax: Challenges and Debates*, edited by I. Parry, A. Morris, and R. Williams (New York: Routledge).

National Oceanic and Atmospheric Administration, 2018, *Tracking Sea Level Rise…and Fall.* Available at: www.noaa.gov/explainers/tracking-sea-level-rise-and-fall.

Nordhaus, William, D., 2015. "Climate Clubs: Overcoming Free-riding in International Climate Policy," *American Economic Review,* Vol. 105, pp. 1,339–1,370.

________, 2017, "The Social Cost of Carbon: Updated Estimates," *Proceedings of the US National Academy of Science,* Vol. 114, pp. 1,518-1,523.

________, 2018, "Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies," *American Economic Journal: Economic Policy,* Vol. 10, pp. 333–360.

Organization for Economic Co-operation and Development, 2017, *Investing in Climate, Investing in Growth* (Paris, France).

________, 2018, *Effective Carbon Rates 2018: Pricing Carbon Emissions Through Taxes and Emissions Trading*, Technical note on estimates of infrastructure investment needs (Paris, France).

Parry, Ian W.H., 2018, "The Rationale for, and Design of, Forest Carbon Feebates," Unpublished manuscript, (Washington: International Monetary Fund).

________ and Victor Mylonas, 2018, "Canada's Carbon Price Floor." Working paper 18/42 (Washington: International Monetary Fund).

________, Victor Mylonas, and Nate Vernon, 2018a, "Mitigation Policies for the Paris Agreement: An Assessment for G-20 Countries," Working paper 18/193 (Washington: International Monetary Fund).

________, Dirk Heine, Kelley Kizzier, and Tristan Smith, 2018b, "Carbon Taxation for International Maritime Fuels: Assessing the Options," Working paper 18/203 (Washington: International Monetary Fund).

________, Victor Mylonas, and Nate Vernon, 2017, "Reforming Energy Policy in India: Assessing the Options," Working paper 17/103 (Washington: International Monetary Fund).

________, Baoping Shang, Philippe Wingender, Nate Vernon, and Tarun Narasimhan, 2016, "Climate Mitigation in China: Which Policies Are Most Effective?" Working paper 16/148 (Washington: International Monetary Fund).

________, Adele Morris and Roberton Williams, 2015a, *Implementing a US Carbon Tax: Challenges and Debates* (London: Routledge).

________, Chandara Veung and Dirk Heine, 2015b. "How Much Carbon Pricing is in Countries Own Interests? The Critical Role of Co-Benefits," *Climate Change Economics,* Vol. 6, pp. 1550019-1-26.

________, Dirk Heine, Shanjun Li, and Eliza Lis, 2014, *Getting Energy Prices Right* (Washington: International Monetary Fund).

________, and Roberton Williams, 2012, "Moving US Climate Policy Forward: Are Carbon Tax Shifts the Only Good Alternative?" In Robert Hahn and Alistair Ulph (eds.), *Climate Change and Common Sense: Essays in Honor of Tom Schelling*, Oxford University Press, 173-202.

________, Ruud de Mooij, and Michael Keen, 2012, *Fiscal Policy to Mitigate Climate Change: A Guide for Policymakers*, International Monetary Fund, Washington, DC.

Pindyck, Robert S., 2017, "The Use and Misuse of Models for Climate Policy," *Review of Environmental Economics and Policy,* Vol. 11, pp. 100-114.

Rubin, Edward S., John E. Davison, and Howard J. Herzog, 2015, "The Cost of CO_2 Capture and Storage," *International Journal of Greenhouse Gas Control*, Vol. 40, pp. 378–400.

Sastre, Sergio, 2016, *Tax on Fluorinated Gases in Spain*. (Brussels: Institute for European Environmental Policy).

Sanstad, Alan H. and James E. McMahon, 2008, "Aspects of Consumers' and Firms' Energy Decision-Making: A Review and Recommendations for the National Energy Modeling System (NEMS)." Papers from the Workshop on Energy Market Decision-making for the New NEM (Washington: Energy Information Administration).

South Africa National Treasury, 2013, "Carbon Tax Policy Paper: Reducing Greenhouse Gas Emissions and Facilitating the Transition to a Green Economy," (Pretoria, South Africa).

Stern, Nicholas, 2007, *The Economics of Climate Change: The Stern Review* (Cambridge: Cambridge University Press).

________ and Joseph Stiglitz, 2017, "Report of the High-Level Commission on Carbon Pricing," Paper of the Carbon Pricing Leadership Coalition of the World Bank Group (Washington).

Stern, Todd, 2018, *The Paris Agreement and its Future* (Washington: Brookings Institution).

Tollefson, Jeff, 2018, "Carbon's Future in Black and White," *Nature* 556: 422-425.

Trüby, Johannes and Moritz Paulus, 2012, "Market Structure Scenarios in International Steam Coal Trade," The Energy Journal, Vol. 33, pp. 91-123.

UNEP, 2018, *Emissions Gap Report 2018*, UN Environment Programme (since renamed UN Environment), (Nairobi, Kenya).

________, 2016, *The Adaptation Finance Gap Report 2016*, UN Environment Programme (since renamed UN Environment), (Nairobi, Kenya).

UNFCCC, 2016, *Paris Agreement*, United Nations Framework Convention on Climate Change (New York City, NY). Available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf.

________, 2018a, *Nationally Determined Contributions (NDCs)*. United Nations Framework Convention on Climate Change (New York City, NY). Available at: https://unfccc.int/process/the-paris-agreement/nationally-determined-contributions/ndc-registry#eq-4.

________, 2018b, *INDCs as communicated by Parties*, United Nations Framework Convention on Climate Change (New York City, NY). Available at: http://www4.unfccc.int/submissions/INDC/Submission%20Pages/submissions.aspx.

________, 2018c, *Report of the Standing Committee on Finance to the Conference of the Parties*, United Nations Framework Convention on Climate Change (New York City, NY).

van Ruijven, Bas J. Detlef, P. van Vuuren, Willem Boskaljon, Maarten L. Neelis, Deger Saygin, and Martin K. Patel, 2016, "Long-Term Model-Based Projections of Energy Use and CO_2 Emissions from the Global Steel and Cement Industries," *Resources, Conservation, and Recycling,* Vol. 112, pp. 15-36.

Vermeulen, Robert, Edo Schets, Melanie Lohuis, Barbara Kölbl, David-Jan Jansen and Willem Heeringa, 2018, "An Energy Transition Risk Stress Test for the Financial System of the Netherlands," *De Nederlandsche Bank Occasional Studies,* pp. 16–7.

World Bank Group, 2017, *Climate Vulnerability Assessment* (Washington).

________, 2018, *State and Trends of Carbon Pricing 2018* (Washington).

________, 2019, *World Development Indicators* (Washington).

Webster, Mort, Sergey Paltsev, and John Reilly, 2008, "Autonomous Efficiency Improvement or Income Elasticity of Energy Demand: Does it Matter?" *Energy Economics* 30: 2,785-2,798.

World Economic Forum, 2019, *The Global Risks Report 2019* (Geneva, Switzerland).

Weitzman, Martin L., 2011, "Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change," *Review of Environmental Economics and Policy* Vol. 5, pp. 275-92.

________, 2015, "Voting on Prices vs. Voting on Quantities in a World Climate Assembly," NBER Working Paper No. 20925, (Cambridge, Massachusetts).

Whiteman, Adrian, Anjoya Wickramasinghe, and Leticia Pina, 2015, "Global Trends in Forest Ownership, Public Income and expenditure on Forestry and Forestry Employment," *Forest Ecology and Management,* Vol. 352, pp. 99-108.

Zhou, Shaojie, and Fei Teng, 2014, "Estimation of Urban Residential Electricity Demand in China Using Household Survey Data," Energy Policy, Vol. 61, pp. 394-402.