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Implementing the United States' Domestic and International Climate Mitigation Goals: A Supportive Fiscal Policy Approach

by Ian Parry

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Implementing the United States' Domestic and International Climate Mitigation Goals: A Supportive Fiscal Policy Approach

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Abstract

The United States has pledged to become carbon neutral by 2050, meet sectoral objectives (e.g., for carbon free power, electric vehicles) and encourage greater mitigation among large emitting countries and of international transportation emissions. Fiscal policies at the national, sectoral, and international level could play a critical role in implementing these objectives, along with investment, regulatory, and technology policies. Fiscal instruments are cost-effective, can enhance political acceptability, and do not worsen, or could help alleviate, budgetary pressures. Domestically, a fiscal policy package could contain a mix of economy-wide carbon pricing and revenue-neutral feebates (i.e., tax-subsidy schemes) with the latter reinforcing mitigation in the transport, power, industrial, building, forestry, and agricultural sectors. Internationally, a carbon price floor among large emitters (with flexibility to implement equivalent measures) could effectively scale up global mitigation, while levies/feebates offer a practical approach for reducing maritime and aviation emissions.

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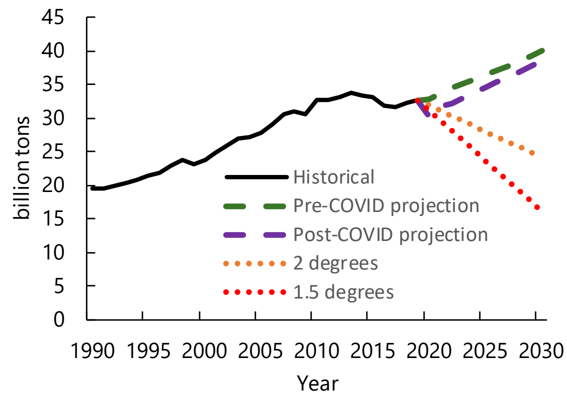
I. INTRODUCTION

The window of opportunity for containing global climate change to manageable levels is closing rapidly. Global carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions must be cut 25–50 percent below 2018 levels by 2030 to be on track with containing projected warming to 1.5°–2°C above preindustrial levels with rapid reductions to emissions neutrality thereafter. Due to the pandemic-induced crisis, projected global emissions in 2020 are about 7 percent below 2019 levels, but without strong mitigation policies emissions are likely to start rising again in 2021 as economies recover (Figure 1). With governments bringing forward investment plans to boost their economies, the pandemic has added to the urgency of ensuring new investment is efficiently allocated to low-carbon technologies—this requires carbon pricing or similar measures.

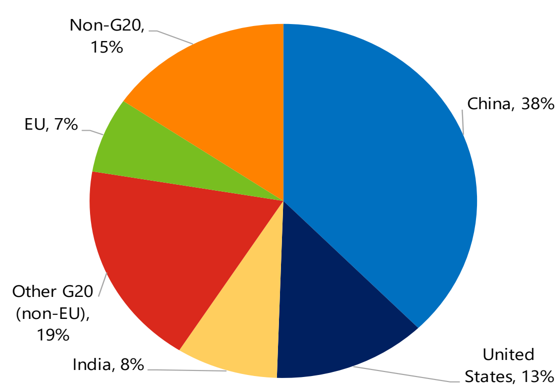
Figure 1. Global Fossil Fuel CO_2 Emissions Trends



Source: IEA (2020), IMF staff calculations, IPCC (2018). (2018).

The United States is one of several key countries that will determine whether the world stays on track with warming targets. China and the United States account for half of projected baseline CO_2 emissions (i.e., emissions in the absence of stronger mitigation policy) worldwide in 2030, and the EU another 7 percent (Figure 2).

Figure 2. Country Shares of Baseline CO_2 Emissions 2030, percent



Source: Updated from IMF (2019a).

The 2015 Paris Agreement is the centerpiece of the international community's efforts to address climate change. 195 countries signed the agreement, with almost all submitting pledges to reduce GHGs within their borders—these pledges are due for revision ahead of COP 26 in Glasgow, November 2021. Even if all countries achieved their pledges however, this would only cut global emissions in 2030 by about a third of the reductions consistent with 2°C, let alone 1.5°C.[2] The United States is rejoining the Paris Agreement in, after withdrawal took effect in November 2020.[3]

Strong mitigation action in the United States would have large climate, local environmental benefits, and (if pricing is used) fiscal benefits. Climate change is impacting the economy through, for example, record forest fires and increased frequency and intensity of natural disasters.[4] If unabated, global climate change could be permanently lowering annual US GDP by several percent by 2050[5]—though the overriding concern is tail risks.[6] Determined US actions would significantly affect global emissions and help catalyze more ambitious mitigation in other countries through its leadership role and by helping to alleviate concerns about competitiveness impacts. Even leaving aside the broader macroeconomic benefits, cutting fossil fuel use is beneficial for the US economy as, up to a point, the domestic environmental co-benefits (e.g., particularly reductions in local air pollution mortality) exceed the economic costs.[7] To the extent that carbon pricing is part of the mitigation strategy significant revenues could be raised (see below) which could be used, for example, to cut distortionary taxes on labor and capital or fund public investment in clean technology networks.

US GHG emissions (excluding land-use) were 6.7 billion tons in 2018, with 78 percent from fossil fuel CO_2 (Figure 3). By sector, power generation accounted for 38 percent of fossil fuel CO_2 emissions, industry 22 percent, transport 24 percent, and (direct fuel combustion in residential and commercial) buildings 15 percent. By fuel type, coal accounted for 26 percent of fossil fuel CO_2 emissions, oil 42 percent, and natural gas 32 percent.

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[2] UNEP (2020), IMF (2019a).

[3] The United States' original submission for the Paris Agreement was to reduce GHGs 26-28 percent below 2005 levels by 2025. On current policies it will fall somewhat short of this pledge (see below).

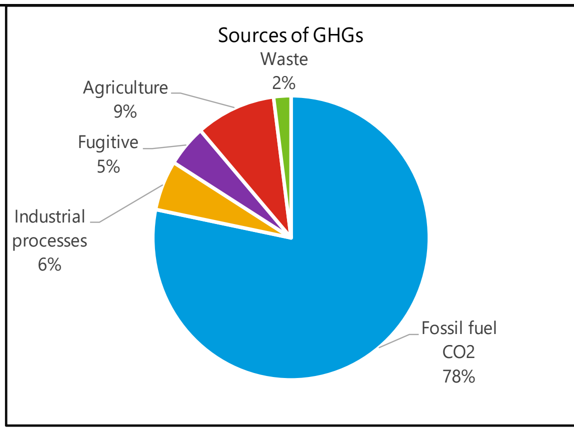
[4] See USGCRP (2017) and Datu Research (2020).

[5] Kahn and others (2019).

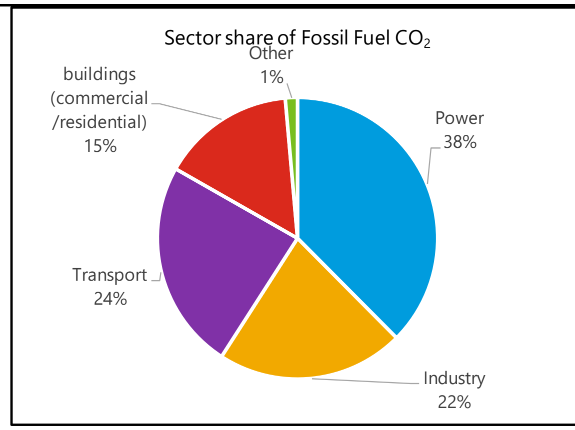
[6] For example, runaway warming from feedback effects, collapsing ice sheets (see IPCC 2019a, Table 6.1, McSweeney 2020).

[7] For example, IMF (2019a, Figure 1.4) put local environmental benefits—principally reductions in local air pollution mortality—from a $50 carbon price in 2030 at 0.2 percent of GDP compared with economic efficiency costs (losses in consumer and producer surplus in fossil fuel markets) of 0.1 percent. Reducing local air pollution can also increase labor productivity (e.g., Graff Zivin and Neidell 2012). US GDP losses for a similarly scaled carbon tax in 2030 with revenues used to substitute for labor income taxes, are put at 0.3 percent on average across six energy models, or about twice as large if revenues are used for lump-sum dividends (see Goulder and Hafstead 2018, Table 5.2, and below).

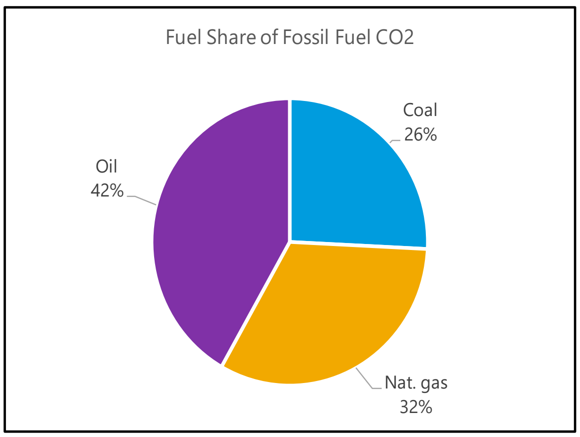
Figure 3. Breakdown of GHG Emissions, 2018



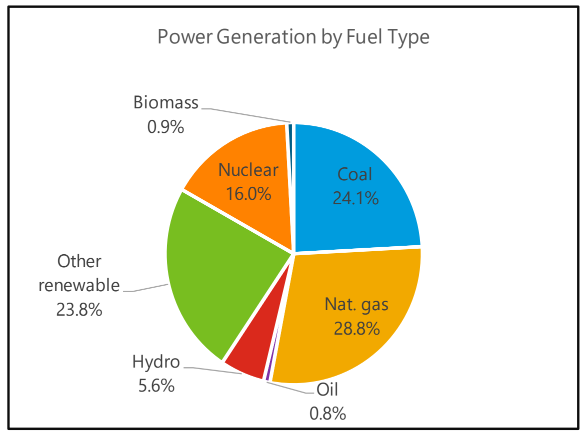
Source: https://di.unfccc.int/detailed_data_by_party



Source: Staff calculations.



Source: Staff calculations.



Source: Staff calculations.

The *Biden Plan for a Clean Energy Revolution and Environmental Justice*[8] sets forth ambitious nationwide and sectoral mitigation goals and envisions a largely regulatory and investment approach to make headway on them. The plan seeks to:

- Achieve zero net CO_2 emissions at the national level by 2050[9] and establish nearer term emissions targets consistent with this goal;
- Achieve zero net emissions from power generation by 2035 (e.g., through expanding renewables and nuclear);
- Tighten fuel economy standards to ultimately promote 100 percent deployment of electric vehicles (EVs) for light/medium vehicles and greater EV deployment for heavy vehicles (500,000 new public charging outlets will be provided by 2030);

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[8] See https://joebiden.com/climate-plan/.

[9] Gross emissions can be positive, if they are offset by negative emissions (e.g., from reforestation, direct removal of CO_2 from the atmosphere).

- Reduce direct (from gas and oil) and indirect (from electricity) building emissions 50 percent by 2035 through stronger appliance and building efficiency standards, building codes, on-site clean power generation, retrofitting public buildings, and requiring all new buildings are zero carbon by 2030;
- Reduce methane leaks from oil and gas extraction;
- Introduce, or scale up, tax incentives for technologies like carbon capture, use and storage (CCUS) and EVs;
- Impose a border carbon adjustment (BCA), that is, a charge on the carbon content of carbon-intensive imports, applied to goods from countries failing to meet their climate obligations;
- Invest $400 billion over ten years in research to develop critical technologies (e.g., electricity storage, small-scale nuclear, green hydrogen, CCUS, direct air capture); and
- Commit $1.7 trillion over ten years in federal funding for mitigation investments (e.g., subsidies for renewables and grid expansions for integrating them, building upgrades).

At the international level, the Biden Plan seeks to promote greater mitigation ambition and stronger agreements to reduce international transportation emissions. Within 100 days, the new administration would convene a summit with major emitters and the aim of strengthening mitigation pledges. And, while the bodies overseeing the international aviation and maritime sectors have developed mitigation targets, the Administration seeks stronger near-term targets and measures to implement them.

Many specific policy actions to implement the Biden Plan need to be fleshed out, but a comprehensive package of fiscal policies could play a critical role alongside proposed public investment, technology, and regulatory policies in promoting effective, cost effective, and acceptable policies without a fiscal cost. Fiscal policies can be implemented at the national, sectoral, and international level.

- At the national level, a carbon tax or emissions trading system (ETS) would provide across-the-board incentives for clean technology investment and redirecting spending to lower-emitting activities while revenues might be used, for example, in assisting vulnerable groups in the transition and for boosting the economy through financing green investment or cutting taxes on work effort and capital investment—revenues are especially valuable given budgetary trends;[10]
- Reinforcing instruments at the sectoral level are needed, given sectoral objectives, uncertainty about the effects of pricing, and likely constraints on its acceptability—feebates (see below), which can be applied to the transportation, power, industry, buildings, forestry, and agricultural sectors, are cost effective, can complement regulatory approaches, avoid the

[10] The ratio of federal debt to GDP has increased from 35 percent in 2007 to a projected 98 percent for 2020 and 142 percent for 2040 (CBO 2020).

fiscal cost associated with subsidies, and may enhance acceptability by limiting new tax burdens on the average household or firm; and

- At the international level, a carbon price floor arrangement among large emitters (allowing flexibility in approaches at the national level) could be a highly effective mechanism for scaling up global mitigation, while carbon levy/feebate variants can provide the critical price signal for clean technologies in international aviation and maritime while mobilizing the needed research/investment funds and limiting burdens on industries and consumers.

Pushing on multiple fiscal, regulatory, investment, and technology policies makes sense given uncertainties over the political and legal feasibility of individual instruments and federal-level policies are more efficient and simpler. Carbon pricing—with efficient revenue use and in conjunction with investment and technology policies—is the least costly way to meet the Administration's emissions goals. If pricing is not feasible, the next best approach is a combination of feebates or regulations (with credit trading provisions) that reduce emissions intensity across the major energy and land use sectors, ideally with implicit emissions prices harmonized across sectors. A balance between the two approaches is appropriate where some, but not the full amount, of carbon pricing is feasible. At the state level, ETSs operate in California (covering most emissions sources) and in the Northeastern states (covering power generation) and most states have renewable and energy efficiency policies. These policies might be extended, and harmonized, across states. A federal level approach however, which is the focus here, is more cost effective (i.e., it can equate incremental mitigation costs across sectors and regions unlike under multiple state policies), transparent (i.e., there is one uniform policy), and simplifies administration (with one implementing federal agency rather than multiple state agencies).

This paper describes a comprehensive package of federal and international fiscal measures—summarized in Table 1—that could play a key role in combination with other instruments in implementing the major goals of the Administration's climate plan. The focus is on the rationale for these policies, their practical design, their emissions and other impacts, and strategies for enhancing their acceptability. The paper differs from other recent discussions of US climate mitigation policies[11] by its focus on a broad range of fiscal instruments at the national, sectoral, and international level and its quantitative analysis comparing effects in the US with other large emitting countries. The three main sections of the paper focus on nationwide, sectoral, and international policies, respectively and the last section offers concluding remarks.[12]

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[11] For example, Goulder and Hafstead (2018), Flannery and others (2020).

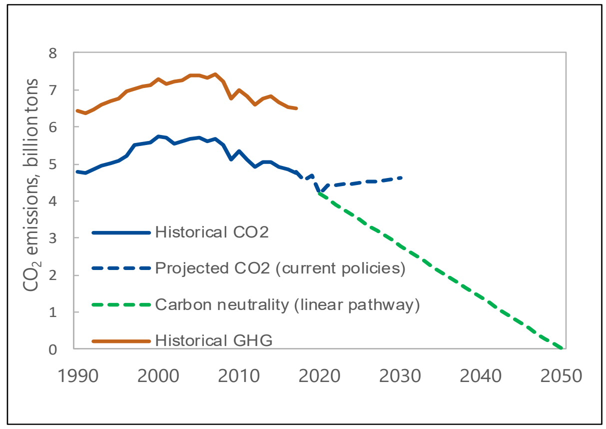
[12] Public investment, technology, and regulatory policies are largely beyond the paper's scope. On the former, IMF (2020) find that deficit-financed public investment in clean energy infrastructure can boost output and employment in the current context of low long-term interest rates and recovery from the pandemic-induced crisis while, in the presence of carbon pricing, catalyzing private investment in clean technologies. For a discussion of US technology policies see Newell (2015) and on regulatory policies Burtraw and Palmer (2015) and Krupnick and others (2010).

Table 1. Summary of Fiscal Mitigation Instruments to Help Implement US Climate Goals	
Sector	**Recommended Instrument at Federal or International Level** (to reinforce investment, technology, and regulatory policies)
Economy-wide	Carbon tax or ETS, with price rising to $75 per ton by 2030 (this would cut emissions about 25 percent). Revenues might be used for: (i) supportive investment; (ii) lowering taxes on work effort and investment; (iii) assisting vulnerable groups.
Power	Introduce feebate: a sliding scale of fees/rebates on generators with above/below average CO_2/kWh to promote shifting to cleaner fuels without a new tax burden on the average generator (carbon pricing is more efficient but may be constrained).
Road transport	Introduce (as a generalization of the gas guzzler tax, EV tax credits, and out-of-compliance fees for fuel economy regulations) feebates for light-duty vehicles: a sliding scale of fees/rebates applied to sellers whose fleets have above/below average CO_2/mile for the vehicle classification. Incentives can be set aggressively to promote EVs without a new tax burden on the average motorist, and can cost effectively reinforce regulations.
Industry	Introduce feebates: a sliding scale of fees/rebates on firms with emission rates above/below the industry average emission rate. Feebates can provide powerful incentives for cleaner production processes without a large tax burden on the average firm which lessens concerns about competitiveness and emissions leakage.
Buildings	Supplement energy efficiency regulations, building codes, and renovation programs with: (i) tax-subsidy scheme promoting shift from natural gas/oil heating systems to electric heat pump or other clean fuel systems; (ii) feebates to promote more efficient appliances and lighting.
Forestry	Introduce a nationwide feebate applied to landowners equal to an (annualized) CO_2 price times the difference between forest carbon storage on their land in a baseline year and carbon storage in the current year. This promotes the full range of nationwide mitigation responses with no burden on the average landowner or fiscal cost to the government. Forest carbon inventories are monitored with satellite and aerial imagery and on the ground sampling.
Agriculture	Introduce a charge on farm-level emissions with revenues returned in proportion to the value of output to improve acceptability. Emissions can be estimated based on farm-level inputs and default emissions factors. A shift from beef and dairy to poultry and crop-based production could be reinforced by fiscal incentives at the consumer level.
Fugitive emissions	Tax methane and CO_2 (from flaring) emissions from extractives based on a default leakage rate with rebates for firms validating their emission rates are lower than the default.
Border carbon adjustment	This instrument could facilitate mitigation at home and promote carbon pricing overseas but there are key design issues to be resolved (some may follow precedent in the EU) and its implementation should not hold up action on mitgation.
International: mitigation in other countries	Promote a carbon price floor arrangement applying to key emitters (e.g., China, EU, India, US) that: (i) includes stricter requirements for advanced countries and technology assistance for low-income countries; (ii) allows policy flexibility at the national level to achive emissions equivalent outcomes.
International: transportation fuels	Promote a global carbon levy for deploying clean technologies and raising R&D funds. A feebate variant would raise less revenue and is less efficient (for aviation), but limits burdens on industries and consumers which may enhance acceptability.

II. NATIONWIDE POLICIES (FOR ENERGY)

The US Administration needs to develop intermediate emissions targets aligned to long-term carbon neutrality. For illustration, on a linear pathway to reduce US fossil fuel CO_2 emissions from (projected) 2020 levels to zero in 2050 the target for 2030 would be 3.3 billion tons, about one-third below projected business-as-usual (BAU) emissions (i.e., emissions in the absence of new mitigation measures) in 2030—see Figure 4.[13] This target—termed here the 'linear target'—would be one of the more stringent intermediate targets among G20 countries (see the red dots in Figure 5) though other countries may submit more stringent pledges for COP 26 (more in line with long-term net zero pledges). Emissions projections discussed here, and the responsiveness of emissions to pricing, are based on an IMF spreadsheet tool described in Annex 1.

Figure 4. Emissions Trends and Targets



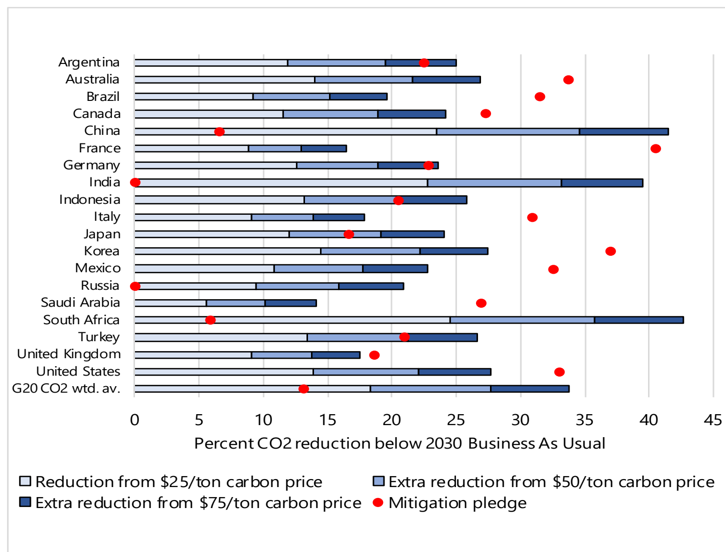
Source: IEA, UNFCCC, staff calculations.

Carbon pricing versus other approaches

The environmental, fiscal, economic, and administrative advantages of federal carbon pricing in the United States have been extensively discussed.[14] Pricing:

- Provides across-the-board incentives for firms and households to reduce energy and shift to cleaner fuels without favoring any specific energy matrix, other than discriminating by its carbon content (by reflecting the cost of carbon emissions in the prices of fuels, electricity, and goods);

Figure 5. CO_2 Reductions for Pledges/from Pricing



Source: Updated from IMF (2019a).
Note. Pledge is from Paris Agreement or subsequent pledge. Price is additional to any existing pricing.

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[13] EIA (2020) projects US CO_2 emissions are flat to 2050 under current policies. The focus year of the analysis below is largely 2030 given that most countries have set intermediate targets for that year.

[14] See also, for example, Goulder and Hafstead (2018), Metcalf (2019), Parry and others (2015), Stavins (2019).

- Automatically minimizes mitigation costs (by equalizing the cost of the last ton reduced across fuels and sectors);
- Redirects new investment to clean technologies (if there is a robust and rising price signal—indeed when businesses are making major investments, they may prefer the certainty of a robust price to regulations);
- Mobilizes valuable revenues for the general government (which can be used, for example, to address distributional concerns, go toward deficit reduction, or finance other spending priorities or tax cuts);
- Generates substantial domestic environmental benefits (e.g., reductions in local air pollution mortality); and
- Is straightforward administratively (if it builds off institutional capacity for existing policies like fuel taxes).

Regulations (e.g., standards for emission rates and energy efficiency) and subsidies for clean technologies (e.g., for EVs, renewable plants) are a less efficient way to promote private sector responses than pricing and forgo fiscal opportunities—but may have greater traction. These approaches cannot promote some potential private sector responses (e.g., conserving on use of air conditioning and vehicles) and lack an automatic mechanism for equating incremental abatement costs across the responses they do promote. They may be more politically acceptable however as, unlike carbon pricing, they may avoid a large increase in energy prices—that is, they do not involve the pass through of carbon tax revenues (or allowance rents under an ETS) in higher electricity, gas, and road fuel prices. And the Executive branch has the legal authority to enact

Table 2. Selected Carbon Pricing Schemes, 2020

Country/ Region	Year Introduced	Price 2020, $/Ton CO_2	Coverage of GHGs	
			Million Tons	Percent
Carbon taxes				
Chile	2017	5	58	39
Colombia	2017	4	46	24
Denmark	1992	26	25	40
Finland	1990	68	41	36
France	2014	49	172	35
Ireland	2010	28	32	49
Japan	2012	3	909	68
Mexico	2014	<1-2	381	47
Norway	1991	3-53	47	62
Portugal	2015	26	16	29
S. Africa	2019	7	512	80
Sweden	1991	119	44	40
Switzerland	2008	99	6	33
Emissions Trading Systems				
California	2012	15.3	375	85
EU	2005	35	2,249	45
Germany	2021	29	238	31
Korea	2015	33	489	70
New Zealand	2008	14	45	51
Regional US	2009	5	108	18
Carbon price floors				
Canada	2019	22	71	9
UK	2013	22	136	23

Source: WBG (2020) and staff calculations.

standards[15]—in contrast, carbon pricing could face a higher hurdle if it requires legislation, though it could have bipartisan support if it is revenue neutral and border-adjusted.[16] The remainder of this section considers carbon pricing, and strategies to enhance its acceptability, while the following section considers complementary measures to the regulatory/subsidy approach envisioned in the Biden Plan that can exploit the price mechanism and are fiscally neutral.

Carbon pricing—design, impacts, and acceptability

Carbon pricing—charges for the carbon content of fossil fuels or their emissions—can be implemented through a tax or ETS. Carbon charges can be applied midstream by integrating them into existing federal gasoline and diesel excises (collected by the Internal Revenue Service within the US Department of Treasury) and extended to coal, natural gas, and other petroleum products.[17] A trajectory of progressively rising tax rates can be announced ahead of time and revenues would accrue to the general federal budget. A federal ETS, which would be administered by the Environmental Protection Agency (either a new program or an extension of the California ETS) is the main alternative. An ETS would be applied downstream at the point of fuel combustion for generators and large industry, but it could also be applied midstream to cover fuels for transportation and buildings.[18] Price stability could be promoted through a rising carbon price floor[19] and allowances could be auctioned to exploit fiscal opportunities.

A carbon price rising to $50 per ton in 2030 is estimated to deliver about two-thirds of the 2030 emissions reductions for the linear emissions target, and a $75 price 85 percent (Figure 5), though acceptable price levels will depend in part on prices elsewhere.[20] The

[15] In 2007, the Supreme Court remanded the matter to EPA, but expressly didn't reach the question of whether EPA must make a finding that GHGs endanger public health or welfare, or whether policy concerns may inform EPA's actions in the event that it makes such a finding. See www.justice.gov/enrd/massachusetts-v-ep.

[16] Nine legislative proposals for a federal carbon tax have been put forward by various representatives and senators in the US Congress since 2018 (for a comparison of their design features see www.energypolicy.columbia.edu/what-you-need-know-about-federal-carbon-tax-united-states). For example, the Energy Innovation and Carbon Dividend Act, which is the first bipartisan climate legislation in a decade, was introduced as H.R.763. The bill includes a carbon fee on fossil fuel suppliers with rate beginning at $15 in 2019 per ton and rising at $10 per ton each year, a BCA, and return of revenues in dividends to households. The main attempt to pass a federal ETS in the United States was the 'Waxman-Markey' bill which passed the House in 2009 but did not make the floor of the Senate. President Biden has pledged not to raise taxes on individuals earning less than $400,000 a year though this refers to income taxes rather than direct taxes.

[17] Taxes could be applied after fuel processing, or upstream as part of the fiscal regime for extractive industries (a small coal tax already exists to fund compensation for black lung disease)—in the latter case, imports should also be covered, and rebates provided for exports. See Calder (2015).

[18] As in, for example, California or the national ETS starting in Germany in 2021.

[19] Again, as in California where the floor price is implemented through a minimum price for auctioned allowances.

[20] For further modelling results on US carbon taxes see Barron and others (2018).

responsiveness of emissions to pricing in the United States is broadly comparable to that in most other countries (Figure 5)—price responsiveness is greater in, for example, China and South Africa due to their greater dependence on coal use. Carbon prices in current carbon tax and ETS schemes are mostly around $5-35 per ton (Table 2), though prices are expected to rise over time.

Table 3. Energy Price Impacts of $50 per ton Carbon Price, Selected Countries 2030

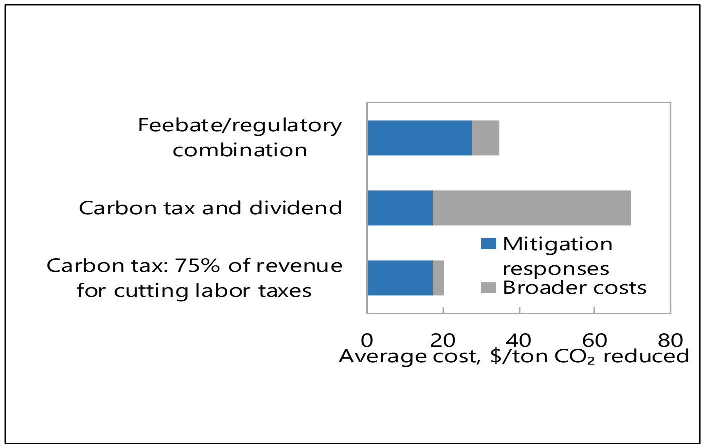
Country	Coal		Natural gas		Electricity		Gasoline	
	BAU price, $/GJ	% increase	BAU price, $/GJ	% increase	BAU price, $/kWh	% increase	BAU price, $/liter	% increase
Australia	2.9	148	8.5	33	0.10	53	1.2	11
Canada	2.9	173	2.6	94	0.10	8	0.9	13
China	2.9	159	8.5	32	0.09	51	1.1	9
Germany	5.2	91	7.9	34	0.13	14	1.7	6
India	2.9	159	8.5	20	0.09	65	1.2	10
Indonesia	2.9	165	8.5	27	0.11	53	0.5	26
Japan	2.9	158	8.5	33	0.11	32	1.3	8
Mexico	2.9	156	2.6	110	0.09	55	0.9	13
UK	5.7	101	7.9	35	0.13	10	1.6	6
US	2.9	170	2.6	103	0.08	39	0.7	15

Source: Updated from IMF (2019a).
Note: BAU prices are retail prices from Coady and others (2019), including preexisting energy taxes, and adjusted for projected changes in international reference prices. Coal and natural gas prices are based on regional reference prices while electricity and gasoline prices are from cross-country databases. Price increases are proportional to carbon emissions factors which are exogenous for coal, gas, and road fuels and endogenous for electricity. Producer prices are taken as fixed. GJ = gigajoule; kWh = kilowatt-hour.

A carbon tax in the United States would impact coal and natural gas prices the most, though electricity prices would also increase significantly (see Table 3). For example, a $50 carbon price would increase coal, natural gas, retail electricity and gasoline prices by 170, 103, 39 and 15 percent respectively above BAU levels in 2030. These percentage price increases would, on average, be smaller for the same carbon price in other G20 countries (especially for natural gas), though this generally reflects higher BAU prices in those countries.

Carbon prices of $50-75 per ton would raise revenues of 0.7-1.0 percent of GDP in 2030 which might be used to boost the economy. Leaving aside the environmental benefits, carbon pricing imposes two sources of distortion or efficiency cost on the economy. First is the cost of the mitigation responses, which can be measured by foregone benefits to fuel users from cutting back on fossil fuel consumption, less reductions in the costs of producing fossil fuels. Second is the broader economic costs as higher energy prices (slightly) contract the economy-wide level of economic activity, which reduces work effort and investment—in turn, this exacerbates the distortions from taxes on personal income, payrolls, and corporate income that reduce labor supply and investment below their economically efficient levels. Using carbon pricing revenues to cut taxes on the income from labor and capital, or to fund productive (green or general) investments, provides offsetting benefits to the economy. In contrast, if revenues are used to fund lump-sum dividends to households there is no efficiency benefit (e.g., no improvement in work incentives) and the overall costs of carbon pricing can be much higher (Figure 6). In fact, a carbon tax and dividend can be costlier overall than a combination of feebates or regulations (see below) achieving the same economy-wide emissions reduction—the broader economic costs are smaller under feebates/regulations as they have smaller impacts on energy prices.

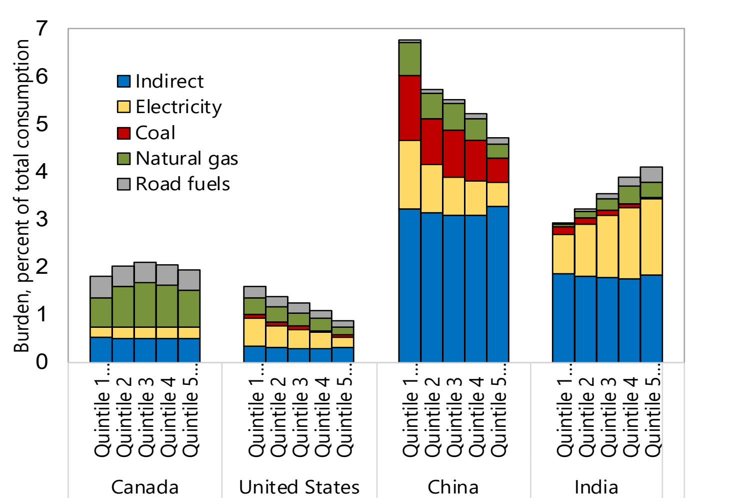
Figure 6. Economic Efficiency Costs of Alternative Mitigation Instruments for the United States ($50/Ton Carbon Tax), 2030



Source: IMF (2019a).
Note: Policies reduce economywide CO_2 emissions 22 percent below BAU.

Carbon pricing in the United States imposes a modest burden on the average household—0.15 percent of consumption for a $50 carbon price in 2030 after revenue recycling—but potentially regressive effects need to be addressed. Prior to revenue use the average burden is much higher, around 1.2 percent of consumption. This burden comes directly through higher prices for electricity, natural gas, and road fuels (which, to varying degrees, are a disproportionately large share of the budget for low-income households), as well as indirectly through higher prices for consumer goods in general (for which budget shares are similar across household groups). Ideally carbon pricing revenues are used in a way that balances efficiency and equity—making this recycling transparent (e.g., through a general cut in payroll taxes) also helps to help build support for the reform. The burden of carbon pricing on households (before revenue use)

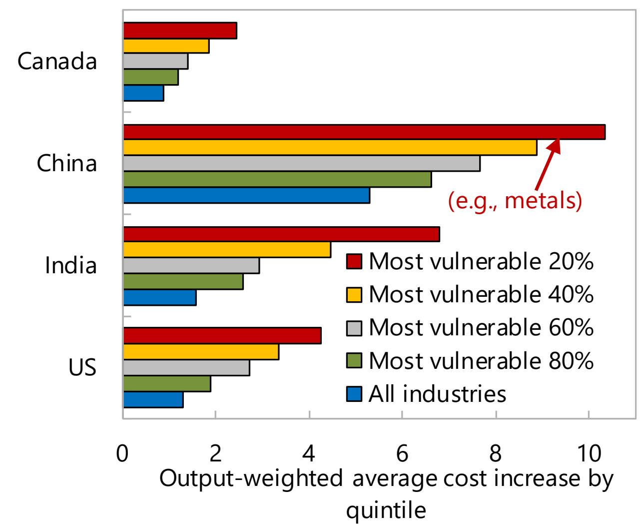
Figure 7. Burden of $50 Carbon Price on Household Income Quintiles in 2030 Before Revenue Use, Selected Countries



Source: Updated from IMF (2019a) after scaling household consumption to be consistent with national accounts.
Note: "Indirect" is the increased price of general consumer goods from higher energy costs. Full pass-through of taxes to consumer prices is assumed. Burdens are measured against consumption as this is generally viewed as a better measure of household wellbeing than income.

would be a lot larger in China where production is far more carbon intensive (Figure 7).

Figure 8. Burden of a $50/Ton Carbon Price on Industries in 2030 Before Pass Through, Selected Countries *(Percent)*



Source: IMF (2019a).

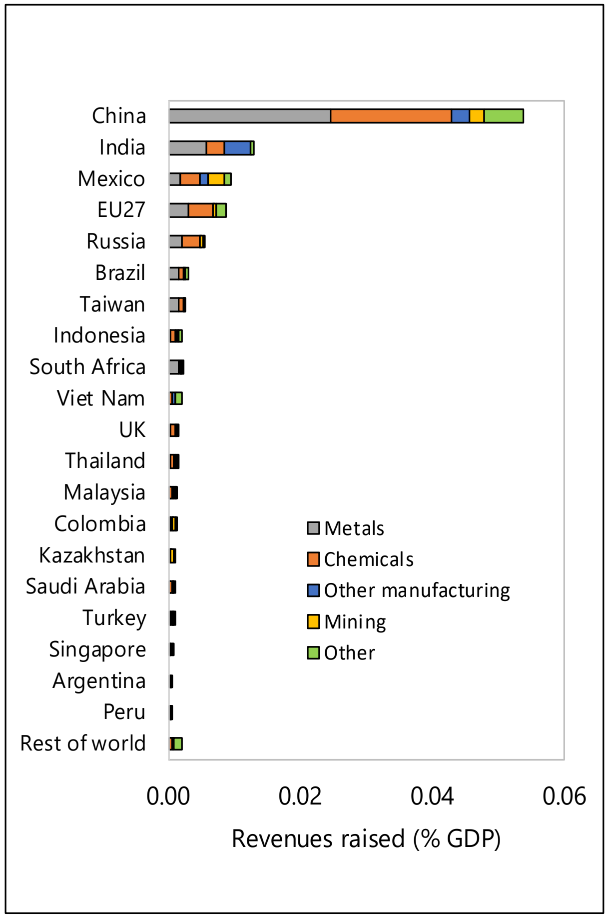
Carbon pricing would moderately increase industrial production costs in the United States (Figure 8). Averaged across all industries, a $50 carbon price in 2030 would increase production costs by 1.5 percent, but much of this would be passed forward in higher consumer prices. Cost increases are, however, somewhat larger for the 20 percent of most vulnerable industries, on average 4 percent. Energy-intensive, trade-exposed (EITI) industries (e.g., aluminum, steel, cement, petrochemicals) are a key concern however, due to the adverse competitiveness impacts, and risks of emissions leakage,[21] stemming from limits on their ability to pass forward higher production costs into higher product prices. Cost increases for the same carbon price are, however, larger for industries in China and India given their higher carbon intensity—about three times as large in the case of China. And cost increases for services in the United States are modest (typically 0.5 percent or less).

A BCA is one possibility for addressing competitiveness concerns, and could encourage pricing in other countries, but delays while design details are finalized should not hold up progress on carbon pricing or other mitigation measures. A BCA would impose charges for the embodied carbon in imports and, if the primary motivation is to address competitiveness and leakage concerns, it should be limited to products competing with EITE industries. Such a BCA, with carbon charge of $50 per ton, would raise revenues of 0.1 percent of US GDP in 2030—with about half of the revenues from Chinese imports and about 10 percent each from Indian, Mexican and EU imports, and 40 percent and 33 percent respectively from metals and chemical products (Figure 9). However, some thorny design issues, including benchmarks for assessing

[21] Emissions leakage refers to the increase in emissions in other countries that partially offset domestic emissions reductions—a potential channel for leakage is increased imports in response to contraction of EITE industries. Some studies suggest leakage rates are modest (e.g., Branger and others 2017, Koch and others 2019) while IMF (2021) estimates more sizable leakage rates for some countries but a relatively modest rate of 5 percent in the case of the United States.

embodied carbon in imports, whether to allow rebates for individual overseas exporters that are less carbon intensive than the industry average, how to adjust charges for carbon pricing or mitigation measures in trading partners, use of BCA revenues, and whether to rebate charges for embodied carbon in US exports. There is also some possibility of legal challenges at the World Trade Organization (WTO), or retaliation by trading partners.[22] And the case for a BCA is less clear if the US eschews carbon pricing in favor of feebates and regulations, as the burden on EITE industries is smaller (see below). It also likely makes sense to delay a US BCA until lessons about design issues and legal risks can be learned from the EU, which is planning to announce its own BCA bill in June 2021 and implement it in 2023.[23] In the meantime, an output-based rebating scheme, or a feebate (see below), are possibilities for addressing competitiveness concerns.[24]

Figure 9. Revenues Raised from $50 BCA on US EITE Imports, 2030



Source: OECD (2020)

Carbon pricing in the United States would face political challenges, though a comprehensive strategy could improve its prospects. Past experiences with energy and

[22] The position under WTO trade rules is complex but those rules do not arguably prohibit countries with carbon taxes from adopting non-discriminatory harmonizing measures (such as BCAs) which would reduce the competitive disadvantage that EITE industries face from exports from countries that do not tax carbon emissions (e.g., Flannery and others 2020). However, the position is even more complex when measures specifically seek to rely on permitted exceptions. In this specific case, only reducing carbon leakage is likely to be a legally permissible justification potentially fall within the environmental exception for trade measures like BCAs under GATT Article XX and not protecting competitiveness—limiting the BCA to EITI industries likely further enhances the prospects for legality of permissibility within that exception under trade law (e.g., Flannery and others 2020). This is because trade measures based on environmental exceptions would not be permissible if they result in arbitrary discrimination or disguised restrictions on trade.

[23] Worldwide, only one BCA has been implemented to date, applying to the embodied carbon in imported electricity under California's ETS (e.g., Pauer 2018).

[24] See, for example, Fischer and others (2015) for a full discussion of assistance measures for EITE industries.

carbon pricing reform across the globe suggests the strategy should include the following basic components:[25]

- A balance between national level pricing and (less efficient but more acceptable) reinforcing sectoral instruments (see below) with progressive implementation;
- Transparent, productive, and equitable use of carbon pricing revenues;
- Assistance for vulnerable groups (low-income households, displaced workers, vulnerable regions, EITE industries);[26]
- Supporting investment and technology policies to address broader market failures (see below) and enhance the effectiveness and credibility of the policy package; and
- Extensive consultations with key stakeholders to garner their support and programs informing the public of the rationale for reform and how they benefit.

III. SECTORAL MITIGATION INSTRUMENTS

Sectoral mitigation instruments have a critical role to reinforce carbon pricing or, if needed, substitute for it entirely, though insofar as possible they should rely on the price mechanism to contain costs on the economy. The greater the political acceptability constraints on carbon pricing, the greater the need for sectoral instruments. And even with aggressive carbon pricing, additional instruments may be needed to achieve sectoral targets, especially for sectors with low responsiveness of emissions to pricing (this will imply some divergence in implicit carbon prices across sectors). Broader market failures (e.g., associated with clean technology infrastructure, coordination failures, or knowledge spillovers in shifting to new technologies) may also warrant additional policies, though often these should be targeted at specific technologies.[27] Where the objective of sectoral instruments is to mimic key behavioral responses that would be induced by pricing, ideally, they would be designed flexibly, allowing firms and households to choose responses that minimize costs for a given emissions reduction. This is one key attraction of the fiscal policies discussed below (the focus of the discussion as

[25] See Clements and others (2013), Coady and others (2018).

[26] See Dinan (2015) for a comparison of mechanisms at the federal level for compensating low-income households including income and payroll tax rebates, incentives for energy-saving investments, increasing the Earned Income Tax Credit, and strengthening the Supplemental Nutrition Action Program (food stamps) and Low-Income Home Energy Assistance Program. Assistance measures at the state level could also be strengthened. Klenert and others (2018) provide a conceptual discussion of equitable recycling. Measures for displaced workers could center around extended unemployment benefits, training and reemployment services, and financial assistance related to job search, relocation, and health care (see Morris (2016). All these household and worker programs need only absorb a modest fraction of carbon pricing revenues. And on balance, employment gains in clean energy jobs are expected to outweigh employment losses in carbon-intensive sectors (e.g., Garrett-Peltier 2017).

[27] Public investment should focus on infrastructure networks (e.g., high voltage transmissions lines to renewables sites in the Great Plains and Southwest, EV charging stations, energy efficient public buildings, pipelines for CCUS) which would be underprovided by the private sector. Technology policies can address knowledge spillovers at various stages during the process of developing, demonstrating, and deploying clean technologies (e.g., Newell 2015, Dechezleprêtre and Popp 2017), especially critical technologies that are currently far from the market (e.g., electricity storage, green hydrogen).

these instruments are more novel), though flexibility can (and has to some extent been) integrated into regulatory approaches through credit trading provisions. The discussion takes in turn road transportation, power, industry, buildings, fugitive emissions, forestry, and agriculture (other emissions sources are discussed in Annex 2).

Road Transportation (19 percent of GHGs)

Road transportation is especially difficult to decarbonize through carbon pricing (or higher gasoline and diesel excises) alone due to the relatively modest impact it has on retail fuel prices (Table 3) and political resistance to higher road fuel prices at the federal level. In fact, federal excises of 18.4 and 24.4 cents per gallon on gasoline and diesel respectively, have been frozen in nominal terms since 1993.[28] Instead, the centerpiece of federal efforts to progressively decarbonize the transport sector is the Corporate Average Fuel Economy (CAFE) program which sets standards for new light-duty vehicle sales fleets. These standards were to rise 5 percent a year from 2021 to reach (on average) a projected 46.7 miles per gallon (mpg) in model year 2026, but in 2019 the annual requirement was reduced to 1.5 percent implying projected fuel economy of 40.4 mpg in 2026.[29] In addition, there is a federal gas guzzler tax of $7,700 applying to passenger vehicles with fuel economy below 12.5 mpg, a tax credit of $7,500 for EVs, and tax credits of between $4,500 and $7,500 for plugin EVs.

Generalizing the gas guzzler tax and EV tax credits with a more comprehensive feebate would strengthen incentives for progressively and cost-effectively decarbonizing the vehicle fleet, while avoiding a fiscal cost to the government. A feebate would provide a sliding scale of fees on vehicles with above average emission rates and a sliding scale of rebates for vehicles with below average emission rates. That is, each new vehicle would be subject to a fee given by:

$$CO_2 \text{ price} \times \{CO_2\text{/mile} - CO_2\text{/mile of the new vehicle fleet}\} \times \{\text{average lifetime vehicle mileage}\}$$

EPA-certified fuel economy by model type (currently used to administer the CAFE program) provides the data needed to assess the fees and rebates for each vehicle. The feebate:

- Promotes the full range of behavioral responses for reducing emission rates, as there is always a continuous reward (lower taxes or higher subsidies) from switching from any vehicle with a higher emission rate to one with a lower emission rate;[30]

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[28] This is despite a strong case on broad environmental and fiscal grounds for substantially higher fuel taxes (e.g., Parry 2011).

[29] See www.nhtsa.gov/corporate-average-fuel-economy/safe. The old and new would cut 2030 emissions of the on-road fleet about 23 and 16 percent respectively (assuming a vehicle life of 15 years and current on-road fuel economy of 30 mpg).

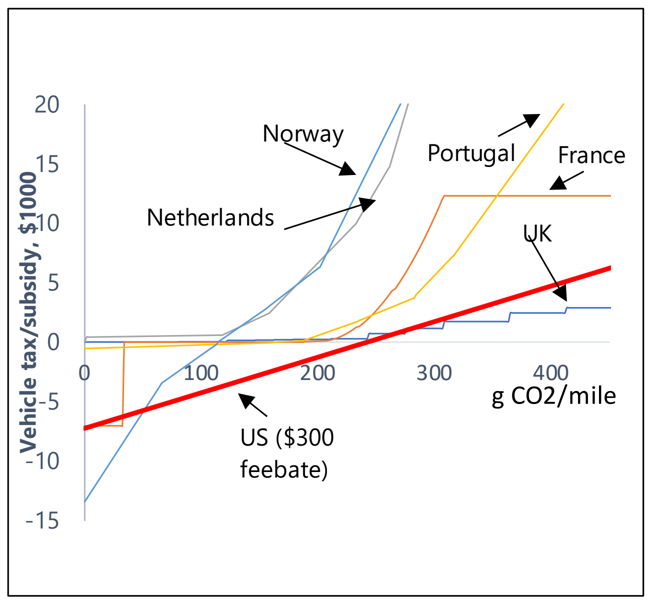
[30] Vehicle manufactures are therefore rewarded for going beyond prevailing fuel economy standards (and penalized for not meeting them)—in this way, the feebate reinforces the CAFE program.

- Is cost effective as the reward is always proportional to the reduction in the emission rate—in contrast under the CAFE program, the reward for additional emissions reductions declines with higher emission vehicles given the focus on miles per gallon rather CO_2 (or gallons) per mile; and
- Maintains (approximate) revenue neutrality—by definition, fees offset rebates as the average emission rate in the formula is updated over time.

At present there are separate mpg standards for seven categories of cars and light trucks where standards are stricter for smaller size vehicles, so in principle a separate feebate (with the CO_2/mile inferred from the mpg standard) could be applied to each category. This approach may be more acceptable to some manufacturers, but it would lower the rewards from increasing the sales shares for smaller size vehicles.

For illustration, a feebate with a price of \$300 per ton CO_2 would apply a subsidy of \$7,500 for EVs and a tax of \$1,800 for a vehicle with fuel economy of 30 mpg (or CO_2 emission rate of 300 grams per mile).[31] Other countries in Europe with elements of feebates generally impose much higher taxes on high emission vehicles than this illustrative feebate (Figure 10) though the sales shares for these vehicles in Europe is smaller than in the United States. Subsidies for EVs would decline over time as the average fleet emission rate declines, which is entirely appropriate as the cost differential between clean vehicles and their gasoline counterparts falls over time (e.g., with improvements in EV batteries). Gauging how fast the average emission rate falls in the future in response to a given feebate price is tricky given uncertainty about how the future penetration of EVs will be affected by changes in relative vehicle prices—the feebate price is, however, easily scaled up if needed to speed up the adjustment.

Figure 10. CO_2-Based Components of Vehicle Taxes



Source: ACEA (2018) and IMF staff calculations.
Note. Assumes discounted lifetime driving of 62,000 miles.

[31] For comparison, a 2015 Honda Fit, Toyota Camry XV70, and Ford ranger T6 currently have mpgs of 49, 41, and 31 respectively or CO_2 emission rates of 181, 217, and 287 g CO_2 per mile respectively.

Power Generation (29 percent of GHGs)

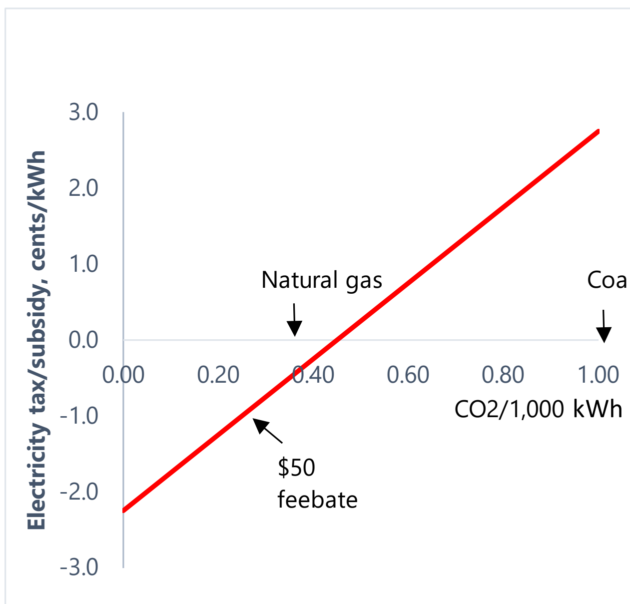
Power generation emissions are relatively more responsive to pricing than emissions in other sectors. This is principally because: (i) the sector uses coal and natural gas and carbon pricing has a more dramatic impact on the prices for these fuels than the prices of other fuels (Table 3); and (ii) there is a wider availability of low-carbon technologies (e.g., nuclear, fossil plants with CCUS, wind, solar, biomass and other renewables) than for other sectors. Federal policies for the sector currently include tax credits for renewable generation. Under the 2015 Clean Power Plan (CPP) states were responsible for developing strategies for meeting emissions targets, which amounted to projected nationwide reductions of 32 percent for the power sector by 2030 relative to 2005 levels—the CPP was repealed in 2017, however.

Even if the CPP were re-instated, incentives for de-carbonizing the power sector could be strengthened with a federal level feebate. Under this scheme, power generators would be subject to a fee given by:

$$CO_2 \text{ price} \times \{CO_2/\text{kWh} - \text{industry-wide average } CO_2/\text{kWh}\} \times \text{electricity generation}$$

The feebate cost-effectively, and in a revenue-neutral way, promotes the full range of responses for reducing emission rates per kWh—improving generation efficiency and shifting the mix of fuels from coal to gas and from these fuels to nuclear, fossil plants with CCUS, and renewables. Current tax credits, for example, promote only the last of these responses and lose revenue. If implemented in conjunction with a reinvigorated CPP, a federal level feebate would provide ongoing incentives to reduce emissions beyond state level targets, would promote cost-effectiveness in reductions across states, and would be a back-up in the event of legal or other challenges to the CPP. The feebate would not require new capacity for monitoring smokestack emissions beyond what is needed for implementing the CPP. And it avoids the politically challenging increase in electricity prices under carbon pricing, though it does not generate the same reduction in electricity demand.

Figure 11. Illustrative Feebate for Power Sector



Source: IMF staff, www.eia.gov/electricity/data/emissions

For illustration, a feebate with a price of $50 per ton would currently apply a subsidy of 2.2 cents per kWh for zero-carbon generation plants and a fee of 2.8 cents per kWh for coal

plants (Figure 11). Natural gas plants would receive a small initial subsidy (0.2 cents per kWh), though this would progressively decrease and become a fee (while subsidies for renewables would decline), as the industry average emission rate declines over time—alternatively the pivot point can initially be defined as the emission rate of a gas plant (in which case it would raise a small amount of revenue initially).

Industry (17 percent of GHGs)

Carbon pricing for industry may be constrained in practice, not least by concerns about competitive impacts. The burden of carbon pricing on industry consists of the costs of cutting emissions (e.g., from switching to cleaner but more expensive technologies) and the, typically much larger, tax or allowance purchase payments for remaining emissions (Annex 3). In other carbon pricing schemes, competitiveness concerns have been addressed through providing industries with free allowance allocations (e.g., in the EU) or charging firm emissions above a threshold level rather than all emissions (e.g., Canada, South Africa) though attention in the EU and United States is currently focused on possible BCAs.

Feebate schemes for industries could reinforce incentives for reducing emissions intensity but with a much smaller burden on the industries than from higher carbon pricing (Annex 3). Under a feebate firms would pay a fee

$$CO_2 \text{ price} \times \{CO_2/\text{production} - \text{industry-wide average } CO_2/\text{production}\} \times \text{production}$$

The focus should be on both direct emissions from fuel combustion and process emissions. The lower burden under a feebate may enhance their acceptability and reduce the pressure for a BCA. Annex 3 provides illustrative comparisons of the impacts of carbon pricing and feebates on production costs in the steel and cement industries.

Buildings (12 percent of GHGs)

Improvements in the energy efficiency of new and existing buildings, and appliances used in buildings, reduce both direct emissions and (through lowering electricity demand) indirect emissions.[32] These improvements may however be hindered by possible market failures (e.g., liquidity constraints, cost-benefit mismatches between owners and renters, unawareness or uncertainty of energy savings from renovation) which would warrant some policy intervention, even if nationwide emissions were adequately priced.[33] The federal government sets energy efficiency standards for a wide range of products (e.g., air conditioners, furnaces, light bulbs, refrigerators, light bulbs); provides tax credits for energy efficiency upgrades in residences and for energy efficient building; and improves consumer awareness of energy efficiency through

[32] Promoting electricity conservation is still important, even if power generation were fully decarbonized, to ensure demand/supply balance given constraints on renewable generation sites.

[33] See for example Arregui and others (2020).

labelling programs. Codes for the design, construction, alteration, and maintenance of buildings are implemented at the state level, in part to account for regional differences in climate.

Various feebate schemes could complement existing regulations to reduce emissions and address market failures by strengthening incentives for energy efficient and low carbon appliances and equipment. For example, sales of refrigerators, air conditioners, and other energy-consuming products could incur a fee given by:

$$CO_2 \text{ price} \times CO_2 \text{ per unit of energy}$$

$$\times \{\text{energy consumption per unit} - \text{industry-wide energy consumption per unit}\}$$

$$\times \text{ number of units}$$

For refrigerators, for example, the energy consumption rate would be kWh per cubic foot cooled (and the number of units would be cubic feet). A similar scheme applying taxes to gas- and oil-based heating systems, and a subsidy for electric heat pumps, could accelerate the transition to zero-carbon heating systems. Again, feebate schemes avoid a fiscal cost (unlike current tax incentives); the carbon prices in feebate programs across different product categories are easily harmonized to promote cost effectiveness (unlike regulatory approaches where there is no automatic mechanism for equating incremental mitigation costs across programs); and these schemes provide ongoing incentives to go beyond current standards.

Fugitive Emissions from Extractive Industries (5 percent of GHGs)

Natural gas, oil, and coal production accounted for 57, 25, and 18 percent of US fugitive emissions in 2018. About half the leaks from natural gas were from extraction—both venting, which releases methane, and flaring, which releases CO_2—and the other half methane leaks from processing, transmission, storage, and distribution, while essentially all fugitive emissions from oil and coal are from extraction.[34] Possibilities for mitigating fugitive emissions include: (i) reinjecting gas (for enhanced oil recovery) or storage (though the feasibility of this varies with the sedimentary rock); (ii) using methane for on-site or regional power generation; (iii) compressing the gas, or liquifying it, for sale; and (iv) improved maintenance of infrastructure for gas processing and distribution.[35] Under a 2016 executive action, which has since been rescinded, new or modified oil and gas wells were required to report their emission rates but these facilities were not subject to emission rate standards and the requirements did not apply to existing wells or coal mines.

Pricing schemes for fugitive emissions would promote the full range of responses for reducing emission rates and are feasible using default emission rates with rebating for

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[34] From https://di.unfccc.int/detailed_data_by_party.

[35] EPA (2019).

firms demonstrating lower emission rates. Emissions monitoring technologies[36] generally provide only discrete measurements at a limited number of sites, though technologies are improving—and CO_2 emissions from flaring are measurable. Fuel suppliers might be taxed based on a default leakage rate with rebates to firms demonstrating lower leakage/venting rates than the default rate through mitigation and installing their own continuous emission monitoring systems. Fugitive emissions are released within the US borders, and therefore should be priced regardless of whether the fuel is for domestic or overseas markets. Pricing approaches are more flexible and cost-effective than regulatory approaches imposing the same standard on all firms, regardless of their mitigation opportunities.

For illustration, an emissions tax of $100 per ton on fugitive emissions would apply charges equivalent (prior to mitigation) of approximately $2 per barrel of oil, $0.4 per thousand cubic feet of natural gas, and $8 per ton of coal under default emission rates. These charges are equivalent to about 4, 11, and 20 percent of current supply prices.[37] Studies suggest however, that this level of pricing would lower emission rates by around 60 percent.[38]

Forestry

Ideally, federal forestry policies should cost-effectively promote, nationwide, the three channels for increasing forest carbon storage. These include: (i) afforestation; (ii) reducing deforestation; and (iii) enhanced management of tree farms (e.g., planting larger trees, longer rotations, fertilizing, tree thinning). Expanding forest coverage generates other environmental co-benefits beyond carbon storage such as biodiversity preservation and reduced risks of water loss, floods, soil erosion, and river siltation. Historically, the US forestry sector has on net absorbed 0.6-0.8 billion tons of CO_2 a year and there is potential to scale up storage at the rate of about 0.2 billion tons a year by fully stocking forestland—forested land in the United States can sequester up to about 3 tons of CO_2 per hectare a year during the growth cycle.[39] Currently, however there are no federal policies that primarily target forest carbon sequestration.[40]

A national feebate program could cost-effectively promote all responses for increasing carbon storage without a fiscal cost to the government. The policy would apply fees to landowners at the agricultural/forestry boundary that reduce stored carbon relative to a baseline level and rebates to landowners that increase stored carbon. That is, the fee is given by:

[36] Including satellites, aircraft, drones, and remote sensing from vehicles.

[37] Calculations using data from https://di.unfccc.int/detailed_data_by_party and www.eia.gov.

[38] EPA (2019).

[39] Figures from Domke and others (2020).

[40] There are however various conservation, grant, and technical assistance programs for forestry and agriculture that can indirectly promote sequestration (e.g., USDA 2016).

{CO_2 rental price}

× {carbon storage on their land in a baseline year − stored carbon in the current year}

The scheme would reward all three channels for enhancing carbon storage, either through reduced fees or increased subsidies (unlike an afforestation subsidy which just rewards one channel or a subsidy for additional storage which does penalize reductions in storage). Feebates can be designed—through appropriate scaling of the baseline over time[41]—to be revenue-neutral in expected terms. Feebates should involve rental payments—on an annualized basis, a CO_2 price times the interest rate[42]—rather than large one-off payments for tree planting, given carbon storage may not be permanent (e.g., due to subsequent harvesting or loss through fires, pests, windstorms).[43] For illustration, fully stocking a hectare that previously had no trees would increase the land value by about $2,000 under a $50 feebate (about 25 percent of current average agricultural real estate values).[44] Fees and rebates could be administered based on the registry of landowners used for business tax collection. While still rudimentary, forest carbon inventories are estimated through a combination of satellite monitoring, aerial photography, and on-the-ground tree sampling.[45]

Agriculture (9 percent of GHGs)

Agricultural GHGs can be reduced through several channels. Reducing livestock herds (particularly beef and dairy cattle) reduces methane releases from enteric fermentation (30 percent of US agricultural GHGs) and nitrous oxide emissions from manure (13 percent) while reducing crops for human and animal consumption (55 percent) reduces nitrous oxide emissions from soils, especially where there is intensive chemical fertilizer use.[46] At the consumer level, shifting from meat and dairy products to plant-based and poultry diets would reinforce mitigation incentives. Currently, a voluntary approach is used to promote emissions reductions from US agriculture.[47]

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[41] See Parry (2020) for details.

[42] Periods might be defined as averages over multiple years given that carbon storage might be lumpy during years when harvesting occurs.

[43] Partial exemptions from fees may be warranted for timber harvested for wood products (e.g., furniture, houses) because the carbon emissions (released at the end of the product life) will be delayed, perhaps by several decades or more.

[44] Calculation assumes the planting sequesters an additional 3 tons of CO_2 each year over a 20-year growth cycle with payments discounted at 5 percent. Agricultural land values were equivalent to $7,500 per hectare in 2019 (USDA 2019).

[45] See Mendelsohn and others (2012), Parry (2020) for further discussion of design issues for feebates.

[46] Emissions shares are from CAT (2020).

[47] USDA (2016).

Pricing could be based on proxy estimates of emissions but a compensation scheme for the farm sector may be needed to enhance acceptability and limit emissions leakage. Direct monitoring of farm level emissions is not currently practical, but emissions can be estimated indirectly using farm-level data (on livestock herds, feed, crop production, fertilizer use, and acreage) and default emissions factors.[48] Emissions taxes would likely face strong political opposition and could cause significant emissions leakage as the tax burden reduced the international competitiveness of US farmers. A feebate approach is worth studying, perhaps based on GHG equivalent emission rates per hectare or nutritional value.[49] Another approach would be to combine an emissions fee with the revenues recycled to the agricultural sector in the form a rebate proportional to the value of farm output. This scheme would cost-effectively promote all behavioral responses for reducing the emissions intensity of farming and, from an administrative perspective, the fees and rebates could be integrated into collection procedures for business tax regimes for farmers. For illustration, an emissions fee of $50 per ton would amount to a charge of about 5 percent on average farm income. With revenue returned in subsidies proportional to value product, on net the scheme would provide modest subsidies for plant-based and poultry farming while taxing beef cattle at 9 percent of output value (Table 4). Demand responses at the household level might be promoted through taxes on meat and dairy products (from both domestic and overseas suppliers) though there may be some lessons to be learned by the mixed success of previous experiences with 'sin' taxes.[50]

Table 4. Impact of Agricultural Emissions Fees, 2018

Farm type	GHGs, million tons CO_2 equivalent	Emissions share	Value of output, $billion	Value output share	Effect of $50 per ton emissions fee			
					Fee payments, $billion	Subsidy from recycling, $billion	Net payment, $billion	Net payment, % value output
Plant-based	117	0.32	182	0.55	5.84	9.97	-4.13	-2.27
Dairy	44	0.12	38	0.12	2.20	2.09	0.11	0.29
Cattle	145	0.40	52	0.16	7.23	2.83	4.40	8.51
Pig	27	0.07	18	0.06	1.34	1.00	0.34	1.87
Poultry	29	0.08	39	0.12	1.43	2.15	-0.72	-1.84
Total	361	1.00	329	1.00	18.03	18.03	0	0

Sources: FAOSTAT, IMF staff calculations

Note. Payments are calculated prior to behavioral responses. Rice cultivation, crop residues, and fertilizer data from 2017.

[48] IPCC (2019b).

[49] Basing the feebate on emission rates per hectare could be problematic because livestock is land intensive but the emissions per hectare could be smaller than for crops. The feebate could be disaggregated with higher pivot points for beef producers and lower pivot points for crop producers—this might enhance acceptability (by lowering fees for the former) though it would lower incentives to switch from livestock to crop operations.

[50] See Batini and Fontana (2021).

IV. Fiscal Policies for International Mitigation

International price floor

The 2015 Paris Agreement was a landmark achievement in international cooperation, but an additional international mechanism is urgently needed to stay on track with climate stabilization goals. The Paris Accord has clearly helped to galvanize the development of climate mitigation objectives at the country level and in some cases (e.g., the EU) strong policies to implement these objectives. Even if all parties achieved their emissions pledges however, this would be cutting global emissions about 10 percent below projected levels for 2030 (based on current policies) whereas emissions reductions of 28 percent and 55 percent would be consistent with a linear emissions pathway to 2ºC and 1.5ºC respectively.[51] One difficulty with the agreement is that there are many signatories (195), negotiating over many targets (one per party), and targets are difficult to compare. Another difficulty is that countries acting unilaterally have limited incentives to scale up mitigation action due to concerns about competitiveness and free rider issues. A complementary arrangement is needed which should be effective, that is, it should contain a concrete plan to deliver the needed emissions reductions by 2030. And it must facilitate negotiation, that is, it should be limited to a few key countries and a small number of transparent parameters.

The US government could convene dialogue on an international carbon price floor (ICPF). It makes sense for China, EU, and the United States to be in discussion (given they collectively account for the huge bulk of global GHGs—see above), and perhaps the United Kingdom (as president of COP 26). A broader forum might include additional G20 countries, not least because some of them (e.g., Japan, Korea) have recently announced long-term carbon neutrality targets. Focusing the agreement on a carbon price floor would have several key attractions: (i) this is an efficient and easily understood parameter; (ii) a simultaneous increase in effective carbon prices would help to address competitiveness and free rider concerns; (iii) the arrangement could be designed equitably, with stricter requirements for higher income countries and/or transparent technological or other assistance for lower income countries; and (iv) the arrangement might be designed flexibly to accommodate different approaches (e.g., combinations of pricing, feebates, regulations) at the national level if they achieved equivalent emissions outcomes as would have been achieved by implementing the price floor.

An ICPF could be highly effective in scaling up global mitigation. For illustration, if the United States, China, and India were subject to price floors of $75, $50, and $25 per ton respectively in 2030 this would cut G20 emissions about 28 percent below baseline levels, which is just consistent with the 2ºC target. Including all G20 countries would increase G20 emissions

[51] Updated from IMF (2019a).

reductions, but only moderately, to about 30 percent. Emissions reductions under the $75/$50/$25 price floor would, broadly speaking, be evenly distributed—about 20 percent below baseline levels in the EU and India, about 28 percent in the US, and somewhat over 30 percent in China.[52]

Table 5. G20 CO2 Outcomes under Alternative ICPF Scenarios

	% reduction in G20 CO2 emissions below baseline, 2030
Required for 2° (1.5) target[a]	28 (55)
Only China, India, and US implement their Paris pledges	4.1
All G20 countries implement their Paris pledges and[b]	
none join an ICPF	10.4
China, India, US join a $50/25 price floor	22.6
All G20 countries join a $50/25 price floor	23.4
China, India, US join a $50 price floor	28.6
All G20 countries join a $50 price floor	29.9
China, India, US join a $75/50 price floor	29.5
All G20 countries join a $75/50 price floor	31.1
China, India, US join a $75/50/25 price floor	28.4
All G20 countries join a $75/50/25 price floor	29.8

Source. IMF staff calculations.

Note. [a]Assumes CO_2 reduced in proportion to total GHGs.

[b]Higher/lower price for advanced/emerging market economies.

[b]Higher/middle/lower price for advanced/high income emerging market/low income emerging market economies.

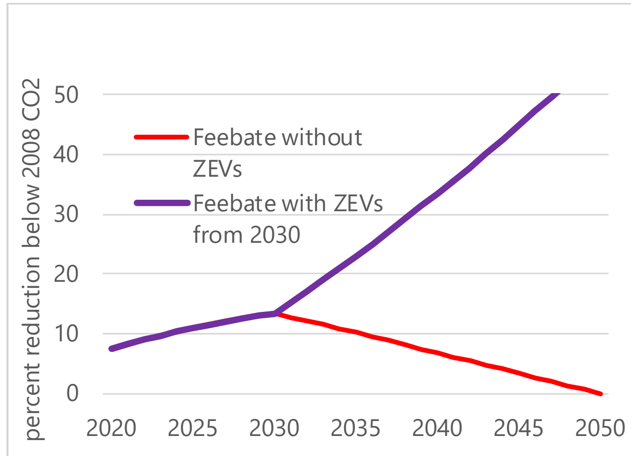
Implementation issues would need to be fleshed out. For example, the focus could initially be on emissions from the power and industry sectors as: (i) these emissions are generally the most responsive to pricing and therefore play the key role in the early stages of clean energy transitions; (ii) most ETSs currently in place are limited to these sectors; and (iii) historically, fuels in these sectors were largely untaxed (or subject to minimal taxes in terms of CO_2 equivalent taxes) making for a clean comparison to a baseline without carbon pricing. Over time, as the arrangement transitions to broader coverage of fossil fuel emissions, and measuring conventions are developed, the focus might transition to countries' 'effective' carbon prices which take account of the possibility of incomplete coverage of formal carbon pricing schemes and changes in pre-existing energy taxes (which are typically large for transport fuels)—participants could agree to increase their effective carbon prices by a given absolute amount over time.[53]

[52] Parry (2020).

[53] See Parry (2020) for further discussion.

International transportation fuels

Figure 12. Estimated Reductions in Maritime Emissions from $75 Carbon Price



Source. Parry and others (2020).
Note. CO_2 price rises progressively to $75 per ton by 2030. ZEVs are available (in the upper curve) by 2030 and replace conventional ships as the fleet turns over.

The US could also promote dialogue on schemes to promote development and deployment of zero-emission vessels (ZEVs) for the international maritime sector. The International Maritime Organization has pledged to reduce CO_2 emissions (currently 2 percent of global CO_2 emissions) by 50 percent below 2008 levels by 2050. Achieving this target will require development and deployment of ZEVs (e.g., using hydrogen fuels, or biofuels) given limits on technical and operational improvements to the efficiency of ships using oil-based fuels. A carbon levy with price needed to promote deployment of ZEVs as the shipping fleet gradually turns over—in the ballpark of $75 per ton (Figure12)—would raise considerably more revenue (tens of billions of dollars a year) than needed for research and investment to develop ZEVs and its high tax burden may face opposition at the IMO. An alternative is to use a feebate variant imposing a much smaller burden on the industry where ship operators are taxed on the difference between their CO_2 emissions per ton-km of freight and a pivot point CO_2 emission rate per ton-km, multiplied by their total ton-km—for a given feebate price, the pivot point can be chosen to meet a revenue target.[54]

The US could also promote emissions pricing reform for international aviation. The International Civil Aviation Organization (ICAO) has pledged to stabilize emissions from the industry at current levels from 2026 onwards, through a scheme where operators can purchase international emissions offsets to cover any excess of their emissions above the benchmark. More ambitious emissions targets will ultimately be required however, for deep decarbonization of the sector, as well as a more robust price signal than provided by current offset markets.[55] In the case of aviation, where fuel costs are a much larger share of transportation costs than for

[54] See Parry and others (2020) for discussion of the rationale for modified feebates for the maritime sector, their design, and quantitative impacts.

[55] The current offset price is below $1 per ton of CO_2 and large offset prices that pass an additionality requirement seem unlikely for the foreseeable future (e.g., Fearnehough and others 2018). International offsets also run the risk of being double counted by both the seller and buyer of the offset towards their mitigation commitments in which case they may not reduce global emissions.

maritime, a carbon levy would reduce the demand for flying, in addition to promoting development and deployment of clean fuels—the former response would not be promoted under a feebate.

V. Conclusion

Using multiple, complementary mitigation instruments to reduce US GHGs is appropriate given uncertainties over the effects and feasibility of individual instruments—and novel fiscal policies have a potentially important role. Fiscal instruments can efficiently enhance the effectiveness and credibility of an overall package that also contains regulatory, infrastructure, and technology policies. And the acceptability of fiscal instruments can be increased by keeping them revenue neutral (in the case of feebates) or using revenues (in the case of carbon pricing) to fund the green transition or broader reductions in taxes on labor.

The United States also has a critical, and urgent role in promoting international coordination to scale up mitigation Large reductions in global GHGs over the next decade are needed to keep alive the possibility of meeting global temperature targets and this cannot be achieved without significant action in China and the United States. Coordinated action, as suggested here through a carbon price floor arrangement, would help facilitate the needed scaling up. Others would likely follow the lead of these three countries and knowing that the future of the planet depends on them should provide an imperative for joint ambition that is absent in the current framework of unilateral voluntary pledges.

Annex I. Spreadsheet Tool for Analyzing Carbon Pricing

IMF staff have developed a spreadsheet model providing, on a country-by-country basis for 150 countries, projections of fossil fuel CO_2 emissions and assessments of the emissions, fiscal, economic, public health and other impacts of carbon pricing and other mitigation policies.

This tool starts with use of fossil fuels and other fuels by the power, industrial, transport, and household sectors and then projects fuel use forward using:

- Projections of GDP;
- Assumptions about the income elasticity of demand and own-price elasticity of demand for electricity and other fuel products;
- Assumptions about the rate of technological change that affects energy efficiency and the productivity of different energy sources; and
- Changes in future international energy prices.

In these projections current fuel taxes and carbon pricing are held constant in real terms.

The impacts of carbon pricing and other mitigation policies on fuel use and emissions depends on: (i) their proportionate impact on future energy prices; (ii) a simplified representation of fuel switching within the power generation sector; and (iii) various price elasticities for electricity use and fuel use in other sectors.

The model is parameterized using data compiled from the International Energy Agency (IEA) on recent fuel use by country and sector and carbon emissions factors by fuel product. Data on energy taxes, subsidies, and prices by energy product and country is from IMF sources. Prices are projected forward using a combination of 2020 prices (50 percent weighting) and an average of IEA, US Energy Information Administration, IMF and World Bank projections for international energy prices (50 percent weighting). Assumptions for fuel price responsiveness are chosen to be broadly consistent with empirical evidence and results from energy models.[56]

One advantage of the model is its flexibility in incorporating a large number of countries, a wide range of alternative mitigation policies (e.g., comprehensive and partial carbon pricing, taxes on electricity and individual fuels, feebates and other policies to improve energy efficiency and reduce emission rates), and sensitivity analyses with respect to parameter values and policy stringency. Another advantage is that the model is highly transparent as differences across policies and countries can be explained in terms of basic economic concepts that are familiar to policymakers.

One limitation of the model is that, for analytical tractability, it does not explicitly incorporate the gradual turnover of energy capital which limits the response of fuel use to pricing in the short to medium term (e.g., while vehicle fleets turn over). This assumption is reasonable, however, given

[56] See IMF (2019b), Appendix III, for a mathematical description of the model and documentation of parameter values.

the focus on longer term policies for 2030, which presumably are anticipated and phased in progressively (nearer-term impacts of policies are analyzed using smaller energy price elasticities). The model abstracts from the possibility of mitigation actions (beyond those induced by current policies) in the BAU, which is a common approach to provide clean comparisons of mitigation instruments to the BAU. More detailed modelling of prospective policies may be needed at the national level however, as individual countries tailor their own, idiosyncratic strategies to implement mitigation objectives.

Another caveat is that, while the assumed fuel price responses are plausible for modest fuel price changes, they may not be for dramatic price changes that might drive major technological advances, or non-linear adoption of technologies like carbon capture and storage. The model also does not account for the possibility of upward sloping fuel supply curves, general equilibrium effects (e.g., changes in relative factor prices that might have feedback effects on the energy sector), and changes in international fuel prices that might result from simultaneous mitigation action in large emitting countries. However, parameter values in the spreadsheet are chosen such that the results from the model are broadly consistent with those from far more detailed energy models that take these sorts of factors into account.[57]

[57] IMF (2019b), Appendix III.

Annex II. Miscellaneous Emissions Sources

This Annex briefly discusses emissions from waste and fluorinated gases, the most important of which is hydrofluorocarbons (HFCs).

For emissions leakage from waste sites (due to the bacterial decomposition of organic waste) the case for fiscal instruments over regulation is less compelling. One reason is that landfills are predominantly managed by the public sector. Another is that mitigation responses are limited—they include capturing the methane for flaring, for use in energy, and diverting waste for recycling and re-use—and are relatively straightforward to specify in regulation. Indeed, the EPA finalized standards to reduce methane emissions from new, modified, and reconstructed municipal solid waste landfills in 2016 though requirements were postponed in 2019.

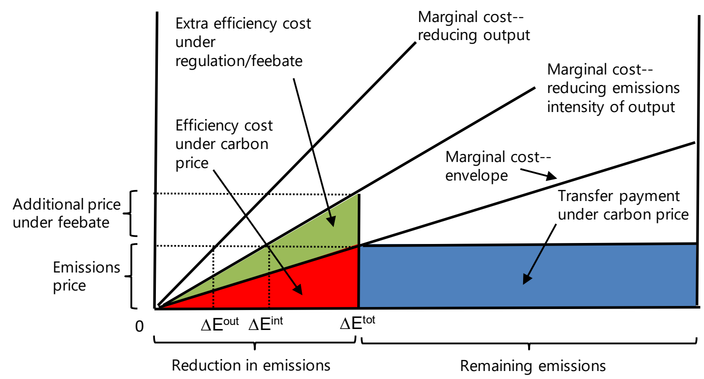
HFCs could be progressively phased out through taxation. These chemicals, which are used in refrigerants, foams, aerosols, and fire extinguishers, were developed as a substitute for ozone-depleting chemicals but have warming potentials hundreds of times higher than CO_2. Unlike other GHGs in the Paris Agreement, HFCs have other international negotiations—under the 2016 Kigali Agreement, advanced countries are required to reduce HFCs 85 percent (relative to 2011-2013 levels) by 2036 (though the United States has not yet ratified the treaty). In 2015, the United States prohibited HFCs for uses where acceptable alternatives were available, however enforcement of this rule was suspended in 2018. Phasing in a tax on HFCs (in proportion to the global warming potential of the gas) would be an administratively straightforward way to progressively reduce their use and would be a more flexible than a regulatory approach.[58]

[58] Denmark, Norway, Poland, Slovenia, Spain, for example, have implemented these taxes with rates equivalent to around US$5-40 per tonne of CO_2 equivalent (e.g., Brack 2015).

Annex III. Burden of Carbon Mitigation Policies on Industries

Conceptual Analysis

Figure A1. Burden of Carbon Mitigation Policies on Industry



The burden—or increase in private production costs—for industries from carbon mitigation policies is depicted graphically in Figure A1. Here the upper, middle, and lower curves are respectively the marginal cost of reducing emissions through reducing domestic industry output, reducing the emissions intensity of output and the envelope of these two curves. A carbon pricing policy reduces emissions by ΔE^{tot}, with ΔE^{int} and ΔE^{out} coming from reduced emissions intensity and reduced output respectively.

The burden of carbon pricing on industries has two components. One is the economic efficiency cost of the behavioral responses (the red triangle in Figure A1) reflecting the resource cost of adopting cleaner (but costlier) production methods. The other is the transfer payment, for example, payments to the government for emission allowances to cover remaining emissions (the blue rectangle).

Alternative mitigation instruments to carbon pricing are less efficient but may impose a much smaller burden on industries. A feebate applied to an industry reduces emissions intensity but (to an approximation) has no impact on output as, unlike a carbon price, it does not charge for remaining emissions. A higher price on emissions is therefore needed to achieve equivalent emissions reductions as under pure carbon pricing, and this implies a higher efficiency cost (the extra green triangle in Figure A1). Under the feebate however there is no transfer payment—the overall burden is therefore generally lower under the feebate.

Illustrative Impacts of Carbon Pricing and Feebates on Production Costs for Steel and Cement

Steel. Traditionally steel is produced using an integrated process involving heating coal to form coke, feeding coke and iron ore into a blast furnace, and using an oxygen furnace to purify the molten metal—the process produces about two tons of CO_2 per ton of steel.[59] Alternatives include an electrified process using scrap metal, and emerging technologies—for example,

[59] Unless otherwise noted, all data in this box is taken from van Reijven and others (2016).

applying CCUS, or feeding an electric furnace with iron made by direct reduction (e.g., using natural gas). These alternatives produce CO_2 emissions of about 0.3–0.4 tons per ton of steel.

A carbon price of $50/ton of CO_2 would increase the cost of integrated production by about $100/ton of steel through the first-order transfer payment, about one sixth of recent steel prices.[60] And it would increase the cost under alternative technologies by about $20/ton of steel.[61] In contrast, under a feebate the cost for integrated production (given an assumed industry average emission rate of 1 ton of CO_2 per ton of steel) would increase $50 per ton of output, while alternative technologies would receive a subsidy of about $30 per ton of output.

Cement. About 90 percent of cement is produced using traditional kilns to decompose calcium carbonate into clinker and CO_2 and then using mills to mix clinker with other minerals like limestone and grinding it—the process produces about 1 ton of CO_2 per one ton of cement, with process emissions contributing about 70 percent of these emissions. Alternatives include state-of-the-art plants in terms of energy efficiency, currently about 10 percent of production, and CCUS—either post-combustion (where CO_2 is extracted from exhaust gases) or oxy-combustion (where fuel is burned with a mixture of pure oxygen and exhaust gases). State-of-the-art plants largely eliminate non-process emissions. Post- and oxy-combustion reduce emissions about 55 and 85 percent respectively, while increasing capital costs by about 25 and 100 percent respectively.

A carbon price of $50/ton of CO_2 would increase the cost of traditional production about $50 per ton of cement, or about 40 percent,[62] while increasing the price of more efficient and CCUS-fitted plants by $30, and $8–25 per ton of output respectively through the first-order transfer payment. In contrast, a feebate with price $50/ton of CO_2 would only increase the cost of traditional production by $5 per ton of cement, while providing a subsidy to more efficient and CCUS-fitted plants of $10 and $18–35 per ton of output.

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[60] See www.focus-economics.com/commodities/base-metals/steel-usa.

[61] Technology switching is more likely to take the reform of retrofitting existing plants, rather than scrapping plants and building new ones, given that existing steel factories can potentially produce for several decades. Incentives will vary across plants, for example with local fuel and electricity prices.

[62] Cement prices are currently around $125 per ton (www.ibisworld.com/us/bed/price-of-cement/190).

REFERENCES

Arregui, N., C. Ebeke, J. Frie, D. Garcia-Macia, D. Iakova, A. Jobst, L. Rabier, J. Roaf, C. Ruo, A. Shabunina, and S. Weber, 2020. "EU Climate Change Mitigation: Sectoral Policies". EUR Departmental Paper, International Monetary Fund, Washington, DC.

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* 9: 1-47.

Batini, Nicoletta and Luigi Fontana, 2021. "Greening Food Demand in Advanced Economies." In *the Economics of Sustainable Food: Smart Policies for Health and the Plane*t, N. Batini (ed.). Island Press and International Monetary Fund.

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

Branger, Frédéric, Philippe Quirion, and Julien Chevallier, 2017. "Carbon Leakage and Competitiveness of Cement and Steel Industries under the EU ETS: Much Ado about Nothing." *The Energy Journal* 37 (3).

Burtraw, Dallas and Karen L. Palmer, 2015. "Mixing it up: Power Sector Energy and Regional and Regulatory Climate Policies in the Presence of a Carbon Tax." In *Implementing a U.S. Carbon Tax: Challenges and Debates*, edited by I. Parry, A. Morris, and R. Williams (New York: Routledge).

CAT, 2020. *USA: Country Summary*. Climate Action Tracker. Available at: https://climateactiontracker.org/countries/usa.

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).

CBO, 2020. *The 2020 Long-Term Budget Outlook*. Congressional Budget Office. Washington, DC.

Clements, Benedict, David Coady, Stefania Fabrizio, Sanjeev Gupta, Trevor Serge Coleridge Alleyne, Carlo A Sdralevich, (eds.), 2013. *Energy Subsidy Reform: Lessons and Implications*. Washington DC, International Monetary Fund.

Coady, David, Ian Parry, and Baoping Shang, 2018. "Energy Price Reform: Lessons for Policymakers." *Review of Environmental Economics and Policy* 12, 197-219.

Datu Research, 2020. *Climate Change Fueled Weather Disasters: Costs to State and Local Economies*. Report prepared for Environmental Defense Fund.

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

Domke, Grant M., Sonja N. Oswalt, Brian F. Walters, and Randall S. Morin, 2020. "Tree Planting has the Potential to Increase Carbon Sequestration Capacity of Forests in the United States." *Proceedings of the National Academy of Sciences of the United States of America* 17: 24,649-24,651.

EIA, 2020. *Annual Energy Outlook 2020*. Energy Information Administration, US Department of Energy, Washington, DC.

EPA, 2019. *Global Non-CO_2 Greenhouse Gas Emissions Projections & Mitigation: 2015-2050*. US Environmental Protection Agency, Washington, DC.

Fearnehough, Harry, Thomas Day, Carsten Warnecke, and Lambert Schneide, 2018. "Marginal Cost of CER supply and Implications of Demand Sources." German Emissions Trading Authority, German Environment Agency, Berlin.

Flannery, Brian P., Jennifer A. Hillman, Jan W. Mares, and Matthew C. Porterfield, 2020. *Framework Proposal for a US Upstream GHG Tax with WTO-Compliant Border Adjustments: 2020 Update*. Resources for the Future, Washington, DC.

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

Garrett-Peltier, Heidi, 2017. "Green versus Brown: Comparing the Employment Impacts of Energy Efficiency, Renewable Energy, and Fossil Fuels using an Input-Output Model." *Economic Modelling* 61: 439-497.

Goulder, Lawrence, and Hafstead, Marc. 2018. *Confronting the Climate Challenge: US Policy Options*. Columbia University Press, New York, NYC.

Graff Zivin, Joshua, and Matthew Neidell, 2012. "The Impact of Pollution on Worker Productivity." *American Economic Review* 102: 3652–3673.

IMF, 2019a. *Fiscal Monitor: How to Mitigate Climate Change*. International Monetary Fund, Washington, DC.

________, 2019b. *Fiscal Policies for Paris Climate Strategies—From Principle to Practice*. International Monetary Fund, Washington, DC.

________, 2020. "Mitigating Climate Change." In *World Economic Outlook, October 2020: A Long and Difficult Ascent*, International Monetary Fund, Washington, DC.

________,2021. *World Economic Outlook*, forthcoming International Monetary Fund, Washington, DC.

IPCC, 2018. Global Warming of 1.5 °C. Intergovernmental Panel on Climate Change, Geneva.

IPCC, 2019a. *Special Report on the Ocean and Cryosphere in a Changing Climate*. International Panel on Climate Change, Geneva, Switzerland.

IPCC, 2019b. *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. International Panel on Climate Change, Geneva, Switzerland.

Kahn, Matthew E., Kamiar Mohaddes, Ryan N. C. Ng, M. Hashem Pesaran, Mehdi Raissi and Jui-Chung Yang, 2019. "Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis." Working paper 19-215, International Monetary Fund, Washington, DC.

Klenert, David, Gregor Schwerhoff, Ottmar Edenhofer, and Linus Mattauch, 2018. "Environmental Taxation, Inequality and Engel's Law: The Double Dividend of Redistribution." *Environmental and Resource Economics* 71: 605–24.

Koch, Nicolas, and Houdou Basse Mama, 2019. "Does the EU Emissions Trading System Induce Investment Leakage? Evidence from German Multinational Firms." *Energy Economics* 81: 479–492.

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 Futureand National Energy Policy Institute).

McSweeney, Robert, 2020. *Nine 'Tipping Points' that Could be Triggered by Climate Change*. Carbon Brief. Available at: www.carbonbrief.org/explainer-nine-tipping-points-that-could-be-triggered-by-climate-change

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

Metcalf, Gilbert E., 2019. *Paying for Pollution: Why a Carbon Tax is Good for America*. Oxford University Press, Oxford, UK.

Morris, Adele, 2016. *Build a Better Future for Coal Miners and their Communities*. Brookings Institution, Washington, DC.

Newell, Richard G., 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).

OECD, 2019. *Taxing Energy Use 2019: Using Taxes for Climate Action*. Organization for Economic Cooperation and Development, Paris, France.

OECD, 2020. *CO_2 Emissions Embodied in Domestic Final Demand by Source Country and Industry*. Organization for Economic Cooperation and Development, Paris, France.

Parry, Ian W.H., 2011. "How Much Should Highway Fuels Be Taxed?" In Gilbert E. Metcalf (ed.), *US Energy Tax Policy*, Cambridge University Press, 269-297.

Parry, Ian W.H., 2019. "The Rationale for, and Design of, Forest Carbon Feebates." Unpublished manuscript, Washington: International Monetary Fund.

Parry, Ian W.H., 2020. "A Proposal for an International Carbon Price Floor Among Large Emitters." Unpublished note, International Monetary Fund, Washington, DC.

Parry, Ian, Dirk Heine, Kelley Kizzier, and Tristan Smith, 2020. "A Carbon Levy for International Maritime Fuels." *Review of Environmental Economics and Policy*, forthcoming.

Parry, Ian, Adele Morris, and Roberton Williams (eds.), 2015. *Implementing a US Carbon Tax: Challenges and Debates*. New York, Routledge.

Pauer, Stephan, 2018. "Including Electricity Imports in California's Cap-and-Trade Program: A Case Study of a Border Carbon Adjustment in Practice." The Electricity Journal 31: 39-45.

Stavins, Robert N., 2019. "The Future of US Carbon-Pricing Policy." Working paper 25912, National Bureau of Economic Research, Cambridge, MA.

UNEP, 2020. *Emissions Gap Report 2020*. UN Environment Programme, Nairobi, Kenya.

USDA, 2016. *Building Blocks for Climate Smart Agriculture and Forestry*. US Department of Agriculture. Washington, DC.

USDA, 2019. *Land Values: 2019 Summary*. US Department of Agriculture. Washington, DC.

USGCRP, 2017. *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. US Global Change Research Program, Washington, DC.

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* 112: 15-36.

WBG, 2019. *State and Trends of Carbon Pricing 2019*. World Bank Group, Washington, DC.

WBG, 2020. *Carbon Pricing Dashboard*. World Bank Group, Washington, DC. Available at: https://carbonpricingdashboard.worldbank.org/map_data.