STAFF

CLIMATE

NOTES

Getting on Track to Net Zero

Accelerating a Global Just Transition in This Decade

Simon Black, Jean Chateau, Florence Jaumotte, Ian Parry, Gregor Schwerhoff,
Sneha Thube, and Karlygash Zhunussova

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Getting on Track to Net Zero: Accelerating a Global Just Transition in This Decade

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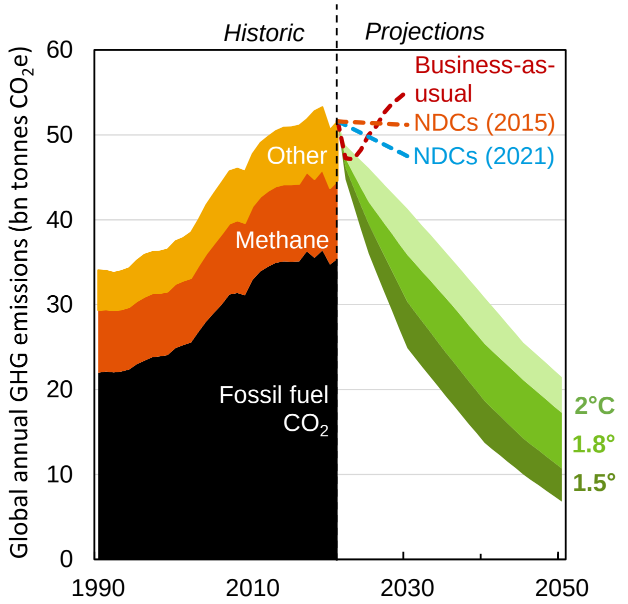
Summary

To contain global warming to between 2°C and 1.5°C, global greenhouse gas emissions must be cut 25 to 50 percent below 2019 levels by 2030. Even if fully achieved, current country pledges would cut global emissions by just 11 percent. This Note presents illustrative options for closing this ambition gap equitably and discusses their economic impacts across countries. Options exist to accelerate a global just transition in this decade, involving greater emission reductions by high-income countries and climate finance, but further delays in climate action would put 1.5°C beyond reach. Global abatement costs remain low under 2°C-consistent scenarios, with burdens rising with income levels. With efficient policies of carbon pricing with productive revenue use, welfare costs become negative when including domestic environmental co-benefits, before even counting climate benefits. GDP effects from global decarbonization remain uncertain, but modeling suggests they exceed abatement costs especially for carbon-intensive and fossil-fuel-exporting countries. Ratcheting up climate finance can help make global decarbonization efforts more progressive.

Introduction

Limiting global warming to 2°C or 1.5°C requires cutting carbon dioxide (CO_2) and other greenhouse gases (GHGs) by 25 or 50 percent by 2030 compared with 2019, followed by a rapid decline to net zero emissions near the middle of the century (Figure 1). Global warming is already having severe impacts, such as heatwaves, droughts, floods, hurricanes, sea-level rise, and forest fires. The frequency and severity of these impacts will rise as the planet warms and risks of "tipping points" such melting permafrost could lead to runaway warming.[1] If emissions are not cut rapidly in this decade, it may put the Paris Agreement's temperature goals beyond reach. Although emissions may decline in 2022-3 due to the recent surge in energy prices (with significant uncertainty), without new mitigation policies emissions are projected to grow to continue to 2030 in the business as usual (BAU) scenario. A total of 139 countries have proposed or set 'net-zero' targets for mid-century.[2] These pledges are important, but 2030 targets in countries' nationally determined contributions (NDCs) remain insufficient.

Figure 1. Global GHG Emissions, Nationally Determined Contributions (NDCs), and Temperature Targets



Sources: Intergovernmental Panel on Climate Change (2022); and IMF staff using the IMF-WB Climate Policy Assessment Tool.

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[1] Intergovernmental Panel on Climate Change (2018, 2021). Indeed, per the Glasgow Climate Pact (Art IV.21), parties "recognizes that the impacts of climate change will be much lower at the temperature increase of 1.5°C compared with 2°C and *resolves* to pursue efforts to limit the temperature increase to 1.5C" (UN Framework Convention on Climate Change 2021).

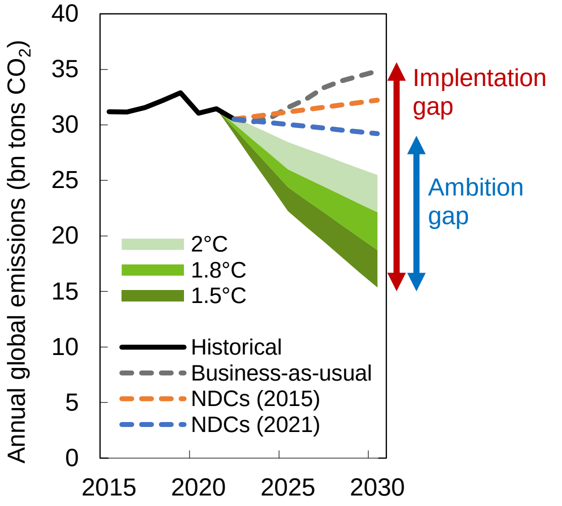
[2] Target years for net zero emissions range from 2035 (Finland) to 2070 (India). See www.climatewatchdata.org/net-zero-tracker.

The world is not yet on track to net zero on two fronts (Figure 2).

- **Despite progress at and since COP26, there remains a large global climate mitigation ambition gap.** Even if 2030 pledges were achieved, they would only reduce global CO_2 emissions 11 percent below 2019 levels. Pledges were strengthened at COP26, mostly by high-income countries. The first round of NDCs (when the Paris Agreement was signed in 2015) would only cut emissions by 7 percent below 2019 levels by 2030. More than two thirds of the additional emissions cuts announced at COP26 are from enhanced ambition among high-income countries. At COP26, countries were asked to 'revisit and strengthen' their targets to align emissions with Paris' temperature goals. Since COP26, 23 countries have submitted enhanced NDCs. **However, current global ambition still achieves less than one half of what's needed for 2°C and about one fifth for 1.5°C.**[3]
- **There is an even larger gap in policy implementation.** Without new policies, emissions will rise well over levels required by the Paris Agreement's temperature goals.

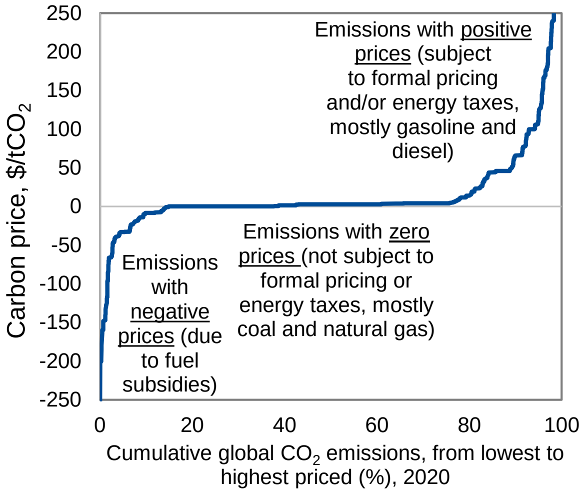
Getting fossil fuel prices right to 2030 remains critical to cutting emissions. But fuels remain mostly untaxed or subsidized (Figure 3). Costs for renewable energy have declined precipitously,[4] but taxes on competing fossil fuels remain too low. Preexisting excise taxes on fuels (mostly road fuels) are equivalent to a global carbon price of $9 per tonne, but two-thirds of global emissions (largely coal and natural gas) are effectively unpriced, and 15 percent have a negative price due to explicit fuel subsidies. Carbon pricing schemes are now operating (at regional, national, or subnational level) in 45 countries, but these schemes frequently have limited coverage and low prices (Parry, Black, and Zhunussova 2022, Figure 2). Indeed, the global average carbon price is only $5 per tonne,[5] whereas new measures equivalent to a global carbon price exceeding $75 per tonne are needed by 2030 (see the following).

Figure 2. CO_2 Emissions, Mitigation Ambition and Implementation Gaps to 2030



Sources: Intergovernmental Panel on Climate Change (2022); IMF staff using the IMF-WB Climate Policy Assessment Tool.
Note: CO_2 = carbon dioxide; NDCs = nationally determined contributions.

Figure 3. Global Average Net Taxes and Subsidies on Fossil Fuels (Expressed as a Carbon Price), 2020



Source: IMF staff calculations.
Note: Shows explicit carbon prices, fuel taxes, and explicit subsidies expressed as an unadjusted carbon price (weighted by carbon content), by cumulative global CO_2 emissions. CO_2 = carbon dioxide; tCO_2 = ton of carbon dioxide.

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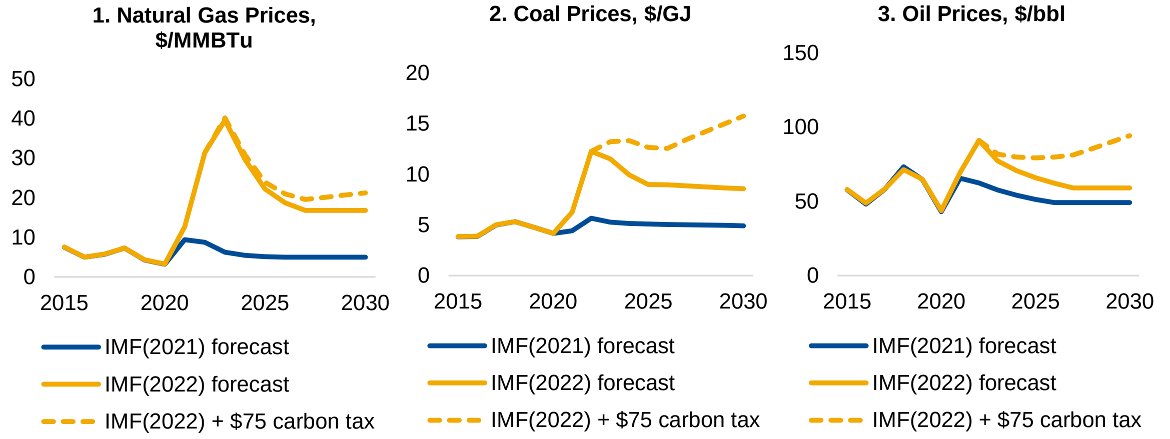
[3] This finding of a large global 2030 climate mitigation ambition gap is also found by UNEP (2022) and UNFCCC (2022b).
[4] Between 2010 and 2021 the global weighted average levelized costs of utility-scale solar photovoltaics declined by 88 percent and onshore wind, concentrating solar, and offshore wind by 60 to 68 percent. See https://irena.org/publications/2022/Jul/Renewable-Power-Generation-Costs-in-2021.
[5] All monetary figures below are expressed in terms of 2021 US dollars or thereabouts.

Taxes on fuels can be raised as fossil fuel prices recede from their current elevated levels (Figure 4). Global gas, coal, and oil prices increased about 850, 190, and 110 percent, respectively, between mid-2020 and mid-2022. This was in part due to the recovery in global energy demand, weak fossil fuel investment, and disruptions following the Russian invasion of Ukraine. These high prices are a challenge for the political acceptability of carbon pricing (see IMF 2019a). However, though uncertain, projections suggest fuel prices will decline. This provides an opportunity to gradually increase carbon prices, while allowing the price of gas to decline below current levels. For illustration, phasing in a $75 carbon price on top of projected prices would imply 2030 gas prices that are 32 percent *below* mid-2022 levels, while oil and coal prices would be 3 and 28 percent higher, respectively. Without carbon pricing, projected fuel prices will not be sufficient for decarbonization as the relative increase in gas prices has caused switching to coal and price changes are seen as partly temporary, which blunts incentives for households and firms to adopt low-carbon technologies.

Figure 4. Trends in International Fuel Prices



Source: IMF staff.

Note: Prices in real 2021 US dollars, deflated by respective IMF projections. Carbon tax starting at $10 in 2022 and rising to $75 in 2030 is assumed on top of IMF (2022b) baseline assuming elastic supply (this assumption is likely reasonable for coal and gas, although possibly less so for oil). Natural gas prices are a weighted average of natural gas in Europe, North America (Henry Hub), and LNG market (Japan). Coal prices are a weighted average of domestic sectoral coal prices in China, India, and the United States. Oil prices are an average of Brent, Dubai Fateh, and West Texas Intermediate. The carbon tax is assumed to be fully passed forward into demand prices. bbl = billion barrels; GJ = gigajoule; MMBTu = Million British Thermal Units.

At an international level, climate mitigation ambition needs to be scaled up equitably. Parties to the Paris Agreement are required to periodically ratchet up their pledged emissions cuts. Initially, this was on a five-yearly basis starting at the 2021 UN 'Conference of Parties' (COP26), but given persistence of the ambition gap it will be discussed annually starting with the 2022 UN climate conference (COP27) in Egypt (UNFCCC 2022, article IV.27). To help move dialogue and policy forward, information is required, at the country group and individual country level, on (1) regimes for aligning emissions commitments with alternative temperature goals and (2) mitigation burdens implied by these commitments. Regimes should respect the Paris Agreement's equity principle,[6] generally understood as including that the speed of emissions cuts should rise with per capita incomes, complemented with climate finance.

This IMF Staff Climate Note provides extensive quantitative analysis to inform international dialogue. The Note updates a previous IMF assessment of options for closing ambition and policy gaps (Black and others 2021). It also considers a broader range of regimes and metrics for comparing mitigation burdens. The latter include (1) welfare costs, which reflect pure abatement costs (primarily the costs of shifting to more expensive low-carbon technologies), less fiscal benefits

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[6] Known also as the principle of "common but differentiated responsibilities and respective capabilities in the light of national circumstances." See UN Framework Convention on Climate Change (UNFCCC 2015).

from recycling mitigation policy revenue, and less domestic environmental co-benefits (for example, reductions in local air pollution mortality); and (2) GDP impacts, which incorporate abatement costs and changes in trade and investment. Analysis is presented for high-, middle-, and low-income country groups (HICs, MICs, and LICs, respectively) and selected individual countries—an accompanying spreadsheet provides results for 135 countries.[7]

The Note employs the IMF-WB Climate Policy Assessment Tool (CPAT) and the IMF-ENV computable general equilibrium model—Annex 1 describes these models and their comparative applications and strengths. Unless otherwise noted, the analysis focusses on fossil fuel CO_2 emissions given their dominant role in GHG emissions (Figure 1) and long-range temperature targets as well as greater confidence in measuring abatement costs for these gases.[8] The following sections of the Note discuss emissions scenarios and mitigation burdens, respectively.

The key message is that there are options for getting on track to net zero emissions in this decade equitably and with manageable costs. For example, a scenario (termed "high equity"—see the following) with CO_2 reductions of about 46, 27, and 17 percent below 2030 BAU levels for HICs, MICs, and LICs, respectively, is consistent with 2°C. Achieving 1.8°C or 1.5°C would require even further increases in climate mitigation ambition and action.

For the 2°C scenarios, the estimated impacts are as follows:

- Pure abatement costs are about $0.5 trillion or 0.4 percent of GDP worldwide in 2030. Costs are higher for HICs (about 0.7 percent of GDP) and lower for LICs (0.3 percent of GDP).
- However, implementing carbon taxes or emissions trading systems and using revenues for productive public investment (while compensating vulnerable households for elevated fuel prices) could cut these costs for MICs and LICs by two-thirds or more.
- Additionally, including domestic environmental co-benefits would make the net welfare costs of mitigation negative for many countries. This is notably due to better human health from improved air quality, as fossil fuels burning is a major contributor to local air pollution. These domestic co-benefits are especially large in MICs (valued at 1.3 percent of GDP) where local air pollution is a major problem.
- Climate benefits are not estimated here at the domestic level, but at the global level would swamp abatement costs. That is, the costs of action are small relative to the costs of inaction.
- Global impacts on GDP vary between a reduction relative to baseline in 2030 of 0.6 and 1.5 percent depending on effort distribution and revenue recycling. The midpoint is 1.0 percent globally, equivalent to around 0.1 percentage point reduction in annual global GDP growth. Given projected average global growth of 3 percent a year to 2030, this implies costs that are very small compared to the broader welfare benefits (see earlier discussion). However, GDP costs are somewhat larger for fossil fuel exporters (2–2.5 percent) and carbon-intensive MICs (0.6–1.5 percent). GDP impacts may be lower when carbon pricing revenues fund investment or measures are taken to limit output losses.
- Moderate increases in climate finance flows from HICs to lower-income countries can ensure that the global distribution of mitigation burdens is progressive and supports the development needs of low-income countries.

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[7] See the online appendix at https://www.imf.org/-/media/Files/Publications/Staff-Climate-Notes/2022/English/SCN2022010-S001.ashx.

[8] This can overstate mitigation burdens for countries where changes in land use have a key role in mitigation, though significant cost uncertainties surround these possibilities. Parry and others (2022) discuss policies to reduce methane emissions and their global and country impacts.

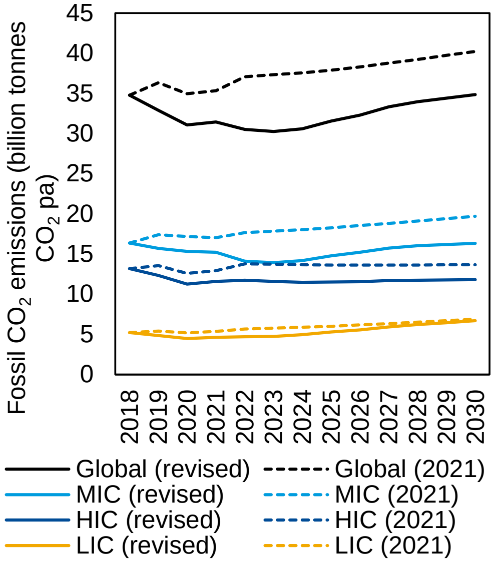
Emissions Analysis

Emissions Projections and Current Ambition

BAU CO_2 projections for 2030 have declined significantly relative to projections as of mid-2021 (Figure 5). Global fossil fuel CO_2 emissions are projected to rise 12 percent from 31 billion tonnes in 2020 to 35 billion in the 2030 BAU, compared with 40 billion tonnes as projected in 2021. The decline in projected emissions reflects a general reduction in fossil fuel demand in response to higher fuel prices and moderately lower GDP, though changes in relative fuel prices have caused a partially offsetting switching from gas to coal.[9] BAU emissions growth is faster in LICs (49 percent between 2020 and 2030) compared with HICs and MICs (5 and 7 percent each), reflecting LICs' faster growth and needs for expanded energy access. Emissions increase by less than in proportion to GDP due, for example, to improving energy efficiency and growth in services relative to manufacturing. See Annex 3 for a discussion of BAU emissions projections by individual countries.

Developing countries account for a growing majority of global annual emissions, though a smaller share of per capita and historical emissions (Figure 6). By 2030, MICs and LICs are expected to account for 66 percent of global BAU CO_2 emissions, up from 44 percent in 1990. They will also account for 54 percent of cumulative historical emissions, up from 39 percent in 1990.

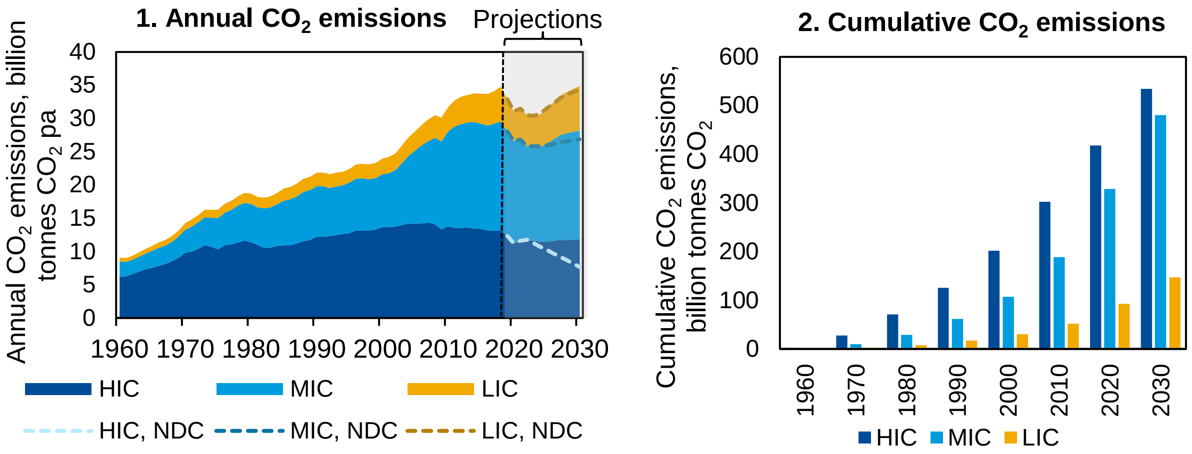
Figure 5. Comparing Recent and Previous CO_2 Emissions Projections



Source: IMF staff using the IMF-WB Climate Policy Assessment Tool.

Note: 2021 projections are from Black and others (2021). CO_2 = carbon dioxide; HIC = high-income country; LIC = low-income country; MIC = middle-income country; pa = per annum.

Figure 6. Historical and Projected BAU Annual and Cumulative CO_2 Emissions



Sources: Friedlingstein and others (2022); UN Framework Convention on Climate Change (2021); and IMF staff using the IMF-WB Climate Policy Assessment Tool.

Note: Cumulative emissions from 1960, assuming a depreciation rate of 2 percent per annum (median estimate in the literature of range 1.6 to 2.8 percent) accounting for atmospheric CO_2 depreciation (see van den Berg and others 2020). CO_2 = carbon dioxide; HIC = high-income country; LIC = low-income country; MIC = middle-income country; NDC = nationally determined contribution; pa = per annum.

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[9] On the supply side, restricted imports of gas from Russia compound this effect for EU countries with impacts on global gas prices.

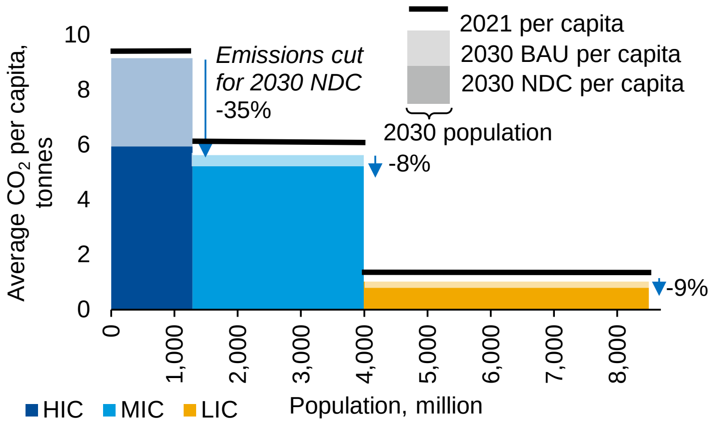
Developed countries have significantly enhanced their climate mitigation ambition (Figure 7). Collectively, HICs, MICs, and LICs have pledged to reduce their emissions 35, 8, and 9 percent, respectively, below BAU levels in 2030.[10] This compares to previous pledged reductions of 21, 3, and 5 percent, respectively, below 2030 BAU levels in first-round NDCs from 2015 (see also Black and others 2021). However, enhanced ambition is needed to narrow the global ambition gap, especially from developing countries. If pledged reductions were achieved, CO_2 emissions in HICs would fall to 6 tonnes per capita in 2030, almost at the level in MICs (5.2 tonnes per capita), though still six times the level in LICs.

Enhanced Ambition Scenarios

There are various possibilities for integrating equity into the allocation of mitigation burdens across countries.[11] Annex 3 discusses several regimes that have been considered by policymakers and analysts and uses them to infer a “high equity” scenario for emissions reduction allocations under alternative temperature targets. Two further possibilities are considered. One defines efforts in terms of reducing the emission intensity of GDP, which gives more leeway to fast-growing countries. Targeting emission intensity reflects an approach used by some large emitters in their NDCs, but also allows quickly growing countries to turn around their economies more gradually than absolute emission reductions would.[12] The other is the international carbon price floor proposed by the IMF (Parry and others 2021; Chateau, Jaumotte, and Schwerhoff 2022) to facilitate an equitable scaling up of global mitigation action through coordination over minimum price floors differentiated according to countries’ income level. For a given emissions reduction allocation across countries, a further possibility for promoting equity is transfers from HICs to LICs.

This Note considers five enhanced ambition scenarios that achieve Paris temperature goals while respecting international equity. Three scenarios focus on a 2°C temperature target to consistently compare outcomes under alternative equity regimes for a given temperature goal. The remaining two scenarios scale emissions allocations to be consistent with more ambitious global goals of 1.8°C and 1.5°C. In all scenarios, reductions are considered relative to 2030 BAU emissions or to emissions intensity (rather than historical emissions) as this better accommodates fast-growing MICs and LICs (indeed some regimes allow some LICs to increase their absolute emissions to 2030). In each scenario, individual countries all follow the rule for their group.

Figure 7. CO_2 Emission Pledges versus BAU, 2030



Source: IMF staff.

Note: Areas on chart represent total group emissions (emissions per capita x population). CO_2 per capita vary significantly within the country groups, especially for MICs. BAU = business as usual; CO_2 = carbon dioxide; HIC = high-income country; LIC = low-income country; MIC = middle-income country; NDC = nationally determined contribution.

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[10] Comparing ambition relative to future BAU levels better reflects countries’ mitigation efforts as it allows for rising total emissions in MICs and LICs over the next decade.

[11] Technically, the most efficient solution to global mitigation is to implement a globally uniform carbon price and address equity through international transfers entirely. However, the political feasibility of such transfers is severely limited. In practice, a differentiation of global mitigation efforts by income levels, either through different quantitative targets (for example, on emission reductions or emission intensity reductions) or differentiated carbon prices, helps to reduce the needed international transfers.

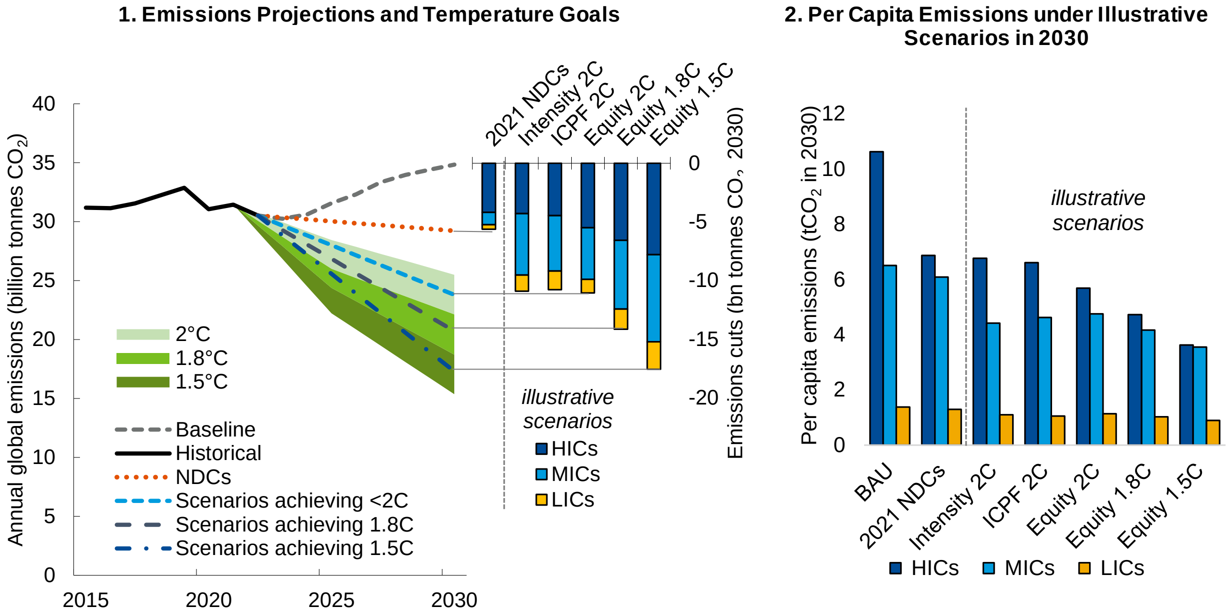
[12] Targeting emission intensity does however introduce large uncertainties in terms of absolute emission reductions if realized GDP growth deviates significantly from projected levels, suggesting the need for regular updating of intensity targets.

The scenarios are as follows:

- **Emission intensity reduction (“Intensity”) 2°C:** All HIC, MIC, and LIC countries cut their CO_2 emissions/GDP intensity by 36, 32, and 21 percent, respectively, relative to 2030 BAU.[13]
- **International carbon price floor (“ICPF”) 2°C:** All HIC, MIC, and LIC countries implement a minimum carbon price of \$75, \$50, and \$25 per tonne in 2030, respectively. This implies HICs, MICs, and LICs cut CO_2 emissions by 38, 29, and 24 percent below 2030 BAU, respectively.
- **High equity (“Equity”) 2°C:** HICs, MICs, and LICs reduce their CO_2 emissions below BAU levels by 46, 27, and 17 percent, respectively.
- **High equity 1.8°C:** To meet the more ambitious temperature target, emissions reductions for each country group from the 2°C high equity case are raised by around 9 percentage points.
- **High equity 1.5°C:** emissions reductions for each country group from the 1.8°C high equity case are raised by around 10 percentage points.

In all scenarios it is assumed that countries achieve the more stringent of their groups’ emissions reduction target or their existing NDC target. Additional scenarios consider transfer payments among countries and are discussed later.

Figure 8. Illustrative Options for Closing the Global Climate Ambition Gap (Annual and per Capita Emissions in High-, Low-, and Middle-Income Countries in 2030)



1. Emissions Projections and Temperature Goals

2. Per Capita Emissions under Illustrative Scenarios in 2030

Sources: Intergovernmental Panel on Climate Change (2022); and IMF staff using the IMF-WB Climate Policy Assessment Tool.
Note: Shows energy-related CO_2 emissions (exc. international aviation and maritime). CO_2 = carbon dioxide; Equity = high equity scenarios; HICs = high-income countries; ICPF = international carbon price floor; Intensity = emission intensity reduction; LICs = low-income countries; MICs = middle-income countries; NDC = nationally determined contribution.

The three 2°C scenarios would achieve 1.5 to 2°C with varying emissions reductions across country groups (Figure 8, panel 1). The 2°C scenarios (Intensity, ICPF, and Equity) would cut global CO_2 emissions by 31 percent compared with BAU, equivalent to a 27 percent cut on 2019 levels. The Intensity and ICPF scenarios are similar in their allocations across country groups, though they would vary within groups as countries have differing responsiveness to carbon pricing

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[13] For comparison, in the baseline between 2021 and 2030 the CO_2 emissions intensity of GDP declines 8, 41, and 49 percent in HICs, MICs, and LICs, respectively.

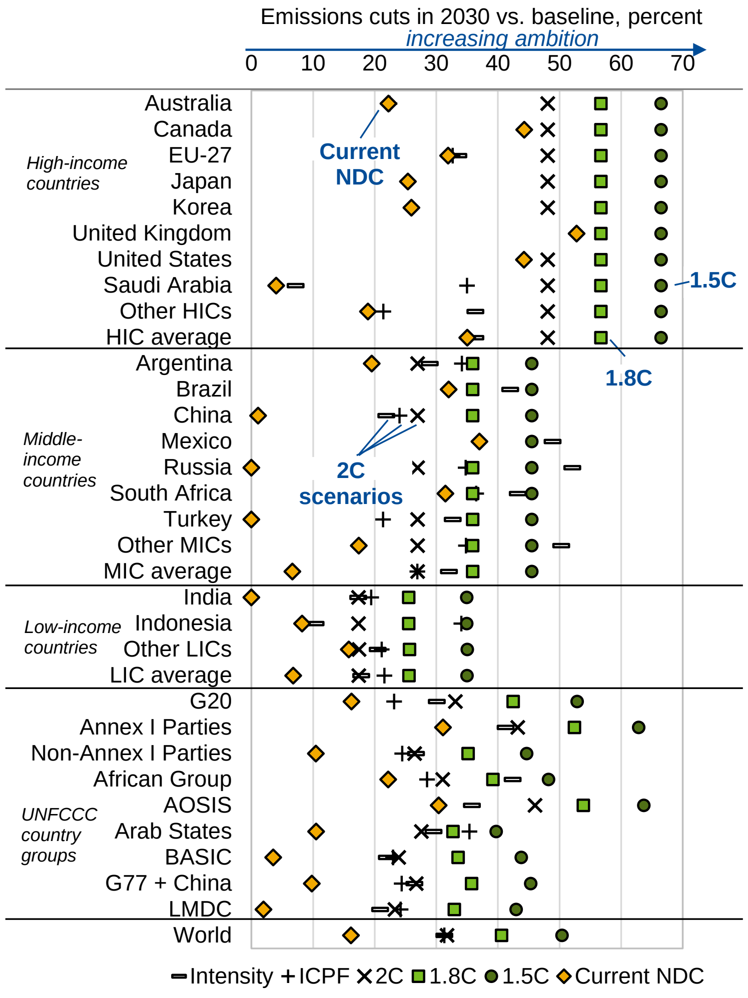
under the ICPF. The Equity scenario would allocate even more of the emissions cuts to developed compared with developing countries.

All scenarios imply some convergence in emissions per capita (Figure 8, panel 2). 2030 per capita emissions are broadly similar in HICs and MICs across the scenarios—indeed this is the case even when countries only meet their NDC commitments—while the difference between HIC/MIC and LIC per capita emissions is progressively reduced with the more stringent temperature scenarios. Emissions per capita of LICs also decline (relative to 2030 baseline levels) but only moderately.

Stabilizing the climate at lower temperatures would require more drastic emissions cuts. The 1.8°C and 1.5°C scenarios would cut global emissions by 37 and 47 percent compared with 2019 levels, necessitating substantial further increases in climate ambition across all countries. For example, the 1.5°C scenario would imply emission cuts of 67 and 43 percent for HICs and MICs on 2019 levels. This pushes the bounds of feasibility, especially for HICs. At COP26, countries resolved to pursue efforts to limit warming to 1.5°C,[14] but further delays in action would likely put this temperature goal beyond reach.

For Group of Twenty (G20) countries, the emissions reductions needed across these scenarios are shown in Figure 9. For many countries, 2030 NDC pledges are not yet aligned with 2°C, and the shortfalls tend to be larger for MICs and LICs than for HICs**.** The analysis here converts all pledges into an absolute emissions target for 2030 and compares these targets with the model's BAU emissions projections, which provides a consistent cross-country comparison of effective mitigation ambition. NDCs are not currently binding in some MICs and LICs, while on the other hand South Africa's NDC is already consistent with the 2°C scenario. It is also possible that some countries may go beyond their existing targets with current policies (for example, India).

Figure 9. Current and Illustrative CO_2 Emissions Cuts for G20 and Country Groups versus 2030 BAU



Sources: IPCC (2021); and IMF staff using the IMF-WB Climate Policy Assessment Tool.

Note: In some country cases, the 2°C scenarios are not visible as the NDC is the binding constraint. AOSIS = Alliance of Small Island States; BASIC = Brazil, South Africa, India, China; BAU = business as usual; CO_2 = carbon dioxide; G20 = Group of Twenty; G77 = Group of 77; HICs = high-income countries; ICPF = international carbon price floor; LICs = low-income countries; LMDC = Like-Minded Developing Countries; MICs = middle-income countries; NDC = nationally determined contribution; UNFCCC = UN

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[14] See Glasgow Climate Pact, article IV.21, 2021: https://unfccc.int/sites/default/files/resource/cma2021_10_add1_adv.pdf.

Current ambition among all eight selected UN Framework Convention on Climate Change country and negotiating groups falls short of what's needed for 2°C (Figure 9). These groups include, for example, Annex I and non-Annex I parties (advanced and developing countries), the African Group, the Alliance of Small Island States, Arab States, and Like-Minded Developing Countries. In addition, only about one-third of Parties to the Paris Agreement have substantively enhanced their climate ambition since 2015.

Cost Assessment

Assumed Mitigation Instrument: Carbon Pricing

Least-cost mitigation strategies implemented through comprehensive carbon pricing are considered for an illustrative benchmark. Pricing is cost-effective as it imposes a uniform price on CO_2 emissions, which promotes equalization of incremental abatement costs across fuels and sectors. Previous IMF work showed that the costs of mitigation strategies could be larger to the extent countries rely instead on packages of less efficient (but perhaps more acceptable) sectoral-based instruments like regulations, feebates, and clean technology subsidies as under these approaches there may be significant disparities in incremental abatement costs across sectors and fuels.[15] From a modeling perspective, however, the extra costs are difficult to pin down without more specifics on alternative policy packages to meet a given ambition target and the least cost benchmark provides a consistent cross-country comparison.

Figure 10. CO_2 Intensity of GDP in 2030 BAU

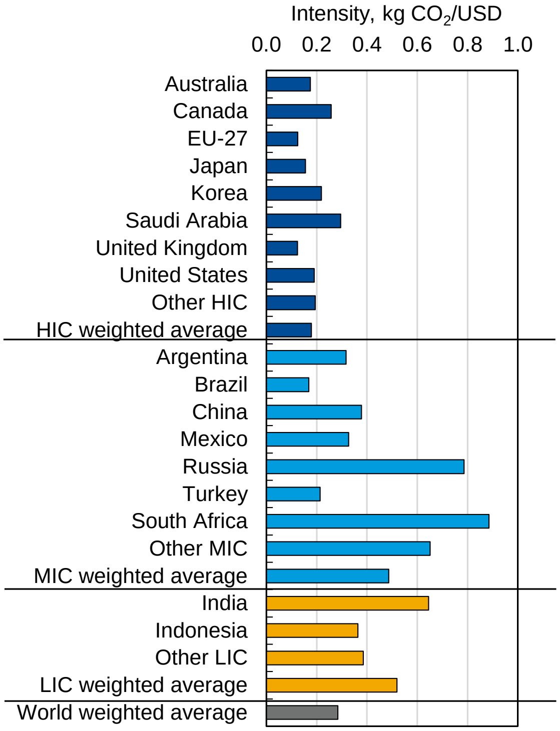
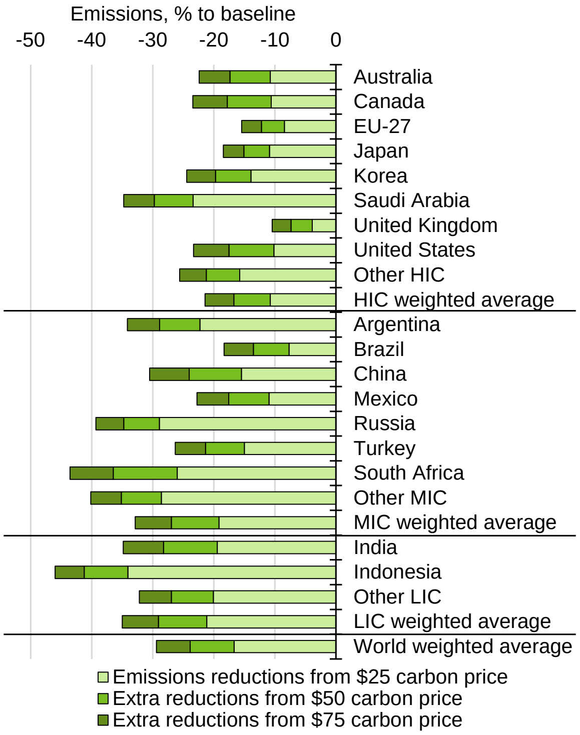


Figure 11. CO_2 Emissions Impacts from Carbon Pricing, G20 Countries, 2030



Source: IMF staff using the IMF-WB Climate Policy Assessment Tool.
Note: BAU = business as usual; CO_2 = carbon dioxide; HICs = high-income countries; LICs = low-income countries; MICs = middle-income countries.

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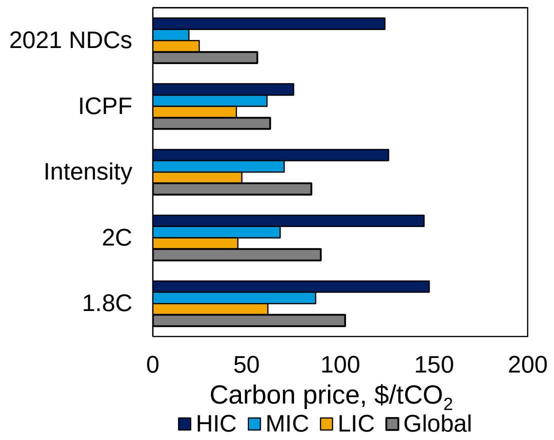
[15] See IMF (2019a), Table 1.4, for estimates of the costs of alternative policy packages relative to the costs of carbon pricing for G20 countries. Chateau, Jaumotte, and Schwerhoff (2022) compare GDP impacts of mitigation policies. In the electricity sector, regulation and feebates can achieve the same emission reductions at only moderately higher GDP cost compared to carbon prices when there is ample opportunity for fuel switching.

One key driver of abatement costs is the CO_2 intensity of GDP, which differs substantially across groupings and countries (Figure 10). Higher BAU CO_2 intensity implies a larger absolute emission cut from a given percent emissions reduction. Emissions intensity in 2030 is much higher in developing countries than developed countries. However, there is large variation within the groups, especially due to the varying levels of coal use in power generation which, for example, is high in South Africa and China but lower in Brazil and Mexico.

Another key driver of costs is the price responsiveness of emissions (Figure 11). The lower the cost of cutting emissions by a given amount, the greater the responsiveness of emissions to pricing (or other measures). A $50 carbon price, for example, cuts HIC, MIC, and LIC emissions by 17, 27, and 29 percent below BAU levels, respectively. Again, there is considerable variation within the country groups. Emissions price responsiveness tends to be relatively high in countries where a large share of BAU CO_2 emissions comes from coal, because coal has high emissions intensity and is usually relatively cheap to substitute with renewables and other cleaner fuels.

The global average carbon price consistent with the 2°C scenarios is around $80 per tonne, while that for the 1.8°C scenario is $100 per tonne (Figure 12). The 2°C-aligned global prices are in line with previous assessments[16] though are sensitive to BAU energy price projections and price responsiveness assumptions. Prices for HICs, MICs, and LICs are on average $115, $65, and $45, respectively, across the different 2ºC scenarios. Less confidence should be placed in the estimates of needed carbon prices for more stringent temperature targets due to the high uncertainties,[17] and for this reason carbon prices and costs for the 1.5°C scenario are not reported here.

Figure 12. Implied Carbon Prices by Scenario, 2030



Source: IMF staff using the IMF-WB Climate Policy Assessment Tool.
Note: Weighted by BAU emissions in 2030. BAU – business as usual; CO_2 = carbon dioxide; HICs = high-income countries; LICs = low-income countries; MICs = middle-income countries; NDCs = nationally determined contributions; tCO_2 = tonnes of CO_2.

Mitigation Burdens: Economic Welfare Costs

Mitigation burdens are calculated in this section based on principles of welfare economics, which is the standard approach to measuring policy costs among economists.[18] For current purposes, welfare costs have three key components (see Box 1) which are estimated for 170 countries using the CPAT model (Annex 1): *pure abatement costs*, *potential fiscal benefits*, and *domestic environmental co-benefits*—the latter two components reduce welfare costs and may change the sign of the welfare cost. Welfare costs are calculated and then divided by GDP, but they can differ significantly from GDP impacts (see the following).

At the global level, abatement costs—before considering revenue recycling and co-benefits—are around 0.4 percent of GDP for 2°C and 0.8 percent for 1.8°C, with costs generally higher for higher-income countries (Figure 13, panel 1). Global emissions reductions are about 25 percent higher in the 1.8°C than the 2°C scenario, but pure abatement costs are about 40 percent

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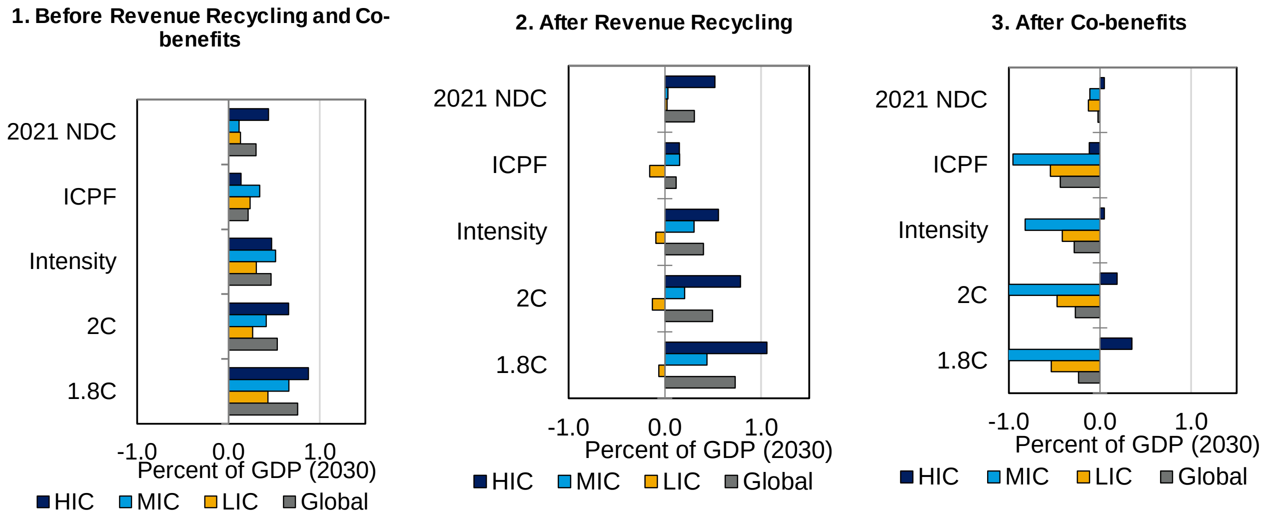
[16] See Black and others (2021), IMF (2019a), and High-Level Commission on Carbon Prices (2017). BAU emissions for 2030 are lower here compared with earlier studies but counteracting factors include the need for slightly more stringent global emissions targets in 2030 due to continued depletion of the "carbon budget" and updating nominal carbon prices for inflation.
[17] For example, very high carbon prices could induce nonlinear adoption of new technologies like carbon capture and storage and direct air capture, but the future practicality and costs of deploying these technologies are highly speculative at present.
[18] See Just, Hueth, and Schmitz (2005). Technically, welfare cost is the value of resources society gives up for all the different actions taken to reduce CO_2 emissions. The welfare cost concept has been endorsed by governments around the world for evaluating regulations, investments, taxes, and other policies.

larger—this reflects progressive exhaustion of low-cost mitigation opportunities (or upward sloping marginal abatement costs—see Box Figure 1.1). And although MICs tend to have higher BAU CO_2/GDP intensity than HICs, often this is more than offset by their lower percent CO_2 reduction requirements and generally lower carbon prices needed to achieve a given percent CO_2 reduction. In the high equity 2°C scenario, for example, abatement costs for HICs, MICs, and LICs are 0.7, 0.4, and 0.3 percent of GDP, respectively.

However, when considering benefits from revenue recycling and co-benefits, total welfare costs become moderately negative for most groups and scenarios (Figure 13, panels 2-3). Potential fiscal benefits substantially reduce welfare costs for MICs and LICs (where there is limited erosion of the base for carbon pricing), while domestic environmental co-benefits imply further substantial reductions in welfare costs in all cases**.** For example, in the 2°C scenarios, potential fiscal benefits reduce welfare costs for MICs around 60 percent and for LICs over 100 percent, while interactions with the broader tax system modestly increase costs for HICs (see Figure 14, panel 2).

Figure 13. Welfare Costs under Alternative Ambition Scenarios by Country Grouping in 2030



Source: IMF staff using the IMF-WB Climate Policy Assessment Tool.
Note: Shows welfare costs (panel 1) before revenue recycling, after revenue recycling (panel 2), and including domestic co-benefits such as health benefits from improved air quality and road safety (panel 3). Co-benefits do not include climate benefits. HICs = high-income countries; ICPF = international carbon price floor; Intensity = emission intensity reduction; LICs = low-income countries; MICs = middle-income countries; NDCs = nationally determined contributions.

These results largely reflect the differing scale of emissions reductions across the country groupings which affects the size of fiscal benefits relative to pure abatement costs.[19] The results also account for an additional, economy-wide cost, as the slight contraction in economic activity in response to higher energy prices slightly reduces work effort and investment, compounding the adverse effect of tax distortions in factor markets (Box 1).

Domestic environmental co-benefits are large for all country groups and climate benefits are very large at the global level. Domestic co-benefits are, especially for MICs, largely due to human health improvements from reduced local air pollution in heavily polluted cities. Overall (see Figure 13, panel 3), global welfare costs are slightly negative (that is, there are net benefits) at –0.25 percent of GDP across the 2°C scenarios. Climate benefits are not included as they are not estimated at the country level, but at the global level they swamp abatement costs (Box 1).

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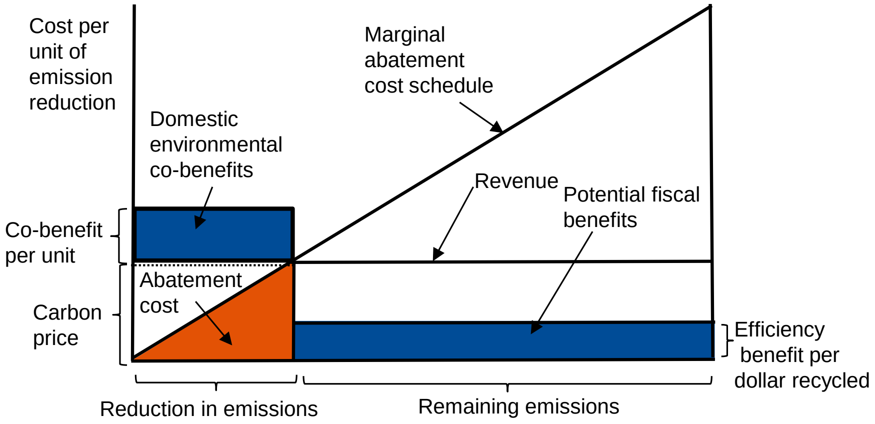
[19] See Box Figure 1.1. Indeed, beyond a point revenue starts to decline with further increases in carbon pricing (in the limit revenues approach zero as emissions reductions approach 100 percent).

Box 1. Economic Welfare Impacts of Carbon Pricing

The welfare impacts of carbon pricing have three key components, as depicted in Box Figure 1.1:

Box Figure 1.1. Components of Welfare Costs and Benefits



Source: IMF staff
Note: Fiscal benefits will be smaller to the extent some revenue is used in ways (for example, lump-sum transfers) that do not increase economic efficiency.

Pure abatement costs. These reflect (1) (most importantly) the annualized costs of adopting cleaner but more expensive technologies, net of any savings in lifetime energy costs and avoided investment in emissions intensive technologies; and (2) the costs to households and firms from reduced energy use. Pure abatement costs largely reflect integrals under marginal abatement cost schedules[20] and, at least for more moderate levels of emissions reduction, are measured with reasonable confidence. Marginal abatement costs may however overstate pure abatement costs in various regards (see Annex 4).

Potential fiscal benefits. These reflect economic efficiency gains from productive use of carbon pricing revenues—that is, revenue raised times the efficiency benefit per dollar recycled. This component is smaller if some revenue is instead used for transfers—for example, compensating the bottom 20 and 40 percent of low-income households under carbon pricing requires around 10 and 30 percent of revenues raised, respectively.[21] The analysis is illustrative, given uncertainties over how revenues would be used in practice, and assumes countries use 70 percent of revenues productively. In middle-income and low-income countries, this takes the form of productive public investment,[22] and in high-income countries cutting labor income taxes—the latter form of recycling promotes work effort and discourages informality and other inefficient tax-sheltering behavior. At the same time, there is an offsetting effect as higher production costs and consumer prices lower the real returns to work effort and investment, which can deter labor supply and investment. The latter effect can dominate the former at higher levels of emissions abatement when the tax base for carbon pricing is narrower. See Annex 1 for further discussion.

Domestic environmental co-benefits. These reflect, most notably, reductions in local air pollution from less combustion of fossil fuels—total co-benefits are the emission reduction times the co-benefit per tonne of carbon dioxide reduced. Co-benefit estimates here are based on detailed country level estimates.[23] Climate benefits from cutting emissions are not included in co-benefits as they vary substantially across countries. However, studies suggest these benefits would swamp the pure abatement costs at the global level.[24]

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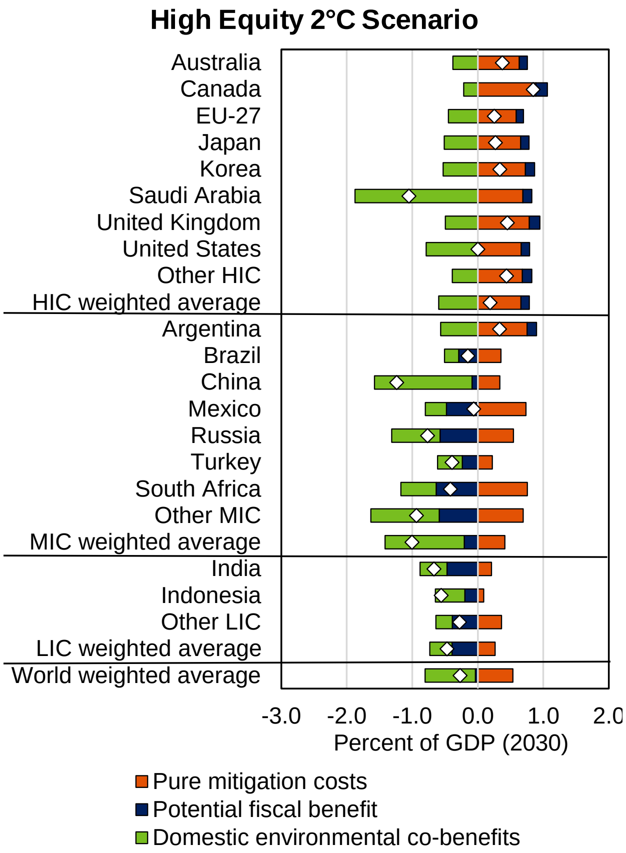
[20] Pre-existing fuel taxes (or subsidies) are included and imply marginal abatement cost curves have positive (negative) intercepts.
[21] IMF (2019a, 2019b).

Within country groupings, disparities in pure abatement costs are more pronounced among MICs and LICs than HICs (Figure 14). For example, pure abatement costs are 0.6 to 0.9 percent of GDP among HICs in the high equity 2°C scenario, respectively, though most of these costs are offset by domestic environmental co-benefits.[25] Among MICs, pure abatement costs vary from 0.2 percent of GDP (Turkey) to 0.8 percent (South Africa), though potential fiscal benefits and domestic environmental co-benefits imply negative welfare costs in almost all cases.

Figure 14. Welfare Costs after Co-benefits under Alternative Ambition Scenarios by Country, 2030



Source: IMF staff using the IMF-WB Climate Policy Assessment Tool.

Note: Group averages weighted by emissions in 2030. HIC = high-income countries; LIC = low-income countries; MIC = middle-income countries.

Mitigation Burdens: GDP

GDP impacts differ from welfare costs in several regards. Welfare costs focus on changes in the level of consumption, while GDP also includes changes in the levels of investment and net exports but excludes domestic environmental co-benefits. On net exports, these can change due to (1) downward pressure on demand for fossil fuels due to global decarbonization, which adversely affects energy exporters; and (2) impacts of carbon mitigation policies on the competitiveness of energy-intensive, trade-exposed industries, though countries usually implement measures (like free allowance allocations) to limit competitiveness impacts. To an approximation, changes in net exports wash out at the global level, but these changes can be significant at the domestic level.[26]

Evidence on both the magnitude and the sign of the GDP impacts of carbon pricing and mitigation policy are unsettled. Besides the form of revenue recycling, GDP effects are sensitive to assumptions about how mitigation policy affects the allocation of investment across sectors and time, demand and supply elasticities in world energy markets, the future availability of low-carbon technologies, and the rate at which learning-by-doing lowers their costs, all of which are difficult to pin down. Estimates also vary depending on whether policies are assumed to be budget neutral or

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[22] A large amount of productive investment is needed for countries to achieve their Sustainable Development Goals (Gaspar and others 2019), but revenue from broader fiscal instruments is often constrained by extensive informality and public borrowing is subject to a premium. The calculations here assume investments have benefit cost ratios of 1.33.

[23] See Parry and others (2022) on methodologies. Co-benefits also include reductions in traffic congestion and accident externalities from higher road fuel prices.

[24] Rennert and others (2022) put the discounted flow of global climate benefits at $185 per tonne of CO_2 reduced. Under a global carbon price of $75 per tonne, this would imply climate benefits that are five times the pure abatement costs (IMF staff calculations).

[25] Co-benefits are notably large for Saudi Arabia where a disproportionately large share of emissions reductions come from reducing oil use and the combined local environmental externalities (air pollution, congestion, accidents) can be relatively large.

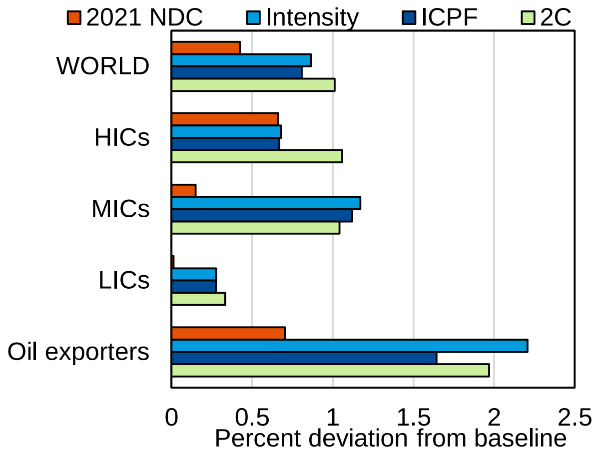
[26] Impacts of mitigation policies on inflation are beyond the scope here; however, inflationary impacts should be negligible if policies are implemented immediately, progressively, and credibly (IMF 2022d).

involve a fiscal expansion financed by debt. For example, studies by the IEA and OECD suggest that with clean energy investment, decarbonization policies can significantly boost global GDP over the medium to longer term; the most recent IPCC report finds that mitigation pathways aligned with the 2ºC temperature goal would moderately reduce GDP, while an earlier IMF study suggests mixed results for 2030 (see International Energy Agency 2021; IMF 2020; IPCC 2022; OECD 2017). At the national level, a review of computable general equilibrium models found that just over half of studies showed increases in GDP from carbon pricing (Freire-González 2018; see also Bernard and Kichian 2018; Bretscher and Grieg 2020; review in Heine and Black 2019). Ex post empirical studies decomposing the effects of climate policies on GDP find either zero or small positive impacts of reforms implemented in Europe and North America (see Metcalf and Stock 2020; Azevedo and others 2022; Metcalf 2019).

With these uncertainties in mind, this section uses the IMF-ENV model to estimate GDP impacts for key countries and country groupings. A key attraction of IMF-ENV is that it accounts for changes in investment, international fuel prices, and trade patterns for energy-intensive, trade-exposed industries induced by global mitigation policies. The model distinguishes 19 individual countries and groups other countries into six regional aggregates. The model also captures the costs of reducing all GHG emissions, including non-CO_2 emissions which account for 30 percent of GHG emissions globally. See Annex 1 for further details. In reporting GDP effects, the country groupings for HICs, MICs, and LICs roughly correspond to those used earlier, but in addition impacts on oil-producing countries are separated out. The simulations are run for budget-neutral policies. Carbon pricing revenues are assumed to reduce labor taxes though other possibilities are considered later (see Figure 18). As discussed in Annex 2, the differences between welfare costs and GDP impacts mostly reflect conceptual factors rather than differences in underlying assumptions between the CPAT and IMF-ENV models.

Global GDP costs are around 0.8 of BAU GDP by 2030 for the 2°C scenarios, with proportionate GDP losses moderately larger for MICs and more so for oil producers (Figure 15). Although GDP losses are larger than welfare costs (see the following), in the context of economic growth the global losses are manageable—even a 1 percent GDP loss in 2030 is equivalent to a reduction in annual global GDP growth (projected to average about 3 percent a year to 2030) of only around 0.1 percentage point. These estimates are in line with those recently released in IMF (2022d). For MICs, GDP losses vary from 1 percent in the high equity 2°C scenario to 1.2 percent in the Intensity scenario. GDP losses are much smaller for LICs at around 0.3 percent, but much higher for oil producers at 1.6–2.2 percent. Of the three scenarios considered, the high equity 2°C scenario is the most progressive—because it shifts some of the mitigation burden from MICs to HICs compared with the other scenarios. From a global perspective, the ICPF scenario is the most efficient, as measured by a lower GDP cost, because the common carbon price by income group targets the emission reductions to where they are cheaper.

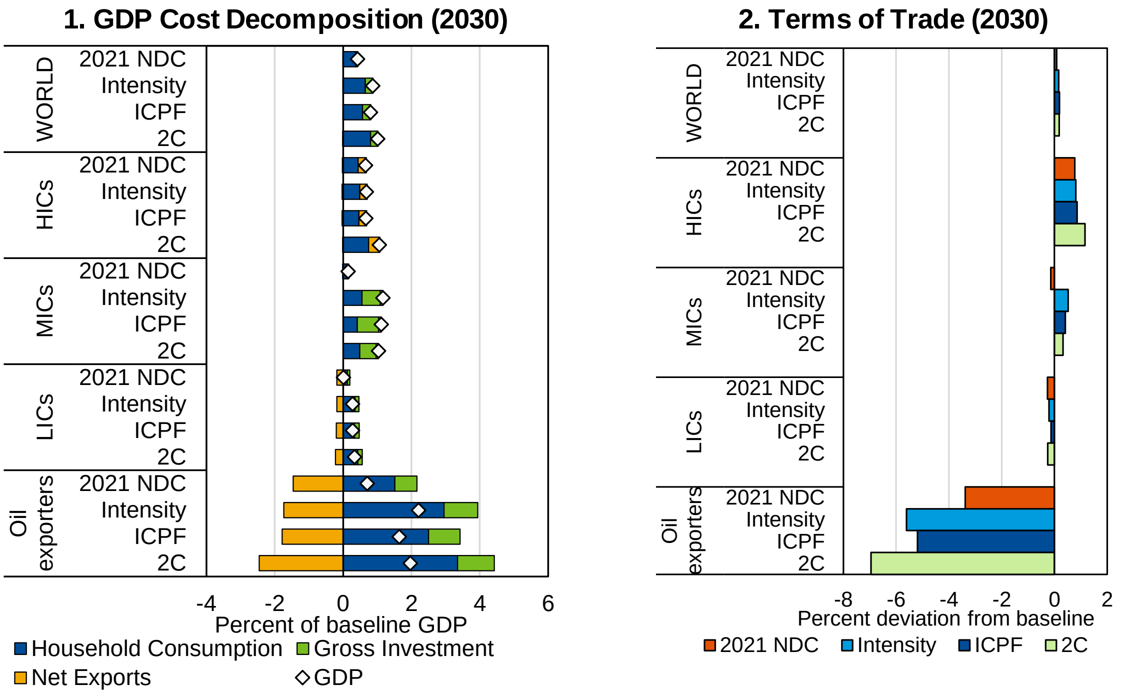
Figure 15. GDP Costs under Alternative Ambition Scenarios by Country Grouping in 2030



Source: IMF staff using IMF-ENV.
Notes: 2C = High equity 2°C consistent scenario ; HIC = high-income countries; ICPF = international carbon price floor; Intensity = emission intensity reduction; LIC = low-income countries; MIC = middle-income countries. NDC = nationally determined contribution.

GDP costs are larger than pure abatement costs because of reductions in investment (especially in MICs and oil producers) and trade effects (especially in oil producers; Figure 16). Investment falls to the extent production levels fall in the power and industry sectors (reductions in the emissions intensity of production generally reflect a redirection of investment to cleaner capital). In MICs, coal is often used intensively in power generation and industry, and therefore carbon pricing has a proportionately bigger impact on production costs. This production/investment effect could to some extent be offset by using carbon pricing revenues for output-based rebates for power/industrial firms, or using other instruments like tradable performance standards or feebates in place of carbon pricing.[27] For the oil producers—besides high carbon intensity and high share of fossil electricity—there is also a deterioration of their terms of trade from lower international demand for oil, especially for high-cost producers, which translates into lower income, reducing private consumption and investment. Real net exports increase but this reflects that import volumes reduce more than exports, offsetting some of the decline in GDP.[28]

Figure 16. GDP Cost Decomposition under Alternative Ambition Scenarios by Country Grouping in 2030



Source: IMF staff using IMF-ENV.
Note: Terms of trade is a GDP weighted average for the countries in the region. 2C = High equity 2°C consistent scenario ; HIC = high-income countries; ICPF = international carbon price floor; Intensity = emission intensity reduction; LIC = low-income countries; MIC = middle-income countries; NDC = nationally determined contribution.

GDP impacts can differ substantially within country groupings (Figure 17). For example, within MICs GDP impacts for the high equity 2°C scenario are 1.5 percent in Mexico (an energy exporter), 1.1 percent in China, 0.5–0.7 percent in Argentina and Brazil (relatively decarbonized power sectors), 0.6 percent in South Africa (heavy coal dependence), and even a marginal gain of 0.03 percent in Turkey. For China—which has an outsize influence on the MIC group—half of the GDP

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[27] These strategies cost-effectively reduce the emissions intensity of production, though pure abatement costs would be somewhat higher than for pricing, given they do not promote the same reduction in production.

[28] Macroeconomic models project that the current account of oil producers as a percent of GDP would improve as investment would fall much more than saving (see IMF 2022a). In the IMF-ENV model, this results from an assumption ("closure rule") of unchanged nominal current account balance which translates into an increase of net exports-to-GDP given the decline in GDP relative to baseline (see Annex 1 for more details). As a group, oil producers could impose a coordinated carbon tax on oil exports to appropriate revenues and partially offset GDP losses (IMF 2019a, Annex 1.10).

loss reflects reduced investment. In practice, however, the GDP cost in China is likely lower than shown here, because overcapacity exists in some sectors of the Chinese economy and drawing down these overcapacities would be less harmful in terms of GDP than reflected by the models.

Figure 17. GDP Costs under High Equity 2°C Scenario by Country, 2030

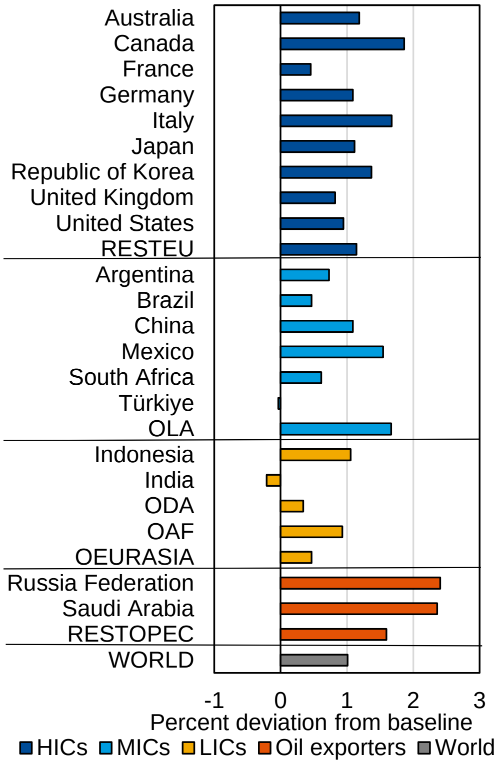
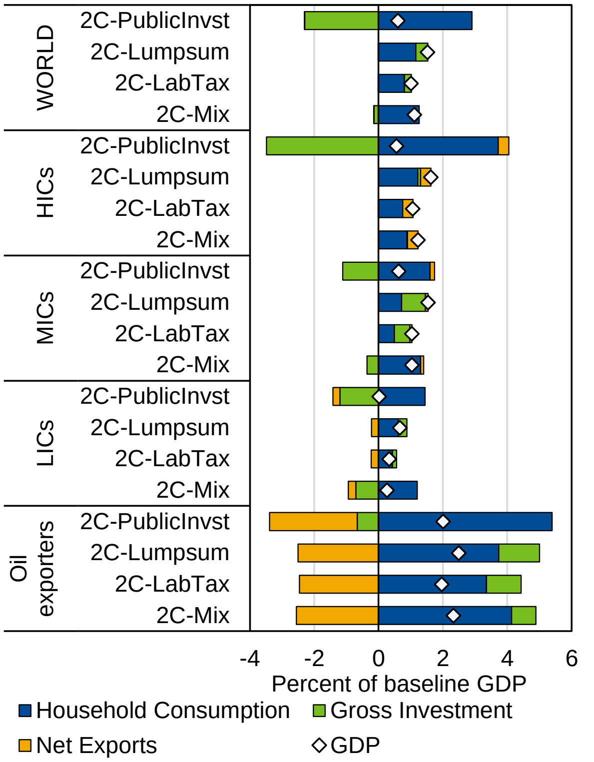


Figure 18. GDP Costs under High Equity 2°C Scenario and Alternative Recycling Schemes by Country 2030



Source: IMF staff using IMF-ENV.

Note: 2C = scenarios achieving 2°C; HIC = high-income countries; LIC = low-income countries; MIC = middle-income countries; OAF = Africa (except South Africa); ODA = other East Asia and New Zealand; OEURASIA = other Eastern Europe and Caspian countries; OLA = other Latin America; RESTEU = rest of European Union and Iceland; RESTOPEC = other oil-exporting countries.

In short, GDP costs may be less progressive across countries than welfare costs (reflecting additional components in the former which disproportionately affect MICs and oil producers) though GDP impacts can be reduced through productive revenue use (Figure 18). Among the considered options, the global GDP costs are the least when revenues are used to fund productive public investments, while costs are largest when revenues are recycled as lump sum transfers to households.[29] Lump sum transfers to households or other affected groups may be helpful to manage the political economy of climate policy, but investments and a reduction in labor taxes are more efficient. Under the high equity 2°C scenario GDP losses fall to 0.6 and 0.02 percent for MICs and LICs, respectively, if revenues fund public investments (implying a net increase in investment overall). In contrast, if revenues fund lump sum transfers, GDP losses for MICs and LICs increase to 1.5 and 0.7 percent, respectively. Costs in the 2C-Mix[30] scenario fall between the range from full public investments and lump sum transfers for all income groups.

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[29] The size of generated carbon revenues varies by income groups due to differentiated emission reduction goals. Under the 2C scenario, carbon revenues generated in HIC, MIC, and LIC regions are equal to 3, 2, and 2 percent of GDP, respectively.

[30] In 2C-Mix, all countries allocate 30 percent of carbon tax revenues toward lump sum transfers to households. The remaining 70 percent is used to reduce distortionary wage taxes in HICs while MICs and LICs use it as public investments.

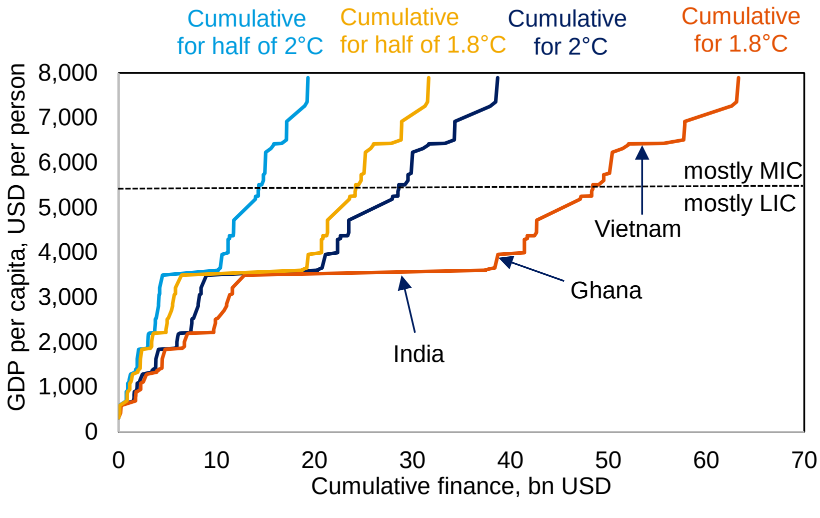
Climate Finance

Climate finance can promote equitable emission reduction regimes without increasing global abatement costs. Scaling up public and private sources of climate finance is critical to addressing climate change (IMF 2022c). At present, HICs pledged to mobilize $100 billion a year from 2020 onwards in climate finance for developing countries.[31] However, estimates of current annual flows fall about one-fifth short of this target. Additionally, a large portion of the finance is from multilateral development banks and private sources, much of it is lending rather than transfers, and the pledge covers financing for adaptation as well as mitigation. Hence current bilateral transfers from HIC government budgets for mitigation in developing countries amount to around $10 billion a year.[32] This subsection discusses how finance could be used to compensate lower-income countries under different scenarios and how such transfers would alter GDP impacts on different income groups.

Abatement costs may be a more appropriate metric for informing dialogue over climate finance than GDP effects. The former is directly related to the costs of shifting away from fossil-based technologies to low-carbon technologies and is estimated with a reasonable degree of confidence—in contrast, GDP effects are sensitive to, for example, domestic fiscal objectives for revenue use.

For illustration, Figure 19 indicates the scale of transfers that would be implied under alternative scenarios for compensating LICs and lower-income MICs for their pure abatement costs. These scenarios include the 2°C and 1.8°C high equity regimes and cases where countries are compensated for 50 and 100 percent of their pure abatement costs. For example, fully compensating all LICs (with per capita income below $5,500) for their pure CO_2 abatement costs under the 2°C scenario would require annual transfers of about $30 billion, while compensating for their abatement costs in the 1.8°C scenario would cost about $50 billion. When total GHG abatement costs (all sources including land use, land-use change, and forestry) are accounted for, with mitigated non-CO_2 emissions being disproportionately higher in LICs, annual transfers of about $60 billion would be needed to fully compensate them under the 2°C high equity scenario. The total amount of transfers needed can be negotiated by countries based on several factors like differences in sources of emissions and GHG coverage. Therefore, the two transfer values of $30 billion and $60 billion are chosen to illustrate differences between the CO_2-only abatement costs and full GHG abatement costs for LICs.

Figure 19. Climate Finance Needed under Alternative Scenarios to Compensate MICs and LICs for CO_2 Abatement Costs, 2030



Source: IMF staff using the IMF-WB Climate Policy Assessment Tool.
Note: Countries are indicated for illustration only. Excludes OPEC countries and China. 1.8C = 1.8°C; 2C = High equity 2°C consistent scenario ; LIC = low-income countries; MIC = middle-income countries; bn=billion.

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[31] Climate finance is distinct from “loss and damage,” which refers to proposed compensation for countries’ climate damages.

[32] IMF staff calculation using Organisation for Economic Co-operation and Development (OECD 2022).

The GDP effects of budgetary contributions to recipient, and from donor, countries can differ from the pure amount of the transfer. GDP impacts will depend on the size of transfers relative to GDP and how they are used in recipient countries. For example, if transfers fund productive public investment, this will directly boost GDP, while if they increase households' disposable income this will increase demand for goods and services which in turn affects domestic production, imports, and exports. The main purpose of the transfers, however, is to ensure global equity irrespective of how they are used. In the illustrative simulations that follow, the international transfers are assumed to be distributed as lump sum payments to households.

Annual transfers in 2030 from HICs to MICs/LICs of $30 and $60 billion, respectively, are considered, using the high equity 2ºC scenario, under three allocation rules:

- *2C-Ability&Need:* HICs (excluding oil producers) contribute in proportion to their share in total HIC BAU emissions while MICs and LICs receive transfers in proportion to their population shares. Among MICs, recipients include only countries that either expressed a need for financial support in any round of NDCs (for example, Argentina, Brazil, and Mexico) or have already received financial support for climate action from HICs (for example, South Africa and Turkey).
- *2C-Compensate:* HIC contributions and the selection of potential recipients are the same as previously stated. However, for recipients, starting from the poorest country, transfers are made in the amount equivalent to the full abatement cost of the country and until cumulatively $60 billion (or $30 billion) are disbursed. All LICs are compensated with the $60 billion mark while $30 billion is sufficient to fully compensate Africa (except South Africa) and India, and partially compensate Indonesia for about three quarter of total GHG abatement costs.
- *2C-RR*: This option is based on the Raghuram Rajan's proposal, which applies to all countries.33 In this case, countries either contribute or receive funding in proportion to the difference between their per capita emissions and the global average per capita emissions scaled by an emissions price and regional population. The globally implied carbon price here is set at $4 per ton of CO2, which implies total transfers of $60 billion.

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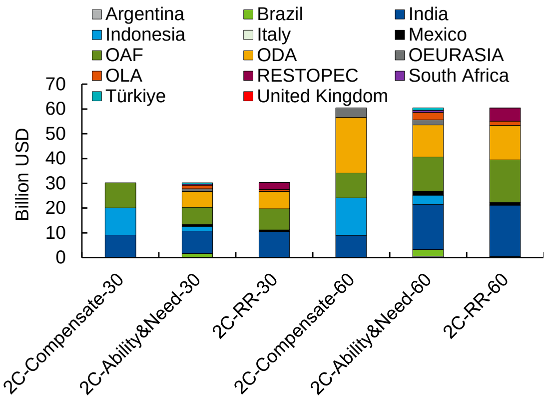
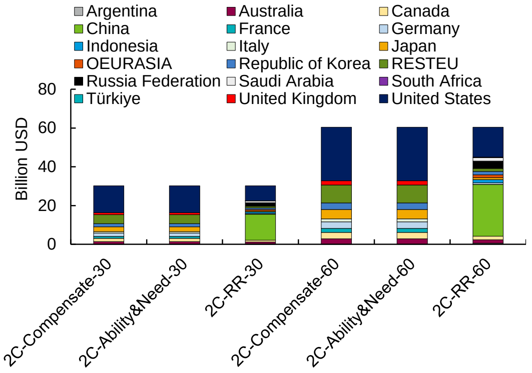
Figure 20. Total Transfers

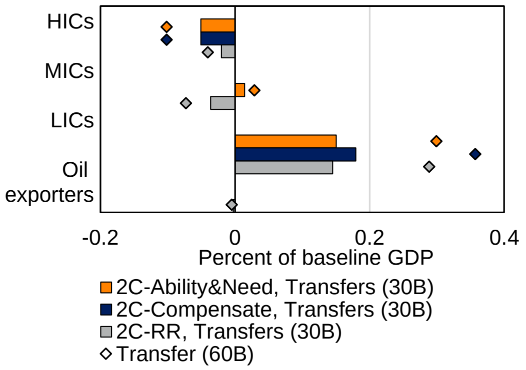
1. Transfers Received (2030)



2. Contributions (2030)



3. Transfers in 2030



Source: IMF staff using IMF-ENV.
Note: HICs = high-income countries; LICs = low-income countries; MICs = middle-income countries; OAF = Africa (except South Africa); ODA = other East Asia and New Zealand; OEURASIA = other Eastern Europe and Caspian countries; OLA = other Latin America; RESTEU = rest of European Union and Iceland; RESTOPEC = other oil-exporting countries.

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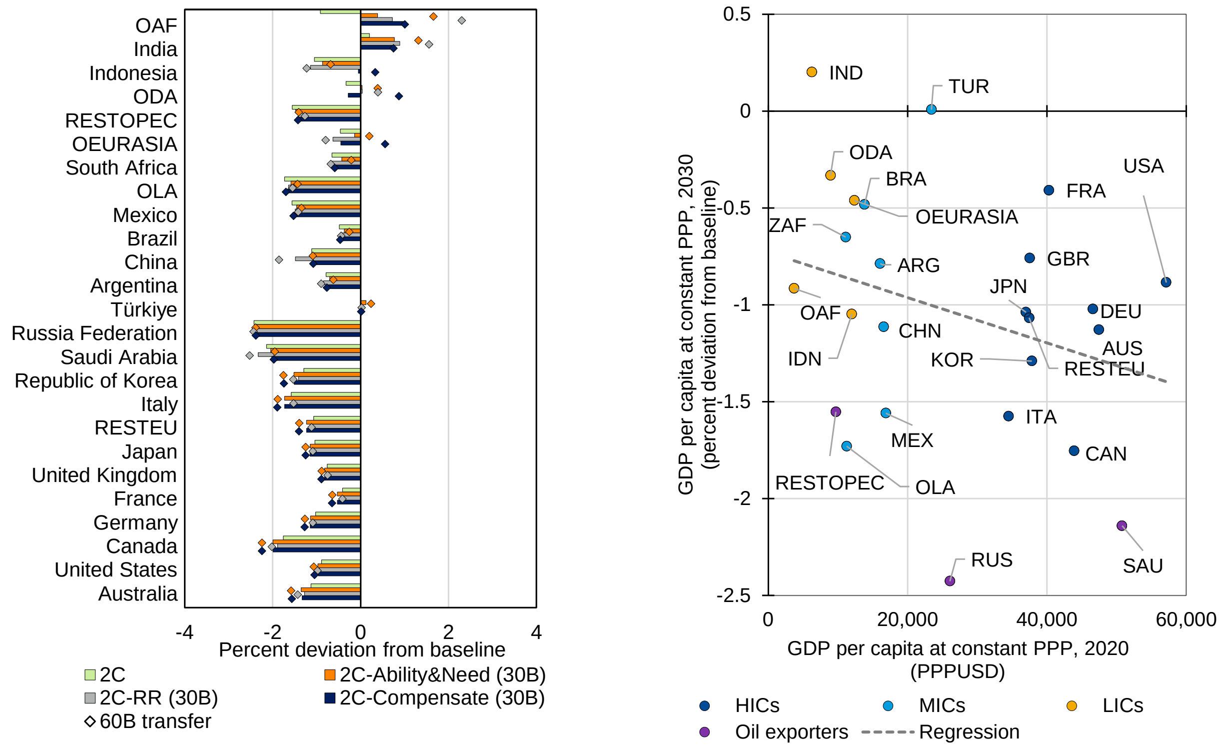
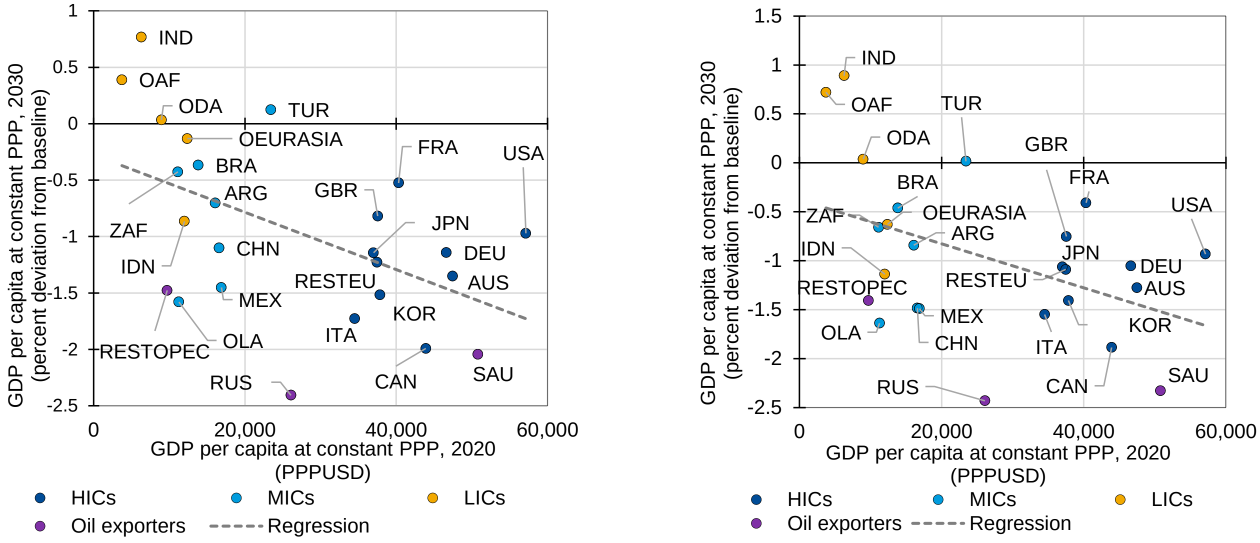
[33] https://www.project-syndicate.org/commentary/global-carbon-incentive-for-reducing-emissions-by-raghuram-rajan-2021-05.

Figure 21. Progressivity in costs with international transfers



1. GDP change for 2C scenario with different transfer scenarios (2030)

2. GDP change as a function of income level in 2C scenario without transfers (2030)



3. GDP change as a function of income level in 2C-Ability & Need scenario (2030)

4. GDP change as a function of income level in 2C-RR scenario (2030)

Source: IMF staff using IMF-ENV.

Note: 2C = High equity 2°C consistent scenario; HICs = high-income countries; LICs = low-income countries; MICs = middle-income countries; OAF = Africa (except South Africa); ODA = other East Asia and New Zealand; OEURASIA = other Eastern Europe and Caspian countries; OLA = other Latin America; PPP = purchasing power parity; RESTEU = rest of European Union and Iceland; RESTOPEC = other oil-exporting countries.

Transfers of $30 and $60 billion from HICs could be funded from only 1.5 and 3 percent, respectively, of potential carbon pricing revenues for this country group (Figure 20). At the country level, the United States is one of the top three contributors, its share of contributions varying from 26 to 46 percent. In the 2C-RR case, China is the largest contributor (45 percent of the total) reflecting its high carbon intensity and the large size of its economy. The transfers received by LICs range from 0.30 to 0.36 percent of GDP for $60 billion. With the $60 billion goal, India (15 to 35 percent) and Africa (excluding South Africa) (23 to 34 percent) are the top two recipient countries. Indonesia switches from a recipient to contributor under the 2C-RR scenario as its per capita emissions exceed the global average.

The transfers help make mitigation burdens, measured in GDP cost terms, more progressive (Figure 21). Even in the high equity 2°C scenario, economic cost is not yet very "progressive" in the sense that HICs have low GDP costs relative to MICs and LICs. The reason is that HICs depend less on GHG emissions economically than MICs and LICs due to past efforts to reduce emissions. Relative to the high equity 2°C scenario, which has relatively "flat" GDP costs, when HICs initiate transfers toward LICs and MICs by using a share of their carbon revenues, the GDP cost distribution becomes more progressive. The contribution of HICs increases and allows LICs (and some MICs) to reduce GDP cost and even in some cases increase GDP. There are global cost savings of 0.03 to 0.06 percent of GDP relative to the high equity 2°C scenario when international transfers from HICs to MICs and LICs are considered in scenario 2C-Compensate and 2C-Ability&Need. When transfers are made according to the Rajan proposal, the progressivity of costs also holds, with a marginal increase of 0.02 to 0.04 percent in the global costs relative to the high equity 2°C scenario.

A robust and predictable carbon price would help catalyze and efficiently allocate private climate finance flows. Private financing has a key role to play in advancing the transition (IMF 2022c). A key concern of private investors is policy uncertainty. By committing to carbon pricing, countries can increase investor confidence and enable private climate finance. While private finance cannot substitute for direct support from public sources, it is a key complement.

Conclusion

Countries need to raise their collective climate mitigation ambition to be consistent with limiting global warming to 1.5°C to 2°C. This Note seeks to inform international dialogue by presenting various equitable, temperature-aligned scenarios, with mitigation burdens generally increasing across income groups. The scenarios encompass reductions in emissions intensity, carbon price floors differentiated by development level, and progressive distributions of emission reductions. They allow for some variety in the exact distribution of emission reductions across HICs, MICs, and LICs, and all imply emissions per capita would further converge.

Options exist for narrowing the global climate ambition gap equitably, but if countries delay further the Paris Agreement's temperature goals may soon be beyond reach. Cuts based in carbon intensity and through an international carbon price floor have similar allocations across income groups, but varying allocations for individual countries given differences in responsiveness to carbon pricing. The high equity scenario would allocate even more of the emissions cuts to developed compared with developing countries. Lastly, the 1.8°C and 1.5°C scenarios require substantial increases in ambition which, if action is delayed further, may soon become technically infeasible.

At the global level, abatement costs are equitably distributed and when including co-benefits costs become negative. This implies that there are net benefits from climate mitigation policies, especially in developing countries. Pure abatement costs are around 0.5 percent of GDP in 2030 for the high equity 2°C scenario and are larger in developed than developing countries. Assuming least-cost abatement strategies – through carbon pricing and using revenues allocated for productive purposes – substantially reduces abatement costs. Additionally, there are large domestic environmental co-benefits from mitigation policies, notably improvements in human health from better air quality, especially in developing countries. When including these local environmental benefits, the net welfare costs of mitigation policies become negative at a global level and for MICs and LICs. This is even before considering (the far larger) global benefits of reducing future damages from further global warming.

GDP impacts are somewhat larger than pure abatement costs due to changes in investment (large for MICs and oil exporters) and trade effects (large for oil exporters). The midpoint of global GDP losses in 2030 is about 1.0 percent for 2°C-consistent scenarios (with a range between 0.6 and 1.5 percent depending on effort distribution and recycling of revenues). However, this is entirely manageable considering it implies a reduction of annual global growth of just 0.1 percentage point. Moreover, there are strategies for limiting investment losses (using carbon pricing revenues for public investment or non-pricing instruments instead of carbon pricing). There are several upside and downside risks around these estimates. On the upside, rapid innovation or learning-by-doing in low-carbon technologies could reduce costs. On the downside, stranded assets and a difficult reallocation of labor across sectors could increase the costs.

Raising climate finance could further ensure that accelerating a global low-carbon transition is equitable. Though GDP effect estimates exclude the (globally progressive) domestic environmental co-benefits mentioned above and pure abatement costs are progressive, GDP impacts are less so: HICs bear relatively lower GDP costs than MICs and oil exporters, for example. However, an increase in annual bilateral transfers from developed to developing countries from currently $10 billion to $30 or $60 billion would make GDP impacts more progressive, while requiring only a small share of potential carbon pricing revenues from HICs.

Annex 1. Models Used for the Analysis

The Climate Policy Assessment Tool

The Climate Policy Assessment Tool (CPAT) provides, on a country-by-country basis for 200 countries, projections of fuel use and carbon dioxide emissions by major energy sector.[34] This tool starts with use of fossil fuels and other fuels by the power, industrial, transport, and residential sectors and then projects fuel use forward in a baseline case using:

- GDP projections;
- 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
- Future international energy prices.

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

The impacts of carbon pricing on fuel use and emissions depend on (1) their proportionate impact on future fuel prices in different sectors, (2) a model of dispatch and investment in the power generation sector, and (3) various own-price elasticities for electricity use and fuel use in other sectors. For the most part, fuel demand curves are based on a constant elasticity specification.

The basic model is parameterized using data compiled from the International Energy Agency on recent fuel use by country and sector (International Energy Agency 2021). GDP projections are from the latest IMF forecasts.[35] Data on energy taxes, subsidies, and prices by energy product and country is compiled from publicly available and IMF sources, with inputs from proprietary and third-party sources. International energy prices are projected forward using an average of World Bank and IMF projections for coal, oil, and natural gas prices. Assumptions for fuel price responsiveness are chosen to be broadly consistent with empirical evidence and results from energy models (fuel price elasticities are typically between about –0.5 and –0.8).

Carbon emissions factors by fuel product are from International Energy Agency. The domestic environmental costs of fuel use are based on IMF methodologies (see Parry, Black, and Vernon 2022).

For this Note, CPAT was extended to include two important linkages between carbon pricing and the broader fiscal system that are referred to as the “revenue-recycling” and “tax-interaction” effects in the academic literature (for example, Goulder, Parry, and Burtraw 1997). The former effect is the economic welfare gain from using carbon pricing revenues productively, for example, to reduce taxes that deter work effort and investment or fund investment projects with benefit-cost ratios above unity. The latter effect is the economic welfare loss as carbon pricing (or other mitigation policies) raise production costs and consumer prices in the economy, thereby lowering the real returns to work effort and investment. Formulas for these effects are taken from the literature (specifically, Parry and Williams 2010) and parameterized with illustrative assumptions about factor tax wedges, factor supply elasticities, and broader behavioral responses to taxes.

One caveat is that the model abstracts from the possibility of mitigation actions (beyond those implicit in recently observed fuel use and price data) in the baseline, which provides a clean comparison of policy reforms to the baseline. 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 rapid adoption of technologies like carbon capture and storage or even direct air capture, though the future viability and costs of these technologies are

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[34] CPAT was developed by IMF and World Bank staff and evolved from an earlier IMF tool used, for example, in IMF (2019a, 2019b). For descriptions of the model and its parameterization, see IMF (2019b, Appendix III) and Parry and others (2021), and for further underlying rationale see Heine and Black (2019).

[35] A modest adjustment in emissions projections is made to account for partially permanent structural shifts in the economy caused by the pandemic.

highly uncertain. The model does not explicitly account for the possibility of upward sloping fuel supply curves, general equilibrium effects (for example, 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 climate or energy price reform in large countries. Parameter values in the spreadsheet are, however, chosen such that the results from the model are broadly consistent with those from far more detailed energy models that, to varying degrees, account for these sorts of factors.

IMF-ENV

The IMF-ENV model[36] is a recursive dynamic neoclassical, global, general equilibrium model, built primarily on a database of national economies and a set of bilateral trade flows. The model describes how economic activities and agents are interlinked across several economic sectors and other countries or regions. The central input of the model is the data of the Global Trade Analysis Project version 10 database (Aguiar and others 2019). The database includes country-specific input-output tables for 141 countries and 65 commodities and real macro flows. It also represents world trade flows comprehensively for a given starting year. The currently used version 10 is based on data from 2014. The model is based on the activities of the key actors: representative firms by sector of activities, a regional representative household, a government, and markets. Firms purchase inputs and primary factors to produce goods and services, optimizing their profits. Households receive the factor income and in turn buy the goods and services produced by firms; household demands result from standard welfare optimization under households' budget constraints. Markets determine equilibrium prices for factors, goods, and services. Frictions on factor or product markets are limited, except as described elsewhere in the following.

The model is recursive dynamic: it is solved as a sequence of comparative static equilibria. The fixed factors of production are exogenous for each time step and linked between time periods with accumulation expressions, like the dynamic of a Solow growth model. Output production is implemented as a series of nested constant-elasticity-of-substitution functions to capture the different substitutability across all inputs. International trade is modeled using the so-called Armington specification, which posits that demands for goods are differentiated by region of origin. This specification uses a full set of bilateral flows and prices by traded commodity. In contrast to intermediate inputs, primary factors of production are not mobile across countries. Model closures assume real government expenditure and nominal current account to be constant to baseline values. Assumptions made on trade closure rules can impact results for export shares of countries in global trade and trade balances for both surplus and deficit countries (Bekkers and others 2020). In the baseline, the values of regional current-account-to-GDP ratios and total foreign-savings-of-government-to-GDP ratios are calibrated to projections from ENV-Linkages and thus, for consistency, the same closure rules are retained in IMF-ENV.

While the capital market is characterized by real rigidities, the labor market is not. One major characteristic of the model is that it features vintage capital stocks in such a way that a firm's production structure and a firm's behavior are different in the short and long term. In each year, new investment is flexible and can be allocated across activities until the return to the "new" capital is equalized across sectors; the "old" (existing) capital stock, on the contrary, is mostly fixed and cannot be reallocated across sectors without costs. As a consequence, short-term elasticities of substitution across inputs in production processes (or substitution possibilities) are much lower than in the long term and make adjustments of capital more realistic. In contrast, labor (and land) market frictions are limited: in each year, labor (land) can shift across sectors with no adjustment cost until

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[36] Applications of the IMF-ENV model can be seen in Chateau, Jaumotte, and Schwerhoff (2022) and Chateau and others (2022). A full model description is under development. Meanwhile, readers interested in the model can consult the documentation of the twin models the current model is built on the ENVISAGE model (van der Mensbrugghe 2019) and the OECD ENV-Linkages Model (, Dellink, and Lanzi 2014).

wages (land prices) equalize, and the labor (land) supply responds with some elasticity to changes in the net-of-taxes wage rate (land price).

The model also links economic activity to environmental outcomes. Emissions of greenhouses gases and other air pollutants are linked to economic activities either with fixed coefficients, such as those for emissions from fuel combustion, or with emission intensities that decrease (nonlinearly) with carbon prices—marginal abatement cost curves. This latter case applies to emissions associated with non-energy-input uses (for example, nitrous oxide emissions resulting from fertilizer uses) or with output processes (like methane emissions from waste management or carbon dioxide emissions from cement manufacturing). In the very long term, the model may overestimate the cost of decarbonization, since it does not take into account radical technology innovations that could materialize at this longer horizon (hydrogen, second generation of nuclear and biofuel technologies, carbon capture and storage technology). While some of these new technologies are at an experimental stage, it is difficult to include them in the model at the moment because of a lack of information about the future costs of these technologies if they were deployed at industrial scale.

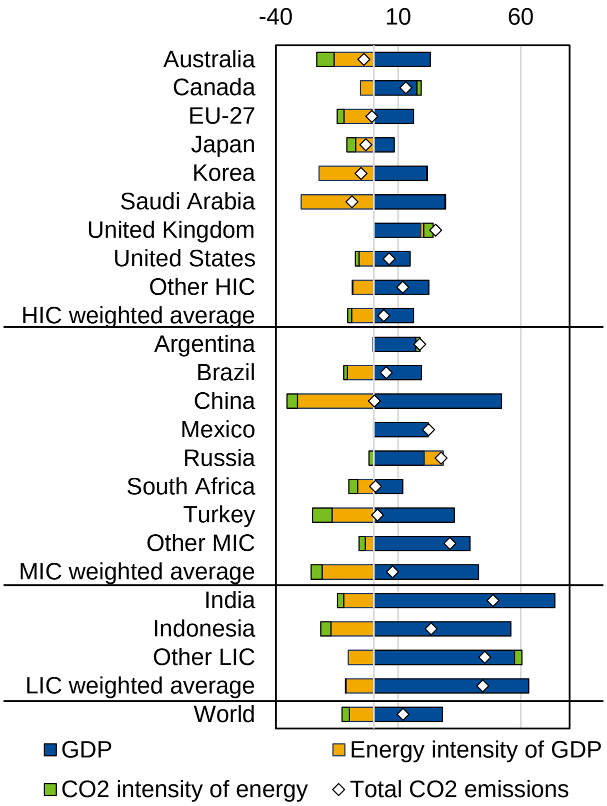
The model can be used for scenario analysis and quantitative policy assessments. For scenario analysis, the model projects up to 2050 an internally consistent set of trends for all economic, sectoral, trade-related, and environmental variables. In this context, the model can be used to analyze economic impacts of various drivers of structural changes like technological progress, increases in living standards, and changes in preferences and in production modes. A second use for the model is quantitative economic and environmental policy assessment for the coming decades, including scenarios of a transition to a low-carbon economy. In this case, the model assesses the costs and benefits of different sets of policy instruments for reaching given targets like greenhouse gas emission reductions. With the recursive dynamic framework of IMF-ENV, in a policy simulation for example of carbon pricing, the model considers not only the direct effects of changes in relative prices of the carbon-intensive fuels but also the second-round effects of the policy on investment and labor over years. Moreover, the model projects the structural changes resulting from the policy over time by differentiating the elasticity of substitution between labor and capital-energy over the short term and the long term (less elastic in short term but more elastic in long term).

There are various upside and downside risks around estimated GDP effects. For example, on the upside, new rapid technological innovations or more learning by doing could reduce the costs. On the downside, stranded assets and a difficult reallocation of labor across sectors could increase the costs. Additional risks might affect abatement costs to stay within the temperature goals of the Paris Agreement positively or negatively, including economic and population growth and strategies used by fossil fuel producers.

Annex 2. Business as Usual Emissions Projections

Projected carbon dioxide (CO_2) emissions growth varies significantly within country groupings (Annex Figure 2.1). In the Climate Policy Assessment Tool (CPAT), for high-income countries (HICs), projected business as usual emissions growth between 2021 and 2030 varies from –9 percent (Saudi Arabia) to +25 percent (United Kingdom); for middle-income countries (MICs) from 1 percent (South Africa) to 28 percent (Russia); and for low-income countries (LICs) from 23 percent (Indonesia) to 45 percent (India). Although GDP grows rapidly over this period (for example, over 50 percent in China and India) this is counteracted by a reduction in the energy intensity of GDP due to improving energy efficiency (as newer capital replaces older) and the (empirically observed) tendency of energy demand to grow less rapidly than GDP. Changes in the emissions intensity of energy are modest, principally because policies to advance renewables are frozen in the business as usual scenario. Different from this, in the IMF-ENV baseline global greenhouse gas (GHG) emissions (including land use, land-use change, and forestry) increase by 23 percent between 2021 and 2030 with a 9 percent increase in HICs, 29 percent increase in MICs, and 27 percent increase in LICs. IMF-ENV captures the linkage between economic activity and CO_2 emissions as well as non-CO_2 emissions for example from methane and nitrous oxide.

Annex Figure 2.1. Drivers of BAU CO_2 Emissions, 2021–30



Source: IMF staff calculations using the IMF-WB Climate Policy Assessment Tool.

Note: Group averages are weighted by total CO_2 emissions in 2030. Countries with fossil fuel subsidies (for example, Saudi Arabia) are assumed to reduce them by half to 2030, which further reduces the energy intensity of GDP. BAU = business as usual; CO_2 = carbon dioxide; HIC = high-income countries; LIC = low-income countries; MIC = middle-income countries.

In both models, GDP growth remains the major contributor of growing CO_2 emissions at the global level and for MICs, LICs, and oil exporters in the baseline. In many MICs and LICs, high economic growth remains the driver of rising emissions as it offsets the emission reductions from reduction in energy intensity. Differently, many HICs (for example, Canada, EU-27, and United Kingdom) are expected to grow moderately, and this, coupled with energy efficiency gains, allows these countries to keep CO_2 emissions growth low and, in some cases, even falling emissions (for example, both baselines project falling CO_2 emissions in Japan compared to current levels). While the contribution of projected developments in the energy intensity of GDP by income groups remains close in the two models,[37] its impact on the carbon intensity of the energy structure differs. In CPAT baseline, there is a reduction in the carbon intensity of the energy mix globally and in HICs and MICs with no change in the LICs. Differently, in

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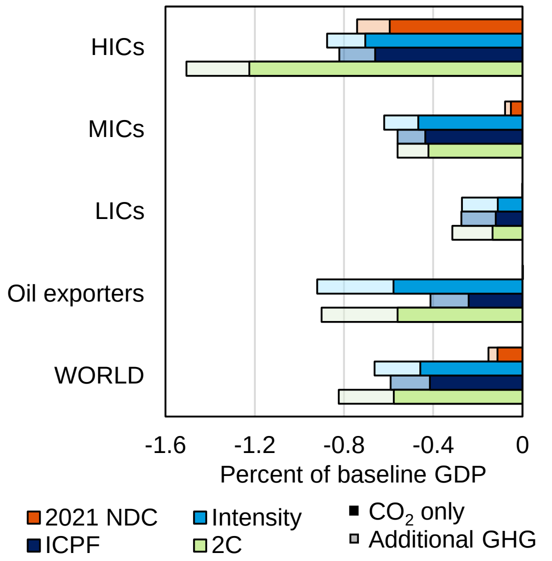
[37] This reflects two offsetting factors. On the one hand, CPAT assumes annual energy efficiency of 1 percent while IMF-ENV assumes 2 percent. On the other hand, CPAT assumes a lower responsiveness of energy demand to GDP growth than IMF-ENV.

the IMF-ENV baseline the carbon intensity of the energy structure is projected to increase globally and in each income group.

The pure CO_2 abatement costs are comparable in CPAT and IMF-ENV. Baseline CO_2 emissions projections from IMF-ENV are higher than those of CPAT. However, IMF-ENV has higher price responsiveness of emissions. Thus, the total CO_2 emissions from fossil combustion from the two models end up in 2°C-consistent emissions range. Overall, the global abatement costs measured as a share of GDP[38] are broadly comparable and abatement costs by income groups progressive in all 2°C-compatible scenarios. For example, in the international carbon price floor scenario, global, HIC, MIC, and LIC CO_2 abatement costs from IMF-ENV are 0.41, 0.66, 0.44, and 0.12 percent of GDP, respectively, while that from CPAT are 0.49, 0.6, 0.38, and 0.27 percent of GDP, respectively.

The share of CO_2 and non-CO_2 abatement costs varies across regions. IMF-ENV applies carbon pricing to all GHGs and hence we can compare abatement costs for CO_2 and non-CO_2 emissions (Annex Figure 2.2). In the 2°C-aligned scenarios, 70 percent of the global abatement costs arise from CO_2 mitigation. By income groups, this share increases to around 80 percent in HICs while in MICs it lies between 75 to 78 percent. However, non-CO_2 GHGs are mitigated in much larger share than CO_2 in LICs and hence, CO_2 mitigation only accounts for about 41 to 44 percent of the total abatement costs. This high share of GHGs other than CO_2 in LICs is due to the relatively high share of emissions from agriculture in these countries. Most other GHGs come from agriculture, where particularly methane is emitted in considerable amounts, especially from livestock production. Expectedly, the total GHG abatement costs are higher than CO_2-only abatement costs and for the international carbon price floor scenario for world, HICs, MICs, and LICs they are 0.59, 0.82, 0.56, and 0.27 percent of GDP, respectively.

Annex Figure 2.2. Abatement Costs for GHG and CO_2



Source: IMF-ENV.

Note: Includes emissions from land use and land use change. 2C = High equity 2°C consistent scenario ; CO_2 = carbon dioxide; GHG = greenhouse gas; HICs = high-income countries; ICPF = international carbon price floor; LICs = low-income countries; MICs = middle-income countries; NDC = nationally determined contributions.

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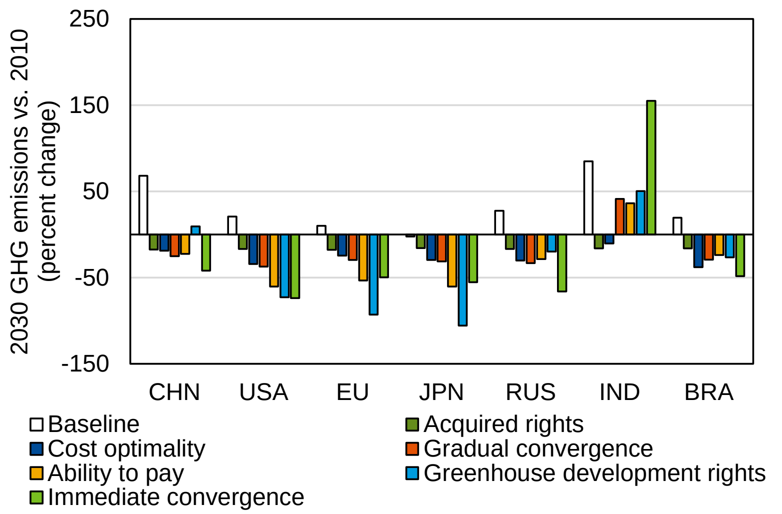
[38] Abatement costs are calculated as one-half times emissions reduced in scenario relative to business as usual times the carbon price. More details in Annex 4.

Annex 3. Perspectives on Equitable Ambition Scenarios

Climate change and international equity are intrinsically linked and have been embedded in international climate change negotiations since the founding of the UN Framework Convention on Climate Change. Analysts have examined what a fair distribution of emissions reductions would be to achieve annual targets or cumulative carbon budgets aligned with Paris Agreement's temperature goals. The various approaches can be summarized as follows, listed roughly from least to most equitable[39]:

1. **Acquired rights** (also known as "grandfathering")—countries cut emissions in proportion to their 2010 emissions
2. **Cost optimality**—emissions are reduced to minimize global abatement costs (which implies equal marginal abetment costs across countries)
3. **Gradual convergence**—per capita emissions converge linearly over time
4. **Ability to pay**—emissions reductions are based on annual per capita GDP, with lower reductions the poorer a country is and considering that costs increase with larger emissions reductions
5. **Immediate convergence**—per capita emissions converge immediately, in proportion to current population shares;
6. **Greenhouse development rights (GDR)**—emissions targets are based on a mixed measure of historical responsibility and capability which includes GDP per capita and carbon intensity

Annex Figure 3.1. Emissions Reductions Under Six Equity Allocations



Source: van der Berg (2020).
Note: Data labels in the figure use International Organization for Standardization (ISO) country codes. EU = European Union; GHG = greenhouse gases.

These differing approaches, when calibrated by a team of researchers (from both developing and developed countries) lead to markedly different impacts on emissions allowances across key countries (Annex Figure 3.1). Acquired rights and cost-optimal paths lead to fewer emissions reductions in high-income countries (HICs) compared with other methods, since their per capita emissions were relatively higher in 2010 and abatement costs are often lower (for example, in coal-intensive middle-income countries [MICs] and low-income countries [LICs]). Gradual convergence and ability to pay lead to intermediate solutions, with all countries required to cut emissions compared with baseline and larger cuts (in absolute terms) in HICs than MICs and LICs. Immediate convergence and greenhouse gas development rights lead to very large cuts in HICs (for example, more than 100

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[39] See van der Berg and others (2020).

percent for Japan under GDR) and much smaller reductions in developing countries (for example, above business as usual for India under GDR).

Given these differences, one approach to estimating a relatively high equity case is "trimming": excluding the least and most equitable approaches (acquired rights and GDR, respectively) and taking an average of the four remaining scenarios (cost optimality, gradual convergence, ability to pay, and immediate convergence). Emissions reductions targets for 2030 compared with business as usual can then be inferred for income groups and then scaled upwards or downwards (in percentage points) to achieve temperature targets (1.5°C, 1.8°C, and 2°C). Lastly, to tilt the estimate toward a higher equity case, this average is then further adjusted so that more emissions reductions come from developed countries and fewer from developing countries.

There are many alternative ways of estimating equitable effort-sharing, but this gives a relatively high equity case, where developed countries are mitigating much more rapidly than developing countries, and LICs are cutting emissions slowest of all.

Annex 4. Toward Better Estimates of Abatement Costs

Economists measure the pure abatement costs through marginal abatement costs curves (MACCs) which, at the economy-wide level, illustrate the cumulative emissions reductions from abatement opportunities in different sectors by ascending order of cost. The canonical example from McKinsey & Company (2007), for example, shows emissions reductions that range from negative cost (for example, LED light bulbs, which are very cheap) to very high cost (for example, retrofitting buildings and carbon capture and storage). There are several weaknesses to this approach, however:

- **Learning effects**—engineering estimates of MACCs do not incorporate the dynamic effects of learning. For many low-carbon technologies, unit production costs decline over time with learning-by-doing. For example, solar costs declined by about 90 percent in 2010s (Way and others 2021). Optimal policy—including interventions such as sectoral Pigouvian taxes/subsidies and public investment—would therefore target the low-carbon technologies that may be currently expensive but can be expected to decline rapidly due to learning effects. Also, since these learning spillovers tend to be global, international cooperation is warranted to accelerate needed technologies down learning curves. This can include coordinated technology policies, patent or finance pools, trade agreements (Pigato and others 2020), and other initiatives such as the "Breakthrough Agenda" on power, road transport, steel, hydrogen, and agriculture (agreed by 45 countries at the COP26 in 2021).[40]
- **Capital stock dynamics**—MACCs cannot represent complexities in optimal abatement pathways caused by differences in physical capital depreciation rates. For example, while retrofitting may be expensive, there are physical limits on the number of buildings that can be retrofitted—delaying retrofits decades into the future (implied by unadjusted MACCs) may be too late for a net zero pathway. Hence, starting with the most expensive abatement opportunities first may make sense in such cases (Vogt-Schilb, Meunier, and Hallegatte 2018).
- **Negative abatement cost opportunities**—MACCs are often based on engineering-style estimates of costs, but the supposed negative abatement cost opportunities can be difficult to explain: if agents are rational, why are they leaving money on the table? This question has fueled debate on the "energy efficiency paradox," which examines whether firms and households underinvest in energy efficiency. Some argue it is due to market failures such as informational and principal-agent slippage, while still others argue the paradox can be overstated where agents have high discount rates or there are hidden transactions costs (Jaffe and Stavins 1994).
- **Welfare co-benefits**—MACCs exclude welfare co-benefits of emissions reductions, such as reduced health hazards from exposure to local air pollution. These benefits vary and may make very expensive opportunities socially desirable (especially those involving coal, which results in significant local air pollution). Some analysts have therefore estimated the "abatement benefit curve" with the large co-benefits (net of abatement costs) being the most desirable opportunities to start with (New Climate Economy 2015). This can lead to different priorities (such as efficient heavy-duty trucks, electric vehicles, and cement clinker substitution), but local co-benefits by intervention can be difficult to estimate and are rare. This Note incorporates the co-benefits.

Ideally, MACCs would therefore incorporate estimates of learning effects, capital stock dynamics, and transactions costs to form a more realistic view of abatement opportunities. The "levelized cost of carbon abatement"—which seeks to incorporate all direct and direct costs and benefits into estimation—is one such approach, though data requirements are location-specific and can be cumbersome (Friedmann and others 2020). In lieu of this, a simplifying assumption of the cumulative welfare costs (areas under marginal abatement cost schedules, excluding co-benefits) is one-half times the carbon price at the optimal or target level of emissions times emissions reductions compared with business as usual. This does not perfectly match welfare costs, which can be different under a variety of assumptions (Morris, Paltsev, and Reilly 2012), but it remains a convenient approximation.

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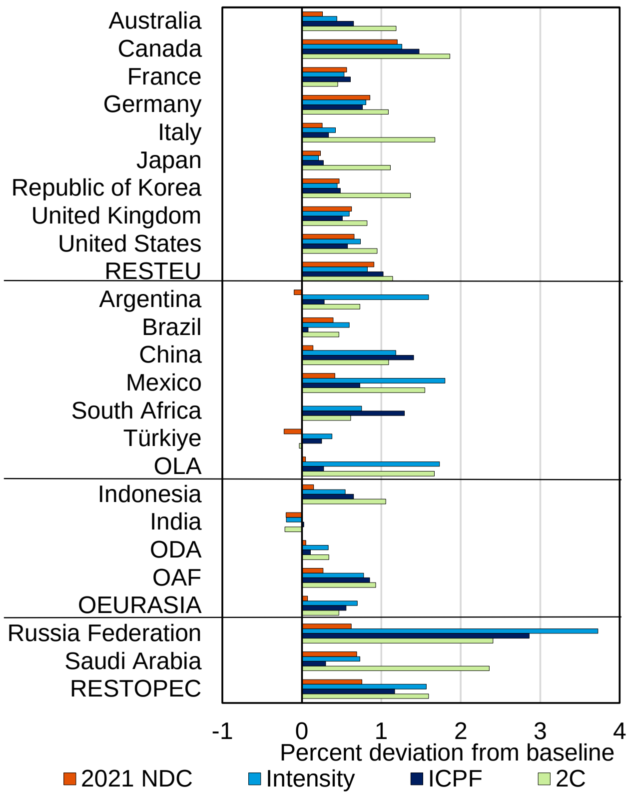
[40] See https://ukcop26.org/cop26-world-leaders-summit-statement-on-the-breakthrough-agenda/.

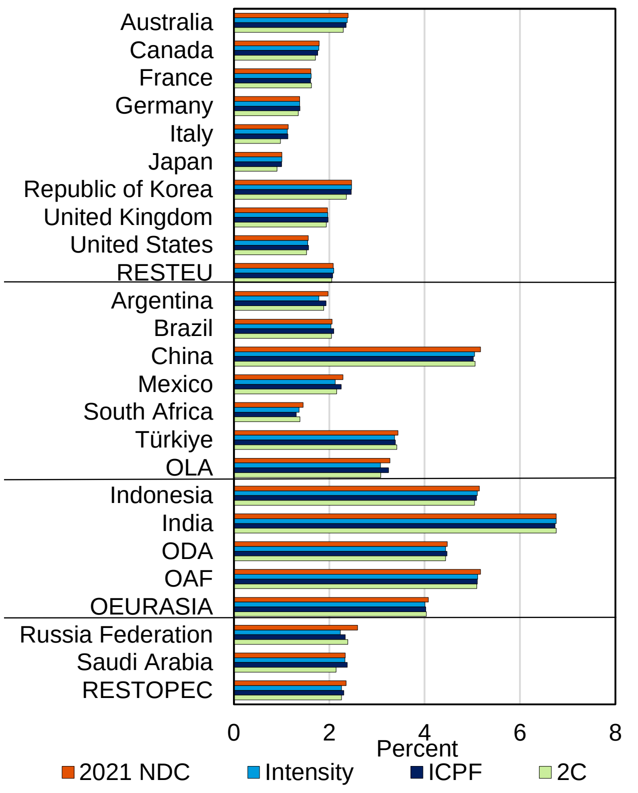
Annex 5. Country-Level Results and Additional Charts: IMF-ENV

GDP costs vary both across and within income groups (Annex Figure 5.1). For high-income countries, GDP costs are typically larger in the high equity 2°C scenario, which requires a larger percent reduction of their emissions than under the international carbon price floor and the Intensity scenario. The cost distribution is quite heterogenous across middle-income and low-income countries. Among middle-income countries, the Intensity and high equity 2°C scenarios imply smaller costs than the international carbon price floor for China and South Africa. In contrast, the Intensity scenario is particularly costly for Latin American countries given that their power sectors are already much more decarbonized, and therefore the stronger reduction in their emission intensity required in the intensity scenario is achieved at a higher cost. Among low-income countries, India even experiences GDP gains under both the Intensity and the high equity 2°C scenario. While these differences appear to be large, a conversion to growth rates, as in Annex Figure 5.2, shows that the differences across scenarios are indeed small and manageable. Though oil producers face a similar shock from falling global oil demand, the experienced costs vary depending on country characteristics (for example, income levels and production prices of oil). Generally, in all the 2°C-compatible scenarios, the largest costs are in Russia (2.4 to 3.7 percent of GDP) with the exception of high equity 2°C scenario where Saudi Arabia has costs comparable to those in Russia owing to the stricter target it faces as a high-income country.

Annex Figure 5.1. GDP Cost by Country and Scenario



Annex Figure 5.2. Annualized Real GDP Growth, 2021–30

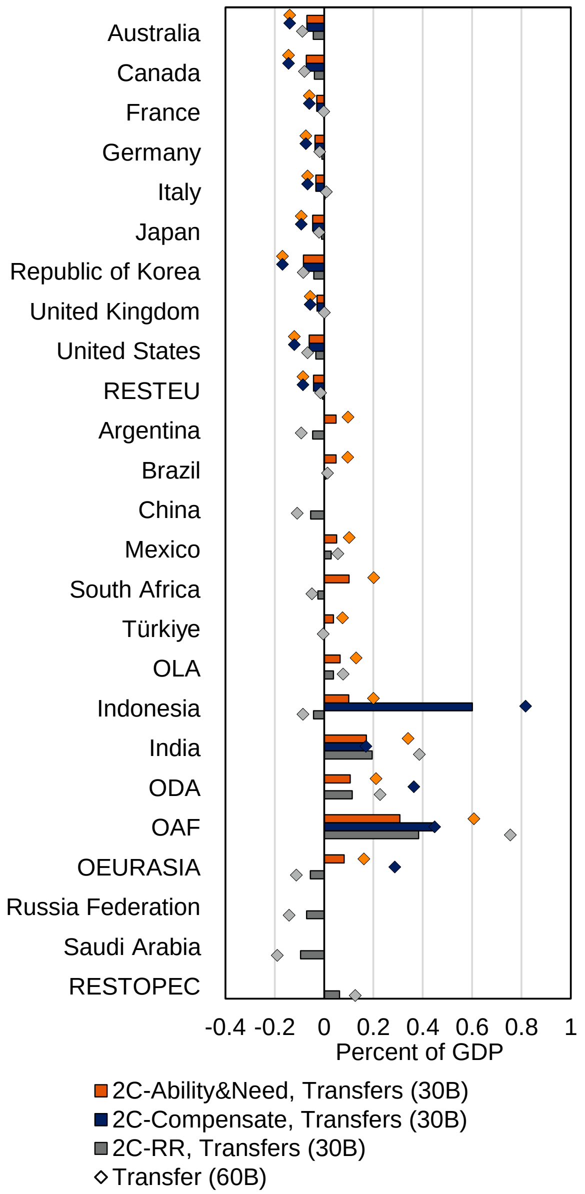


Source: IMF-ENV.

Note: 2C = High equity 2°C consistent scenario; ICPF = international carbon price floor; NDC = national determined contributions; OAF = Africa (except South Africa); ODA = other East Asia and New Zealand; OEURASIA = other Eastern Europe and Caspian countries; OLA = other Latin America; RESTEU = rest of European Union and Iceland; RESTOPEC = other oil-exporting countries.

High-income countries generate carbon revenues that amount to 3 percent of their GDP in 2030 and a contribution of about 0.1 percent of GDP is sufficient to reach $60 billion. In comparison, under the high equity 2C scenario low-income countries generate carbon revenues equivalent to 2 percent of their GDP and receive transfers ranging between 0.16 to 0.82 percent of their GDP to reach the $60 billion goal. Annex Figure 5.3 shows how climate finance contributes to country budgets. In all advanced economies, the contributions to climate finance would be a small share of carbon pricing revenues. When countries' transfers are measured as shares of GDP for the $60 billion goal, under the 2C-Ability&Need and 2C-Compensate scenarios Korea is the largest contributor with 0.17 percent followed by 0.14 percent contributions by Australia and Canada. Africa (except South Africa) region stands out as receiving the highest amounts of climate finance compared to GDP. Transfer payments and receipts between the 2C-Compensate and the 2C-Ability&Need scenarios are quite similar for almost all countries. In the 2C-RR scenarios, China, Saudi Arabia, Russia, and other oil-exporting countries participate in the international transfers. These countries act as contributors towards the transfers albeit in very different shares with the exception of rest oil-exporting countries which act as recipients. For example, China's contribution covers 45 percent of the $60 billion goal, but in terms of share of GDP it only amounts to 0.11 percent of China's GDP. Differently, Russia's contribution would also amount to 0.14 percent of GDP though in total it would make up only 6 percent of the $60 billion goal.

Annex Figure 5.3. Transfers in 2030 (Percent of GDP)



Source: IMF staff using IMF-ENV.
Note: Calculations relative to GDP from respective scenarios. 2C = High equity 2°C consistent scenario; OAF = Africa (except South Africa); ODA = other East Asia and New Zealand; OEURASIA = other Eastern Europe and Caspian countries; OLA = other Latin America; RESTEU = rest of European Union and Iceland; RESTOPEC = other oil-exporting countries.

References

Aguiar, Angel, Maksym Chepeliev, Erwin L. Corong, Robert McDougall, and Dominique Van Der Mensbrugghe. "The GTAP data base: version 10." Journal of Global Economic Analysis 4, no. 1 (2019): 1-27.

Andersson, Fredrik. 2018. “Estimates of the Inflation Effect of a Global Carbon Price on Consumer, Investment, Export, and Import Prices.” Working Papers 2018:22, Lund University, Department of Economics, Lund, Sweden.

Azevedo, Deven, Hendrik Wolff, and Akio Yamazaki. "Do carbon taxes kill jobs? Firm-level evidence from British Columbia." Firm-Level Evidence from British Columbia (October 8, 2022). Climate Change Economics, Forthcoming (2022).

Bekkers, Eddy, Alessandro Antimiani, Caitlyn Carrico, Dorothee Flaig, Lionel Fontagne, Jean Foure, Joseph Frnacois, Ken Itakura, Zornitsa Kutlina-Dimitrova, William Powers, Bery Saveyn, Robert Teh, Frank Van Tongeren, and Marinos Tsigas. 2020. “Modelling Trade and Other Economic Interactions between Countries in Baseline Projections.” *Journal of Global Economic Analysis* 5 (1): 273–345.

Bernard, Jean-Thomas, Maral Kichian, and Misbahul Islam. "Effects of BC’s Carbon Tax on GDP." USAEE research paper series 18-329 (2018).

Black, Simon, Ian Parry, James Roaf, and Karlygash Zhunussova. 2021. “Not Yet on Track to Net Zero: The Urgent Need for Greater Ambition and Policy Action to Achieve Paris Temperature Goals.” IMF Staff Climate Note 2021/005, International Monetary Fund, Washington, DC.

Bretschger, Lucas, Elise Grieg, Paul JJ Welfens, and Tian Xiong. "COVID-19 infections and fatalities developments: empirical evidence for OECD countries and newly industrialized economies." International Economics and Economic Policy 17, no. 4 (2020): 801-847.

Cali, Massimiliano, Nicola Cantore, Leonardo Iacovone, Mariana De La Paz Pereira Lopez, and Giorgio Presidente. 2019. “Too Much Energy: The Perverse Effect of Low Fuel Prices on Firms.” Policy Research Paper 9039, World Bank, Washington, DC.

Carbon Brief. 2015. “The UNFCCC Negotiating Alliances.” November 27. www.carbonbrief.org/interactive-the-negotiating-alliances-at-the-paris-climate-conference

Château, Jean, Rob Dellink, and Elisa Lanzi. 2014. “An Overview of the OECD ENV-Linkages Model: Version 3.” OECD Environment Working Paper 65, Organisation for Economic Co-operation and Development, Paris.

Chateau, Jean, Wenjie Chen, Florence Jaumotte, and Karlygash Zhunussova. 2022. “A Comprehensive Package of Macroeconomic Policy Measures for Implementing China’s Climate Mitigation Strategy.” IMF Working Paper 22/142, International Monetary Fund, Washington, DC.

Chateau, Jean, Florence Jaumotte, and Gregor Schwerhoff. 2022. “Economic and Environmental Benefits from International Cooperation on Climate Policies.” IMF Departmental Paper 2022/007, International Monetary Fund, Washington, DC.

Freire-González, Jaume. 2018. “Environmental Taxation and the Double Dividend Hypothesis in CGE Modelling Literature: A Critical Review.” *Journal of Policy Modeling* 40 (1): 194–223.

Friedmann, S. Julio, Zhiyuan Fan, Zachary Byrum, Emeka Ochu, Amar Bhardwaj, and Hadia Sheerazi. 2020. “Levelized Cost of Carbon Abatement: An Improved Cost-Assessment Methodology for a Net-Zero Emissions World.” Center on Global Energy Policy, Columbia University, New York.

Ganti, Gaurav, Robert Brecha, Jessica Strefler, Falko Uekcerdt, Gunnar Luderer, and Matthew Gidden. 2021. “Coal-to-Gas Bridge Incompatible with Paris Agreement Goals.” https://doi.org/10.21203/rs.3.rs-289099/v1

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

Friedlingstein, Pierre, Matthew W. Jones, Michael O'Sullivan, Robbie M. Andrew, Dorothee CE Bakker, Judith Hauck, Corinne Le Quéré et al. "Global carbon budget 2021." Earth System Science Data 14, no. 4 (2022): 1917-2005.

Goulder, Lawrence H., Ian Parry, and Dallas Burtraw. 1997. “Revenue-Raising vs. Other Approaches to Environmental Protection: The Critical Significance of Pre-Existing Tax Distortions.” *RAND Journal of Economics* 28 (4): 708–31.

Heine, Dirk, and Simon J. Black. 2019. “Benefits Beyond Climate: Environmental Tax Reform in Developing Countries.” In *Fiscal Policies for Development and Climate Action*, edited by Miria A. Pigato, 1–56. Washington, DC: World Bank Group.

High-Level Commission on Carbon Prices. 2017. “Report of the High-Level Commission on Carbon Prices.” Washington, DC: World Bank.

International Energy Agency. 2021. “Net Zero by 2050: A Roadmap for the Global Energy Sector.” https://www.iea.org/reports/net-zero-by-2050

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

International Monetary Fund (IMF). 2019b. “Fiscal Policies for Paris Climate Strategies—From Principle to Practice.” IMF Policy Paper, Washington, DC.

International Monetary Fund (IMF). 2020. *World Economic Outlook: A Long and Difficult Ascent*. Washington DC, October.

International Monetary Fund (IMF). 2022a. *External Sector Report*. Washington DC, August.

International Monetary Fund (IMF). 2022b. *World Economic Outlook: Countering the Cost-of-Living Crisis*. Washington DC, October.

International Monetary Fund (IMF). 2022c*. Global Financial Stability Report: Chapter 2 - Scaling up Private Climate Finance in Emerging Market and Developing Economies: Challenges and Opportunities*, Washington DC, October.

International Monetary Fund (IMF). 2022d. *World Economic Outlook, October 2022, Chapter 3: Near-Term Macroeconomic Impact of Decarbonization Policies*. Washington DC, October.

Intergovernmental Panel on Climate Change (IPCC). 2018. “Global Warming of 1.5°C.” Geneva, Switzerland.

Intergovernmental Panel on Climate Change (IPCC). 2021. “Climate Change 2021: The Physical Science Basis.” Geneva, Switzerland. www.ipcc.ch/report/ar6/wg1

Intergovernmental Panel on Climate Change (IPCC). 2022. “Climate Change 2022: Mitigation of Climate Change.” Geneva, Switzerland. www.ipcc.ch/report/ar6/wg3

Jaffe, Adam B., and Robert N. Stavins. 1994. “The Energy Paradox and the Diffusion of Conservation Technology.” *Resource and Energy Economics* 16 (2): 91–122.

Just, Richard E., Darrell L. Hueth, and Andrew Schmitz. 2005. *The Welfare Economics of Public Policy: A Practical Approach to Project and Policy Evaluation*. Cheltenham, United Kingdom: Edward Elgar.

New Climate Economy. 2015. “Quantifying the Multiple Benefits from Low Carbon Actions in a Greenhouse Gas Abatement Cost Curve.” Technical Note, The Global Commission on the Economy and Climate.

McKinsey & Company. 2007. “Costs and Potentials of Greenhouse Gas Abatement in Germany.” http://www.ecolo.org/documents/documents_in_english/CO2-abatement-Germany-07.pdf

Metcalf, Gilbert E. "On the economics of a carbon tax for the United States." Brookings Papers on Economic Activity 2019, no. 1 (2019): 405-484.

Metcalf, Gilbert E., and James H. Stock. "Measuring the macroeconomic impact of carbon taxes." In AEA papers and Proceedings, vol. 110, pp. 101-06. 2020..

Morris, Jennifer, Sergey Paltsev, and John Reilly. 2012. “Marginal Abatement Costs and Marginal Welfare Costs for Greenhouse Gas Emissions Reductions: Results from the EPPA Model.” *Environmental Modeling & Assessment* 17 (4): 325–36.

Organisation for Economic Co-operation and Development (OECD). 2017. *Investing in Climate, Investing in Growth*. Paris: OECD Publishing.

Organisation for Economic Co-operation and Development (OECD). 2022. *Aggregate Trends of Climate Finance Provided and Mobilised by Developed Countries in 2013-2020*. Paris: OECD Publishing.

Parry, Ian, Simon Black, Danielle Minnett, Victor Mylonas, and Nate Vernon. 2022. “How to Cut Methane Emissions.” IMF Staff Climate Note 2022/008, International Monetary Fund, Washington, DC.

Parry, Ian, Simon Black, and James Roaf. 2021. “Proposal for an International Carbon Price Floor among Large Emitters.” IMF Staff Climate Note 2021/001, International Monetary Fund, Washington, DC.

Parry, Ian, Simon Black, and Nate Vernon. 2022. “Measuring Fossil Fuel Subsidies—A Global and Country View.” In *Data for a Greener World: A Guide for Practitioners and Policymakers*, edited by Serkan Arslanalp, Kristina Kostial, and Gabriel Quirós-Romero. Washington, DC: International Monetary Fund.

Parry, Ian, Simon Black, and Karlygash Zhunussova. 2022. "Carbon Taxes or Emissions Trading Systems? Instrument Choice and Design." IMF Staff Climate Note 2022/006, International Monetary Fund, Washington, DC.

Parry, Ian, and Roberton Williams, 2010. "What are the Costs of Meeting Distributional Objectives for Climate Policy?" *B.E. Journal of Economic Analysis and Policy* 10 (2): Article 9.

Pigato, Miria A., Simon J. Black, Damien Dussaux, Zhimin Mao, Miles McKenna, Ryan Rafaty, and Simon Touboul. 2020. "Policies to Support Low-Carbon Technology Transfer." In *Technology Transfer and Innovation for Low-Carbon Development*, edited by Miria Pigato, Simon Black, Damien Dussaux, Zhimin Mao, Miles McKenna, Ryan Rafaty, and Simon Touboul, 109–52. Washington, DC: World Bank Group.

Rennert, Kevin, Frank Errickson, Brian C. Prest, Lisa Rennels, Richard G. Newell, William Pizer, Cora Kingdon, Jordan Wingenroth, Roger Cooke, Bryan Parthum, David Smith, Kevin Cromar, Delavane Diaz, Frances C. Moore, Ulrich K. Müller, Richard J. Plevin, Adrian E. Raftery, Hana Ševčíková, Hannah Sheets, James H. Stock, Tammy Tan, Mark Watson, Tony E. Wong, and David Anthoff. 2022. "Comprehensive Evidence Implies a Higher Social Cost of CO2." *Nature*. https://doi.org/10.1038/s41586-022-05224-9

UN Environment Programme (UNEP). 2022. "UNEP Emissions Gap: The Closing Window." https://www.unep.org/resources/emissions-gap-report-2022.

UN Framework Convention on Climate Change (UNFCCC). 2015. "Report of the Conference of the Parties on Its Twenty-First Session, Held in Paris from 30 November to 11 December 2015. Addendum. Part Two: Action Taken by the Conference of the Parties at Its Twenty-First Session. (The Paris Agreement)." FCCC/CP/2015/10/Add.1. https://unfccc.int/sites/default/files/resource/docs/2015/cop21/eng/10.pdf

UN Framework Convention on Climate Change (UNFCCC). 2021. "Parties to the UNFCCCC." 2021. https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states

UN Framework Convention on Climate Change (UNFCCC). 2022a. "Report of the Conference of the Parties Serving as the Meeting of the Parties to the Paris Agreement on Its Third Session, Held in Glasgow from 31 October to 13 November 2021: Part Two: Action Taken by the Conference of the Parties Serving as the Meeting of the Parties to the Paris Agreement at Its Third Session (The Glasgow Climate Pact)." FCCC/PA/CMA/2021/10/Add.1. https://unfccc.int/sites/default/files/resource/cma2021_10_add1_adv.pdf

UN Framework Convention on Climate Change (UNFCCC). 2022b. "Nationally Determined Contributions under the Paris Agreement: Synthesis Report by the Secretariat." FCCC/PA/CMA/2022/4. https://unfccc.int/documents/619180.

van den Berg, Nicole J., Heleen L. van Soest, Andries F. Hof, Michel G. J. den Elzen, Detlef P. van Vuuren, Wenying Chen, Laurent Drouet, Johannes Emmerling, Shinichiro Fujimori, Niklas Höhne, Alexandre C. Kõberle, David McCollum, Roberto Schaeffer, Swapnil Shekhar, Saritha Sudharmma Vishwanathan, Zoi Vrontisi, and Kornelis Blok. 2020. "Implications of Various

Effort-Sharing Approaches for National Carbon Budgets and Emission Pathways." *Climatic Change* 162 (4): 1805–22.

van der Mensbrugghe, Dominique. 2019. "The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model: Version 10.01." Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana.

Vogt-Schilb, Adrien, Guy Meunier, and Stéphane Hallegatte. 2018. "When Starting with the Most Expensive Option Makes Sense: Optimal Timing, Cost and Sectoral Allocation of Abatement Investment." *Journal of Environmental Economics and Management* 88: 210–33.

Way, Rupert, Matthew C. Ives, Penny Mealy, and J. Doyne Farmer. 2021. "Empirically Grounded Technology Forecasts and the Energy Transition." INET Oxford Working Paper 2021-01, Institute for New Economic Thinking at the Oxford Martin School, Oxford, United Kingdom.

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