STAFF

CLIMATE

NOTES

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Simon Black, Ian Parry, and Karlygash Zhunussova

IMF STAFF CLIMATE NOTE 2023/002

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Simon Black, Ian Parry, and Karlygash Zhunussova

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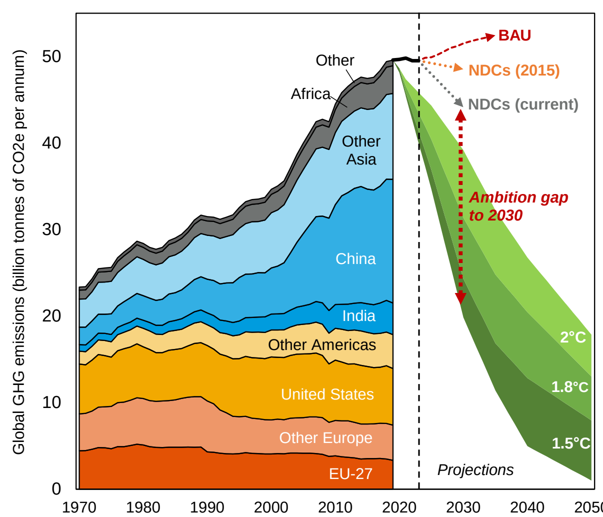
Summary

Urgent and aggressive action to cut greenhouse gas emissions this decade is needed. As countries take stock of the Paris Agreement, this Note provides IMF staff's annual assessment of global climate mitigation policy. Global ambition needs to be more than quadrupled: emissions cuts of 50 percent below 2019 levels by 2030 are needed for 1.5 degrees Celsius, but current targets would only achieve 11 percent. We provide options for ratcheting-up ambition equitably. Implementation could be accelerated via agreements on minimum carbon prices. Drastic increases in mitigation investment are needed, requiring policies to shift private sector incentives. Climate finance should be scaled-up, with a new goal aligned with needs in developing countries. The development and diffusion of low-carbon technologies should be accelerated collaboratively. Overall, the Paris Agreement is making progress, but a response to the Global Stocktake that prioritizes decisive action this decade is critical.

Introduction

Limiting global warming to 1.5 to 2 degrees Celsius requires cutting carbon dioxide (CO_2) and other greenhouse gases (GHGs) by 25 to 50 percent by 2030 compared with 2019. But large gaps in climate ambition and policy remain (Figure 1). First, there is a large ambition gap. Though countries have increased their mitigation ambition since the signing of the Paris Agreement in 2015, current nationally determined contributions (NDCs) would reduce global GHG emissions by just 11 percent.[1] Second, there is a gap in policy implementation. In a business-as-usual (BAU) scenario with no new (or tightening of existing) mitigation policies, global GHG emissions are projected to *increase* 4 percent to 51.5 billion tons in 2030—a rate that would exhaust the carbon budget for 1.5°C by 2035. Indeed, measures equivalent to a global carbon price of at least $85 are needed to get emissions on track to 2°C and even more for 1.5°C.

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



Sources: Intergovernmental Panel on Climate Change 2022; and IMF staff using CPAT. Note: Excludes land use and land use change emissions. BAU = business as usual; GHG = greenhouse gas; CO_2e = carbon dioxide equivalent.

Countries convene at the 28th Conference of Parties (COP28) to take stock of progress under the Paris Agreement. The Global Stocktake (GST) reviews progress since 2015, with countries expected to craft a response, potentially including revised NDCs. To help countries, this Note provides information on: (1) how to align emissions targets with temperature goals; (2) policies and impacts of achieving targets; and (3) how to get finance, investment, and technology on track for global 'net-zero emissions' by midcentury.

[1] UNEP (2022) and UNFCCC (2022) also find similar mitigation ambition gaps for 2030. This Note adds value to policymakers by providing an independent analysis using a transparent, consistent, and comprehensive model able to assess all economy-wide targets in NDCs for over 150 countries while assessing practical options for scaling up ambition and policy action.

This Note provides IMF staff's annual assessment of global climate mitigation policy. It updates earlier assessments (Black and others 2021, 2022a) by leveraging the IMF-World Bank Climate Policy Assessment Tool[2] (CPAT; Black and others 2023a) and assesses whether the Paris Agreement is working for climate ambition, implementation, finance, investment, and technology.

The key message is that despite some progress, the world is not on track to reach net zero. We propose a response to the GST that prioritizes action in this decade. We propose ways to ratchet up global ambition equitably, supported by complementary implementation agreements, and quantify potential impacts. We also assess global climate finance, investment, and technological development and provide proposals on how to get them on track.

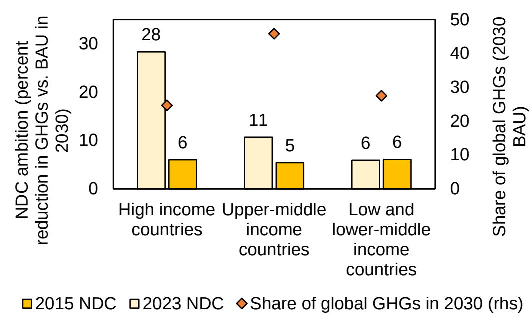
The Note proceeds as follows. The first section assesses the ambition gap and proposes ways to close it equitably. The second section deals with implementation, that is, policies to achieve scaled up ambition. The third and fourth sections assess global climate finance, investment, and policies to accelerate the development, production, and diffusion of low-carbon technologies (LCTs). The conclusion summarizes key messages and recommendations.

Getting Climate Ambition on Track

Background

The 2015 Paris Agreement was predicated on the need to ratchet up climate ambition over time. Since then, ambition has increased but remains insufficient (Figure 2). During the Paris Agreement negotiations, it was recognized that country pledges (in NDCs) would not be sufficient for keeping global warming "well below" 2°C above pre-industrial levels, ideally to 1.5°C.[3] It was envisioned that countries would raise ambition on a five-yearly basis (the "ratchet mechanism", the first at COP26 in 2021 and the next due at COP31 in 2026), supported by periodic progress reviews (GST, the first concluding at COP28 at the end of 2023). The initial NDCs set in 2015 would have cut emissions in 2030 by just 2 percent versus 2019 levels, whereas current NDCs would cut emissions by about 11 percent. While this is an improvement, it is inconsistent with being on track for 2°C or 1.5°C, which require cuts of 25 and 50 percent, respectively.

Figure 2. Distribution of NDC Ambition across Income Groups (2015 versus 2023)

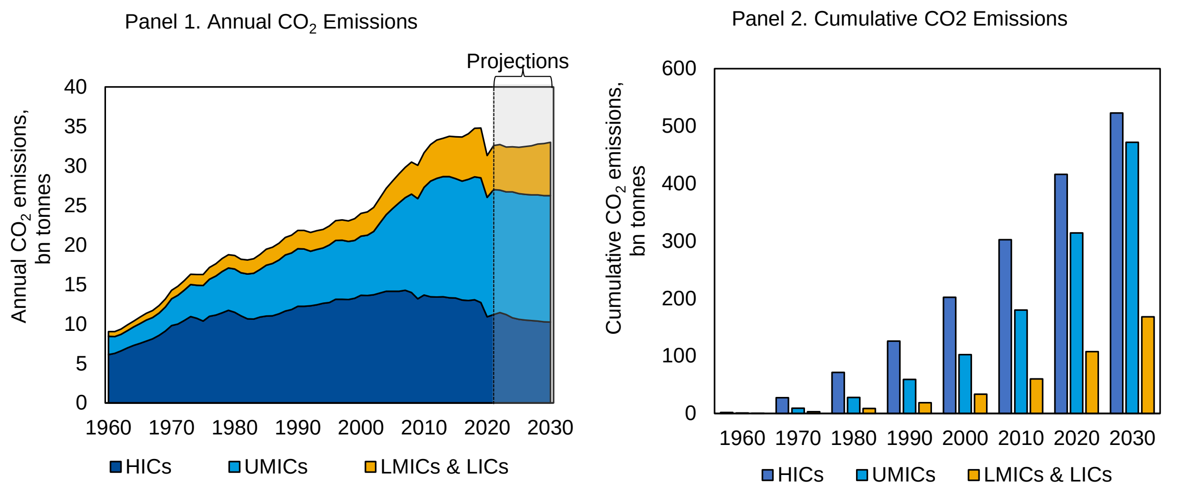


Source: IMF staff.
Note: For developing countries (middle-income countries, lower-middle-income countries, and lower-income countries), unconditional and conditional NDCs are averaged. BAU = business as usual; GHG = greenhouse gas; NDC = nationally determined

High-income countries (HICs) have significantly enhanced their ambition while developing countries have raised ambition more moderately (Figure 3). Our model (CPAT) allows for quantification and comparison of mitigation ambition in NDCs for over 150 countries. By estimating emissions for each country in the BAU and comparing to that implied by NDCs, countries can be compared in a transparent, consistent, and fair manner.[4]

[2] The Climate Policy Assessment Tool is also being made available to country authorities – see https://www.imf.org/en/Topics/climate-change/CPAT . More detailed documentation – authored by World Bank and IMF staff – can be found at https://cpmodel.github.io/cpat_public/.
[3] See https://unfccc.int/process-and-meetings/the-paris-agreement.
[4] Comparing pledges relative to BAU levels better reflects countries' ambition as it allows for rising emissions for, for example, low-income countries: these countries could have an NDC with large emissions reductions relative to BAU even while raising absolute emissions. BAU emissions projections by country authorities (using their own methodologies) may differ from those in the Climate Policy Assessment Tool.

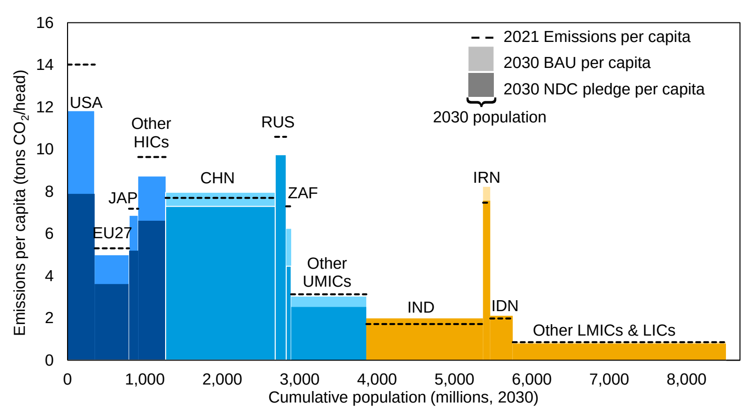
Figure 3. Historical and Projected BAU Annual and Cumulative CO_2 Emissions for High-, Middle-, and Low-Income Countries, 1960–2030



Source: IMF staff using CPAT.
Note: bn = billion; HICs = high-income countries; LICs = low-income countries; LMICs = lower-middle-income countries; UMICs = upper-middle-income countries.

Since 2015, HICs as a group have more than quadrupled their ambition (from 6 to 28 percentage points versus 2030 BAU). Upper-middle-income countries (UMICs) have doubled ambition while ambition among lower-middle-income (LMICs) and low-income countries (LICs) as a group is largely unchanged. Developing countries have an important role as they account for most (69 percent) of annual BAU CO2 emissions by 2030 and over half (55 percent) of historical cumulative CO2 (Figure 3).

Figure 4. CO_2 Emissions Pledges versus BAU, 2030



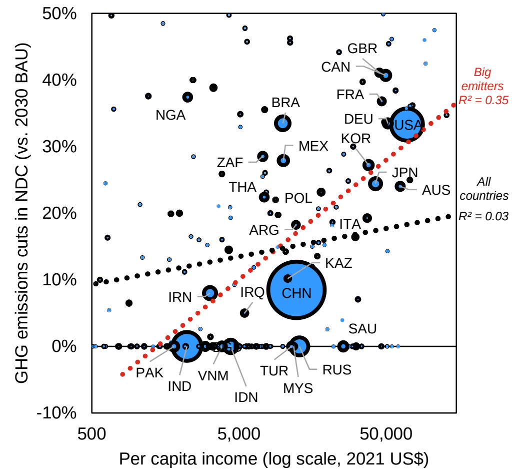
Source: IMF staff using CPAT.
Note: Shows the top three emitters in 2030 in the BAU scenario in each country grouping. Areas on chart represent total country emissions (emissions per capita × population).

Comparing ambition on a per capita basis for major emitters shows a similar pattern: while HICs have generally increased ambition, major UMICs, LMICs, and LICs have not. Under current NDCs, emissions in the European Union, Japan, and other HICs would drop below those of major UMICs such as China and Russia (Figure 4). Emissions per capita would remain lower than both HICs and UMICs in most LMICs and LICs such as India and Indonesia. However, no income group has commitments aligned with 2°C or 1.5°C.

At the country-level, climate ambition varies significantly and fewer than half of countries have substantively raised ambition since 2015. Of the 156 with quantifiable, economy-wide NDCs, 45 countries (accounting for 23 percent of global GHGs) have 2030 emissions targets that are *higher* than Climate Policy Assessment Tool’s BAU (that is, we expect them to be achieved without additional mitigation policies). The remaining 111 countries have NDCs which vary significantly in ambition, with a simple average of 27 percent below BAU (17 percent weighted average). Of these, 97 have targets greater than 10 percent and 53 have ambition greater than 25 percent. Of the 156 countries, fewer than half (63, covering 33 percent of global emissions) have increased their ambition substantively since 2015 (by 5 percentage points or more). Lastly, climate ambition rises with per capita income (Figure 5). Though the relationship appears weak due to small emitters, it is stronger when focusing on large emitters.

Countries will start setting targets for 2035 in new NDCs next year, and many have adopted net-zero-emission (NZE) targets. However, getting on track to net zero requires rapid cuts in global emissions *by* 2030. Countries accounting for over two-thirds of 2020 GHG emissions have committed to NZE in 2050 or 2060, while some have made earlier or later commitments (for example, India 2070). However, countries accounting for about 20 percent of emissions have not set a target for NZE yet, and only 18 percent of total commitments are enshrined in law (the remainder in policy documents or political pledges). In addition, even if NZE targets are met, the path to NZE is what matters. The accumulation of emissions in the atmosphere determines temperature changes so delayed action to 2030 would require significant (possibly infeasible) removals of CO_2 from the atmosphere later in the century. Overall, longer-term goals—whether targets for 2035 in new NDCs or midcentury NZE goals—should not distract from the priority of cutting emissions in this decade.

Figure 5. Country NDC Ambition by per Capita Income and GHG Emissions



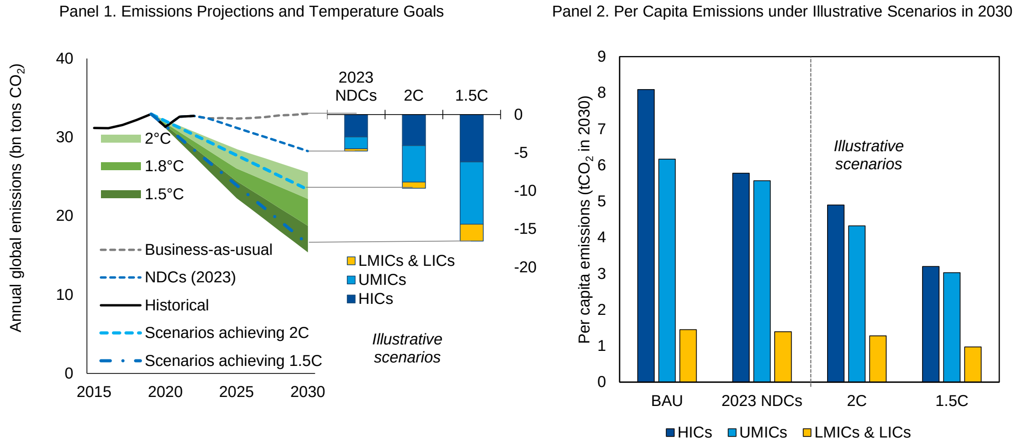
Source: IMF staff using CPAT.
Note: Bubble sizes reflect 2021 GHG emissions. For countries with a nonbinding target (that is, achieved in the BAU), it is assumed to be zero. Trend lines are shown for all countries (black) and major emitters (red; > 300 metric tons of carbon dioxide equivalent in 2030 BAU) who are also labeled. An average is taken of conditional and unconditional targets where both are specified. Data labels in the figure use International Organization for Standardization (ISO) country codes. NDC = nationally determined contribution.

Equitable and Paris-Aligned Emissions Reductions

A response to GST that prioritizes mitigation action in this decade is critical. Specifically, countries could agree to set more ambitious 2030 emissions targets based on per capita income levels. There are many possibilities to allocating global mitigation effort. For illustrative purposes, this Note presents equitable emissions cut allocations between country income groups. These are inferred by averaging over several approaches (for example, scenarios based on per capita income, convergence of per capita emissions, and equalization of incremental mitigation costs across countries) from a large study by developed and developing country academics. This is then averaged over approaches and scaled to achieve emissions cuts required by different temperature goals (1.5°C and 2°C) per the Intergovernmental Panel on Climate Change (see Annex 4 for detail).

Raising ambition in an equitable way could fully close the climate ambition gap (Figure 6, panel 1). The 2°C scenario would cut global CO2 emissions by 29 percent compared with 2030 BAU levels (approximately same cut on 2019 levels). HICs and UMICs would reduce their 2030 CO2 emissions by 39 and 30 percent below BAU by 2030, respectively, while LMICs and LICs would increase the ambition implied by current NDCs by 8 percentage points. The 1.5°C scenario is much more aggressive, with global emissions cuts of 50 percent compared with 2019 levels. This implies (nearly implausible) cuts of 60 and 51 percent for HICs and UMICs compared with 2030 BAU levels.

Figure 6. Illustrative Proposals for Closing 2030 Ambition Gaps



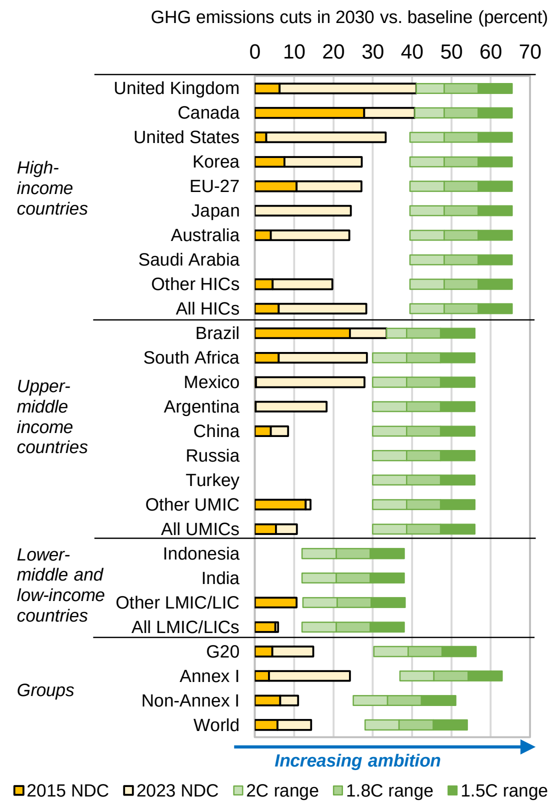
Source: IMF staff using CPAT.

These scenarios are broadly equitable in that they imply large commitments for HICs (Figure 6, panel 2). In both the 2C and 1.5C scenarios, there is a gradual convergence of per capita emissions between HICs and UMICs. LMICs and LICs would maintain lower emissions per capita than HICs and UMICs but would cut by less in absolute terms.

Figure 7 shows the implied gaps between current NDCs and those needed to achieve temperature goals, differentiated by income group. Between groups, shortfalls are larger for UMICs and LIC/LMICs than for HICs. NDCs are not currently binding in some developing countries, though the NDC of Brazil (and almost South Africa and Mexico) are already consistent with the 2°C scenario. It is also possible that some countries may over-achieve their existing targets with current policies (for example, India). For figures showing NDC ambition levels for all countries, refer to 05.

Lastly, while the fiscal and economic impacts depend on implementation, if these targets are implemented in optimal ways the proposal is broadly equitable across countries and can be made equitable within countries (Box 1).

Figure 7. GHG Emissions Cuts for Countries Under Illustrative Proposals



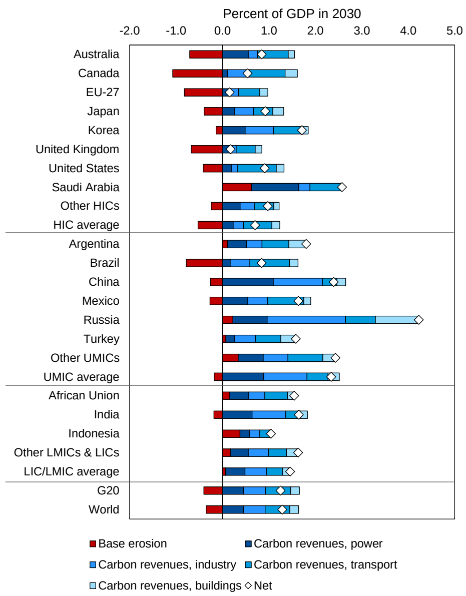
Sources: IMF staff using CPAT.

Note: Where no NDC is shown, the target is nonbinding and is assumed achieved in the baseline or (for Saudi Arabia) is nonquantifiable. An average is taken of conditional and unconditional targets where both are specified. Annex I = developed countries under UN Framework Convention on Climate Change; Non-Annex I = developing countries; G20 = Group of Twenty.

Box 1. Impacts of Closing Ambition Gaps for G20 Countries

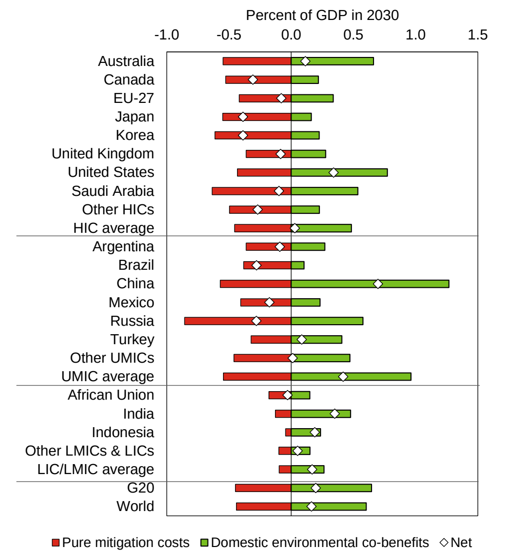
***Fiscal*: Revenue impacts can be positive out to 2030 but requires revenue-raising measures (Figure 1.1).** Carbon pricing revenues can more than compensate for base erosion (reduction in receipts from existing fuel taxes) out to 2030. Net revenues are typically around 0.5 to 2 percent of GDP and tend to be lower in high income countries than most upper-middle-income countries, reflecting lower emissions intensity of GDP. Some fraction of revenues will be needed for compensating low-income households and public investment (that is not funded through user fees) but on net fiscal balances can be improved, or at least will not deteriorate, with carbon pricing (Black and others, forthcoming).[5]

Figure 1.1. Fiscal Impacts of 2 Degrees Celsius Scenario, 2030



Source: IMF staff using CPAT.

Figure 1.2. Welfare Impacts of 2 Degrees Celsius Scenario, 2030

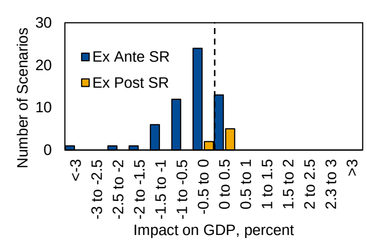


Source: IMF staff CPAT.

***Abatement costs*: At the global level, abatement costs are manageable and are progressively distributed, and there are significant offsetting domestic welfare co-benefits (Figure 1.2).[6]** Co-benefits reflect reductions in premature deaths from local air pollution (accounting for existing emission rate regulations)—large in countries with high population exposure to pollution—and reductions in congestion and accident externalities from reduced vehicle use. These offset a large portion of abatement costs, more than offsetting them in some countries like China, India, and Indonesia. In such cases, countries can move ahead unilaterally with mitigation, raising welfare (co-benefits less abatement costs), before even counting climate benefits.

Lastly, climate mitigation policies can help cut poverty, raise equity, and may have limited GDP effects. Impacts on poor households can be addressed using a small share of revenues—around 10 percent of revenues are needed to compensate the poorest 20 percent of households (Black and others, 2023c). GDP impacts of mitigation policies are uncertain (see IMF 2020) but are usually small and may be positive in certain contexts. There is a lack of consensus in the literature on the magnitude and sign of GDP impacts: ex ante simulations generally suggest small negative impacts while (a smaller number) of ex post empirical studies suggest small positive impacts (Figure 1.3). In short, there may not be a climate-economy tradeoff, and any near-term economic costs (or benefits) are likely to be small and dwarfed by cost of inaction (IMF 2022c).

Figure 1.3. Literature Review: GDP Impacts across Studies



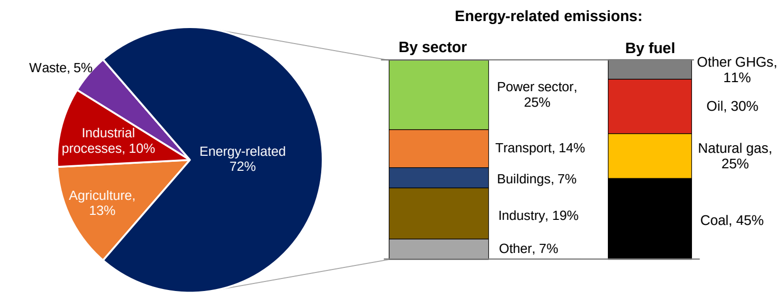
Source: FM 2023. Note: Ex Ante = ex ante simulation-based studies (especially CGE). Ex Post = studies of empirical impacts. SR = Short Run = 5 years.

Getting Policy Implementation on Track

Background

Current targets and pledges are insufficient to getting on track to NZE. At present, there is a gap in implementation and hence stronger mitigation policies are needed, especially in energy. Energy-related CO_2 and other GHG emissions (see Figure 8). accounted for three quarters of global GHG emissions in 2021 with coal, oil, and gas accounting for 45, 30, and 25 percent of these emissions respectively. And by sector, power, industry, transport, and buildings accounted for 25, 19, 14, and 7 percent of these emissions, respectively. Decoupling energy from fossil fuels is critical and will require:

Figure 8. Global GHGs by Sector and Fuel, 2021



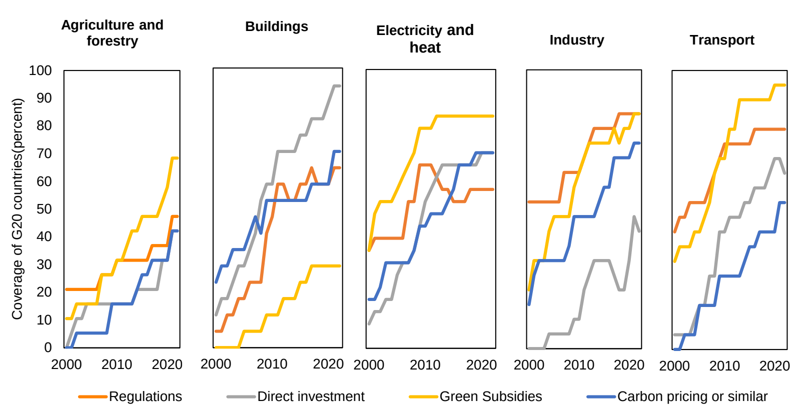
Sources: IMF, Climate Indicators Dashboard; and IMF staff.

- decarbonizing power generation through expanding renewables (like solar, wind, hydrogen, and hydro); fossil power generation with carbon capture, use, and storage, and possibly nuclear (with safeguards for waste disposal and radiation leakage);
- electrifying uses of energy (in buildings, homes, factories, and vehicles); and
- promoting energy conservation (to limit pressures on the grid).

Ideally, this would be done in an effective and efficient manner across countries (albeit at varying rates).

Countries are adopting sectoral approaches to mitigation (Figure 9). By 2022, at least half of Group of Twenty countries had policies covering power, industry, transport, buildings and agriculture and forestry, up from less than a third in 2000. These policies include explicit targets at the sector level, which can be substantive in many cases. Annex 1 provides a stock take of these policies in G20 countries and their contribution to mitigation effort).

Figure 9. Share of G20 Countries that Adopted Key Climate Policies, Percent



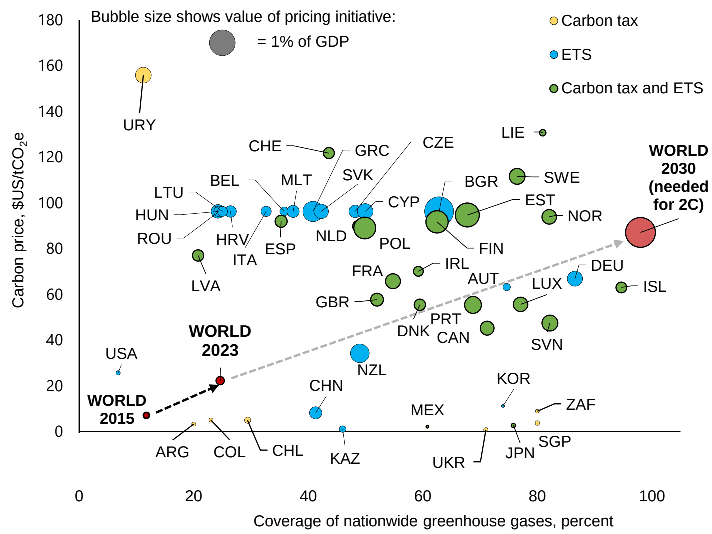
Source: CPI 2022; and Nascimento and others 2022.
Note: For Group of Twenty (G20) countries, excluding African Union and non-G20 member EU countries. Direct investment refers to support for green infrastructure,

[5] IMF (2023) also discusses the fiscal aspects of mitigation policies but the main focus there is on debt dynamics for policy packages that lose revenue on net due to heavy reliance on public investment and subsidies.

[6] Abatement costs correspond to changes in consumer and producer surplus excluding changes in government revenue. This should be treated with caution as costs increase disproportionately with abatement (as low-cost opportunities are exhausted) costs are heterogenous among households and firms. Co-benefits exclude energy security benefits which are hard to quantify.

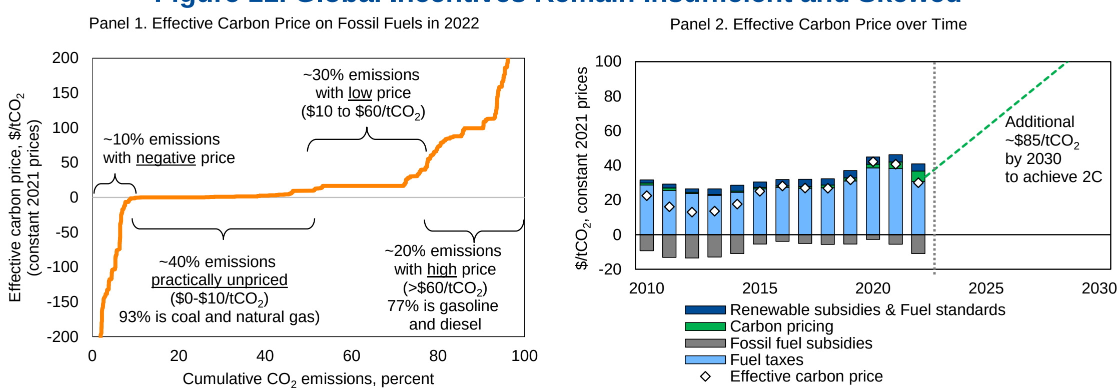
Carbon pricing continues to be adopted by countries, having doubled in emissions coverage since 2015, but the global average explicit carbon price is only $5 per ton (Figure 10).[7] To date, 73 carbon taxes and emissions trading systems (ETSs) are in operation in 47 countries, covering 25 percent of global GHGs, up from 12 per cent in 2015. National coverage of emissions varies, from below 30 percent in some cases to more than 70 percent in others (for example, Canada, Germany, Korea, and Sweden). Carbon prices vary from below $5 to over $100 per ton (mostly in European countries). The average (emissions weighted) price of covered emissions has grown from $7 in 2015 to about $22 in 2023. However, when including uncovered emissions, the global weighted average carbon price is just $5, whereas measures equivalent to a global carbon price of at least $85 would be needed to achieve 2°C (higher for 1.5°C).

Figure 10. Explicit Carbon Pricing Schemes at the National, Sub-National, and Regional Level, 2023



Sources: National sources; World Bank 2023; and IMF staff.
Note: labels use International Organization for Standardization (ISO) codes.

Figure 11. Global Incentives Remain Insufficient and Skewed



Source: IMF staff. Note: Effective carbon prices are equal to explicit carbon price plus the implicit carbon price embedded in excise taxes (weighted by emissions intensity), green subsidies and low-carbon fuel standards, and explicit fossil fuel subsidies (negative implicit carbon price), which are then weighted to account for differences in behavioral responses across fuels.[8]

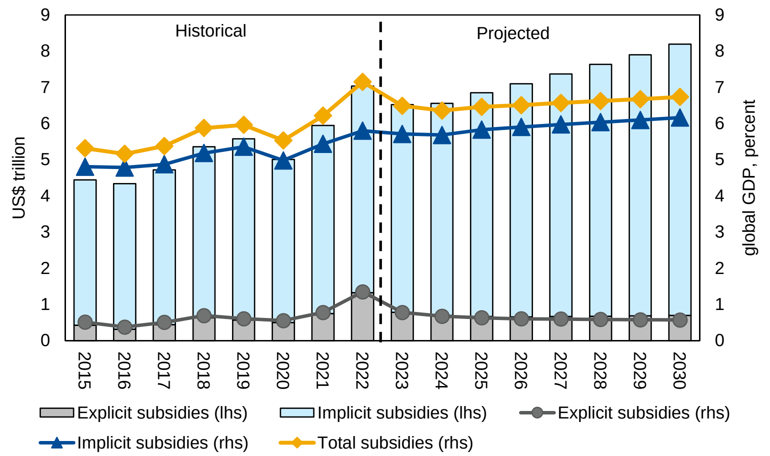
However, even when including fuel excises and renewable subsidies into a measure of implicit carbon pricing, mitigation incentives remain low and skewed (Figure 11). When adding

[7] All prices in this paper are expressed in year 2022 US $ or thereabouts.

[8] The effective carbon price is like the Organisation for Economic Co-operation and Development's "net effective carbon rate" and the World Bank's "total carbon price," the latter being the former plus preferential value-added tax rates (OECD 2022b; Agnolucci and others 2023). However, these measures do not adjust for differences in price elasticities, exclude renewable subsidies (put in place mostly for climate reasons), and the World Bank's concept implies that countries already have carbon pricing (though most fuel taxes have been put in place for non-climate reasons). The effective carbon price concept is also similar to the "comprehensive carbon price" (Carhart and others 2022) but covers more countries and weights by effectiveness.

taxes commonly applied to road fuels (weighted by their carbon content) and renewable subsidies (see the following discussion), the global effective carbon price (ECP) is about $30 per ton – about the same level that prevailed ten years ago (Figure 11, panel 2). Moreover, only about 20 percent of global CO2 emissions have a high price (above $60) while about 40 percent are priced at less than $10 per ton of CO_2 and, due to explicit fuel subsidies, about 10 percent have a negative price (Figure 11, panel 1). Overall, emissions from coal are virtually unpriced globally, from natural gas are mostly unpriced, and from gasoline and diesel are somewhat priced—but emissions from gasoline and diesel are relatively less responsive to emissions pricing (due to its modest impact on retail prices) compared with coal and gas.

Figure 12. Global Fossil Fuel Subsidies (Explicit and Implicit) Have Risen Since 2020

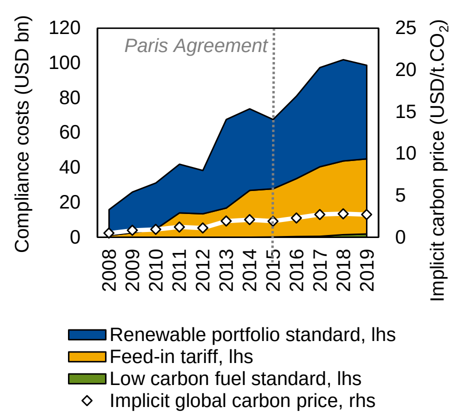


Source: Black and others (2023a).
Note. 2019 and 2022 onwards use projections of fuel use and fuel prices, respectively. lhs = left-hand scale; rhs = right-hand scale.

Defined broadly, fossil fuel subsidies remain very large and have grown over the last two years (Figure 12). Globally, total fossil fuel subsidies amounted to $7 trillion in 2022, equivalent to 7 percent of global GDP. Explicit subsidies (undercharging for supply costs) account for 18 percent of the total while implicit subsidies (undercharging for environmental costs and forgone consumption taxes) account for 82 percent. Explicit subsidies more than doubled from $0.5 trillion in 2020 to $1.3 trillion in 2022, as price support measures blunted the pass through of higher international energy prices to households and firms. Though much of the recent increase is due to temporary price support measures, total subsidies are expected to rise without corrective government policies.

Subsidies and regulations for renewables and low-carbon fuels were growing steadily from 2008 to 2019 (Figure 13), and more recently interest in subsidies to target production of low-carbon technologies has surged, though some caution is warranted. In 25 major emitters accounting for about 85 percent of global CO_2 emissions, the compliance costs for renewable portfolio standards (requirements that power utilities generate a share of power from renewable sources), feed-in tariffs (a fixed price paid for renewable power generation), and low carbon fuel standards (requirements to reduce the carbon intensity of fuels through, for example, blending biofuels) grew from $16 billion in 2008 to almost $100 billion in 2019. Weighing by global CO_2 emissions, this amounts to a modest implicit carbon price of about $3 per ton of CO_2 in 2019, up from $0.5 in 2008.

Figure 13. Subsidies and Regulations: Compliance Costs and Implied Carbon Price (2008-19, 25 Countries)



Source: Carhart and others 2022; and IMF staff. Note: Compliance costs are measured via shadow prices (for example, renewable energy certificates prices). Implicit carbon price equals compliance costs divided by the country's total emissions each year.

Domestic Policy to Close Implementation Gaps

To close the implementation gap and cut emissions to Paris-aligned levels, countries will need a mix of policies. Especially important is getting incentives right through a predictable, reliable price on carbon. Most investments needed to decarbonize the global economy must come from the private sector. Policies are needed to shift private investment in the most effective manner possible. Carbon pricing – ideally carbon taxes – is crucial for achieving this in all countries, since robust pricing can efficiently encourage shifts in investments, direct reductions in energy use, changes in use between fuels, and innovation in new technologies (Annex 2 discusses why economists emphasize carbon pricing; Black and others [2022b] compares carbon taxes and ETSs).

Carbon pricing can support a just transition by helping address poverty and raising equity of the fiscal system. Policymakers are often concerned about the impacts of carbon pricing on households and energy-intensive, trade exposed industries (like metals and chemicals). However, by using a portion of revenues for labor income tax cuts and assistance for vulnerable households, governments can make pricing pro-poor and equity-enhancing. In addition, pricing can be complemented with measures to support affected industries such border carbon adjustments or, ideally, agreements with trading partners on minimum carbon prices.

Policy packages which include measures beyond pricing are needed (Annex 2). As discussed in Annex 3, various market failures can impede the development and deployment of LCTs. Subsidies or mandates can overcome high up-front costs and technology policies can help accelerate the development of new LCT. Additionally, public investments in enabling infrastructure (like extensions of transmission lines to renewable sites and electric vehicle charging stations) are needed. And policies such as feebates, pricing schemes, and regulations are needed to reduce non-CO_2 GHGs from extractives, agriculture, and waste, alongside measures to promote forest carbon storage.

International Policy Coordination to Close Implementation Gaps

A supplementary international coordination mechanism can help reinforce implementation under the Paris Agreement. It can be challenging for countries to aggressively scale up mitigation policy due to concerns about their competitiveness and policy uncertainties in key trading partners. However, when countries coordinate on policies such obstacles can be overcome. An international coordination mechanism could therefore help accelerate implementation. The mechanism would ideally include small number of large emitters to facilitate negotiation while still covering majority of global emissions—for example, China, the European Union, India, and the United States are currently responsible for 61 percent of global GHGs emissions—or their membership could be broader so long as the deal raises ambition in a substantive manner. The mechanism could also focus on a limited number of transparent/monitorable parameters set to align global emissions in 2030 with temperature goals.

Specifically, an *international carbon price floor* (ICPF) among major emitters could be considered. Under this approach, participants would agree to implement whichever is the more stringent of: (1) a minimum carbon price, with prices differentiated by development levels (for example, $75 for HICs, $50 for UMICs, and $25 for LMICs/LICs); or (2) the mitigation pledge in their NDC. Assuming complete coverage of countries, global CO_2 emissions will be aligned with staying below 2°C. However, if a smaller group of just six major emitters were included (Canada, China, European Union, India, United Kingdom, United States) then this would close much of the implementation gap (see Parry, Black, and Roaf 2021). The ICPF could initially target specific sectors, for example power and industry, where emissions are more responsive to pricing and emissions are already covered under explicit carbon pricing mechanisms, with transport and buildings, and forestry added later (as capacity for monitoring of carbon storage from land use are developed). Lastly, for countries where pricing is unlikely, alternative policies that achieve equivalent emissions cuts could be accommodated (using the 'carbon price equivalence' concept – see Black and others 2022a).

Box 2. International Sectoral and Policy-Specific Initiatives on Climate Mitigation

Countries and firms are increasingly collaborating through coalitions to accelerate the development and adoption of specific technologies or policies. Notable multilateral initiatives include the Just Energy Transition Partnerships (JETPs),[9] the Breakthrough Agenda,[10] the Global Methane Pledge, the G7 Climate Club,[11] the Coalition of Finance Ministers for Climate Action,[12] Canada's Global Carbon Pricing Challenge,[13] and the Partnership for Market Implementation,[14] among others. These initiatives can complement the Paris Agreement by raising ambition, highlighting key issues (e.g., methane abatement), accelerating technological development, and diffusing knowledge on mitigation policies.[15] Bilateral partnerships are also flourishing, such as Indonesia and Korea's agreement to accelerate the development of electric vehicle technology, using the latter's natural resources (notably, nickel) and the former's know-how in manufacturing.[16] An important initiative, given the need to decarbonize energy in emerging market economies, are the JETPs. Done well, the JETPs could serve as a model for accelerating climate finance to developing countries. Done poorly, JETPs could reward polluters and waste finite resources by not accelerating the energy transition beyond what would have happened in their absence.

Given finite policymaking resources, some rationalization of these initiatives may be needed. There is a risk of creating overlapping institutions and "talking shops" instead of vehicles to drive substantive policy action. A stocktake of existing initiatives on climate is needed with a careful assessment of which are valuable, scaling those that are and, given finite policy resources, stopping those that are not.

Beyond CO_2, there are other GHG emissions which need to be addressed collaboratively:

- ***Methane emissions*** from extractives, livestock, and waste, account for 20 percent of global GHGs. A total of 125 countries signed the Global Methane Pledge committing to cut global methane emissions 30 percent below 2020 levels by 2030.[17] Differentiating commitments by development level is less critical in this case as mitigation costs are modest.[18] Analogous to the ICPF, a similar but separate international regime might apply to methane emissions, focusing on a coalition of willing countries with large collective methane emissions, such as Global Methane Pledge signatories, and a minimum methane emission price.[19]
- ***International aviation and maritime*** accounts for 1.9 percent of global GHGs in 2021 (0.6 percent and 1.3 percent, respectively[20]). The supervisory bodies for both industries have made net zero commitments by (around) midcentury and an offsetting scheme for aviation is being

[9] A JETP is a platform facilitated by one or several developed countries to facilitate the flow of both public and private climate finance to decarbonize the energy system in key developing countries. JETPs announced to date include South Africa (https://www.thepresidency.gov.za/download/file/fid/2649), Indonesia (https://www.whitehouse.gov/briefing-room/statements-releases/2022/11/15/indonesia-and-international-partners-secure-groundbreaking-climate-targets-and-associated-financing/), and Vietnam (https://ec.europa.eu/commission/presscorner/detail/es/statement_22_7724), and deals reportedly discussed for India and Senegal (https://rmi.org/jetps-101-helping-emerging-economies-go-from-coal-to-clean/).

[10] See https://www.iea.org/reports/breakthrough-agenda-report-2022.

[11] See https://www.bmwk.de/Redaktion/EN/Pressemitteilungen/2022/12/20221212-g7-establishes-climate-club.html.

[12] See https://www.financeministersforclimate.org/.

[13] See www.canada.ca/en/services/environment/weather/climatechange/climate-action/pricing-carbon-pollution/global-challenge.html.

[14] See https://pmiclimate.org/.

[15] Such technology-oriented international agreements have long been known to be likely beneficial for global climate policy, notably if they focus on knowledge sharing, coordination, research, development, or demonstration. However, they are likely to be of limited effectiveness in absence of substantive of domestic mitigation policy; see de Coninck and others (2008).

[16] See https://koreapro.org/2023/07/south-korea-and-indonesia-pledge-joint-efforts-in-green-tech-eye-global-markets/.

[17] See www.globalmethanepledge.org.

[18] Less than 0.1 percent of GDP in 2030 for most emitters in a scenario aligned with 2°C (Parry, Black, Minnett, and others 2022).

[19] To sequence sectoral coverage as monitoring capabilities evolve, the agreement might first focus on extractive emissions.

[20] See International Energy Agency (2023c, 2023d), https://www.iea.org/energy-system/transport/aviation, and https://www.iea.org/energy-system/transport/international-shipping.

phased in to stabilize emissions at 15 percent below 2019 levels. Coordination is especially important for maritime where the mobility of the tax base discourages unilateral taxes. Feebates can establish a robust price signal needed to close the gap for LCTs while avoiding the need to reach country agreement on how to use the large revenues that would be raised from pure carbon charging, though this would preclude using revenues for climate finance.[21]

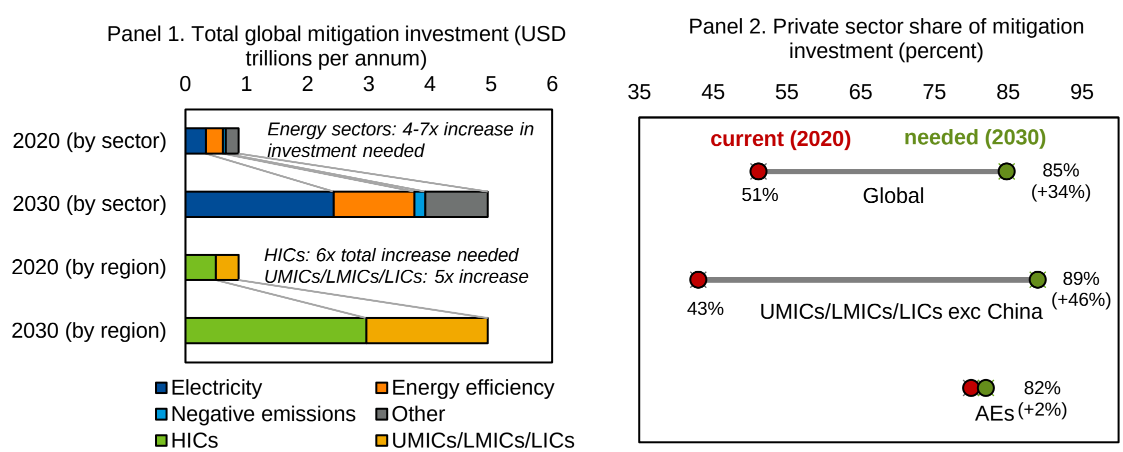
Lastly, there has been a rapid growth in global initiatives on policy implementation at a policy, sector, or technology-specific level (Box 2). Though it remains unclear whether these initiatives will substantively contribute to decarbonization, a stocktake leading to a scaling-down of initiatives that are not contributing to policy implementation (and hence are taking up scarce policymaking resources) and a scaling-up of those that are may be warranted.

Getting Finance and Investment on Track

Background

There is a large gap between current and needed climate mitigation finance and investment: clean energy investment needs to rise sixfold globally and fivefold in developing countries (Figure 14, panel 1). To achieve net-zero by 2050, climate mitigation investment (public and private) would need to rise from $0.9 trillion in 2020 to $5 trillion annually by 2030. About 60 to 70 percent of these investment needs are in the energy sector, notably generation and distribution of electricity (about half) and energy efficiency (about a quarter). Of the total, $2 trillion is needed in developing countries ($1.2 trillion excluding China), a fivefold increase from $370 billion in 2020.

Figure 14. Total Current and Needed Global Mitigation Investment and Private Sector Share



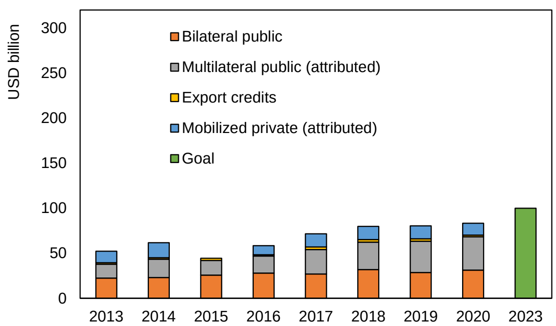
Sources: IMF 2023a; IMF Investment and Capital Stock Dataset, 1960–2019 CPI (2022); IEA 2021a, 2023a; IRENA 2023.

To avoid an excessive burden on public finances, the share of private mitigation investment would need to rise significantly, especially in developing countries (Figure 14, panel 2). Private investment in mitigation includes low-carbon technologies such as EVs, heat pumps, building insulation and (where power generation is liberalized) renewables. Public investments are needed notably in enabling infrastructure such as electricity grid technology, hydrogen and other pipelines, and efficiency upgrades for public buildings. Globally, the private share of climate investment needs to rise from about 50 percent in 2021 to over 80 percent by 2030.

[21] See Parry, Heine, Kizzier, and others (2022).

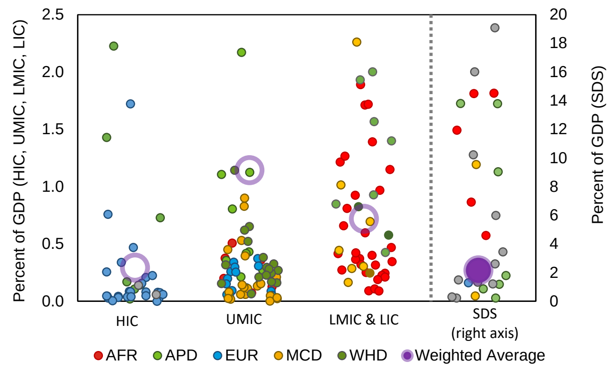
The largest increases would be in developing countries (excluding China), rising from about 40 percent to about 90 percent (shares would remain stable in developed countries). This is concerning since the private sectors' share in climate finance has been flat since the signing of the Paris Agreement (CPI 2022) despite technology costs declining precipitously (see the following technology section). Lastly, the share of mitigation in total investment would need to rise from 4 percent to 17 percent globally and from 3.4 to 12 in developing countries (IMF 2023a), though some of this could come from a shifting away of investment from fossil fuel to renewable energy. **To facilitate the dramatic increases in private mitigation investment, substantive and credible climate policies are needed.**

Figure 15. Climate Finance from Developed to Developing Countries 2013–20 (bn US$ per year)



Source: OECD (2022a).
Note: The gap in time series in 2015 for mobilized private finance results from changes in measurement. As a result, totals in 2016-20 and in 2013-14 are not directly comparable.

Figure 16. Adaptation Investment Needs 2021–30 (Annual, percent GDP)



Source: Aligishiev, Bellon, and Massetti 2022.[22]

Accelerating climate finance from developed to developing countries is a central tenet of the Paris Agreement but flows remain insufficient (Figure 15). Developed countries committed to mobilize $100 billion a year in climate finance from 2020 until at least 2025 in the context of "meaningful mitigation actions and transparency on implementation".[23] This target is expected to be met late, in 2023. In 2020 climate finance flows from developed to developing countries amounted to $83.3 billion (Figure 15Figure 15), with bilateral, multilateral, and privately-leveraged finance accounting for 31, 37, and 13 percent, respectively. To help achieve the fivefold increase in investment in developing countries, accelerating the flow of climate finance (both public and private) from developed to developing countries is needed. Additionally, the composition of climate finance is currently skewed towards projects rather than policies. Currently, financing to support policy reforms accounts for just 14 percent of total multilateral lending (IDB and others 2023). Given the central

[22] Investments include (1) retrofitting of all existing public capital to stand present flood risks, with the exclusion of capital that is expected to depreciate before 2030; (2) strengthening of new public capital investment against present flood risks; and (3) investment for protection against present and future sea level rise with a benefit-cost ratio > 1 in the period 2015–30. The adaptation gap with respect to present flood risks is large, and flood risks are not expected to change significantly in the next decade. Investment needs assume a 15-year time horizon for completion. Investment needs are re-scaled for a 10-year time horizon. Purple circles indicate group means using 2019 GDP as weight. AFR = African Department; APD = Asia and Pacific Department; EUR = European Department; HICs = high-income countries; LICs = low-income countries; LMICs = low-middle-income countries; MCD = Middle East and Central Asia Department; SDS = small developing states and countries with investment needs in adaptation greater than 2.5 percent of GDP; UMICs = upper-middle-income countries; WHD = Western Hemisphere Department.

[23] At COP15 in 2009 it was agreed that finance "shall be provided to developing countries […] to enable and support enhanced action on mitigation" (UNFCCC 2009, para 8). It was formalized at COP16 and reaffirmed in the Paris Agreement at COP21, described in the "context of meaningful mitigation actions" and "taking into account the needs and priorities of developing countries" (UNFCCC 2015). At COP27, developed countries authored a 'delivery plan' to reaffirming commitment to the target with a revised date of 2023 – see https://ukcop26.org/wp-content/uploads/2021/10/Climate-Finance-Delivery-Plan-1.pdf

importance of policy reforms to accelerate mitigation action, policy-based financing should be scaled-up.

The most important way to accelerate climate finance is a robust carbon price. Without this price signal, private finance and investment flows will continue to languish, especially in developing countries where incentives remain low and, accordingly, the private sector's share of mitigation investments remains low (see Figure 14 above).[24]

There are also needs for adaptation finance, especially in LICs and small developing states (SDSs) that are especially vulnerable (Figure 16). There is wide variation of adaptation investment needs both between and within income groups. On average, HIC investment needs are estimated at around 0.3 percent of GDP a year this decade, compared with 1.1 percent for MICs and 0.7 percent for LICs. Needs are significantly higher in vulnerable SDSs[25] where annual adaptation investment needs are around 2 percent on average but can be as high as 10 percent.

Lastly, carbon offsets remain a highly uncertain source of climate finance for developing countries and may undermine ambition within the Paris Agreement (see Annex 6). It remains critical that any use of international carbon credits serves to raise country ambition (per Article 6 of the Paris Agreement) or, at worst, does not disincentivize increases in ambition. However, at present, Article 6 may be holding back developing country ambition (since they may expect to generate credits for emissions below their NDC level). Additionally, potential finance and revenues from offsets may be limited, given questionable appetite in buyer countries (for example, the European Union has ruled out purchases of sovereign offsets as part of achieving its NDC). In the meantime, developing countries could abate domestic emissions through substantive mitigation policies, notably putting an additional price on carbon (which carbon credits do not) through explicit carbon pricing or similar instruments.

New Collective Quantified Goal on Climate Finance

A new collective quantified goal on climate finance is needed, though ideally based on transparent calculations. Some relevant considerations include the following:

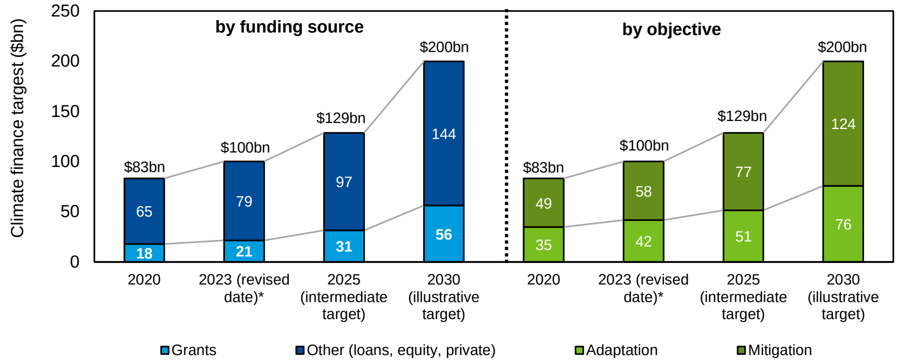
- First, adaptation and mitigation are not the same challenges, and hence their respective shares in the new climate finance goal should not be the same. Imposing an equal share of funds for adaptation versus mitigation is arbitrary: needs for adaptation and mitigation will vary significantly over time and relative needs can be higher at one time and lower in another.
- Second, low-income and small developing countries will find it difficult to self-finance mitigation and adaptation investments, hence concessional finance will be needed. LICs and SDSs face major obstacles in attracting private finance for adaptation and mitigation. Hence there is a strong justification for concessional finance for example in the form of grants or preferential loans. For adaptation, annual investment needs in 2030 are estimated at about $30billion and $10 billion for LICs and SDSs, respectively (Aligishiev, Bellon, and Massetti 2022). For mitigation, investment needs should be defined net of avoided investments in fossil fuel technologies and lifecycle savings. Estimated annual abatement costs in 2030 are $0.5 billion and $1 billion for LICs and SDSs, respectively (for a 2°C scenario). Total grants for abatement and mitigation would therefore be about $42 billion per year, more than double 2020 grant-based climate finance ($18 billion).

[24] See Lim and others (forthcoming) on broader barriers to climate finance.
[25] Small developing countries with investment needs in adaptation greater than 2.5 percent of GDP.

One illustrative, bottom-up approach to estimating a Paris-aligned new collective climate finance goal yields targets of roughly $130 billion in 2025 and $200 billion by 2030 (Figure 17)

Assuming that financing needs in developing countries are with climate financing accounts for a relatively stable share yields a target of about $200 billion in 2030.[26] Interpolating linearly from developed countries' own revised date of achieving the $100 billion target (2023), this would imply a 2025 target (that is, an new collective quantified goal) of about $130 billion. Both mitigation and adaptation finance would increase substantially (though their shares would not be the same) from $49 billion and $35 billion in 2020 to $124 billion and $76 billion in 2030, respectively. This illustrates one possible approach, though there are many.

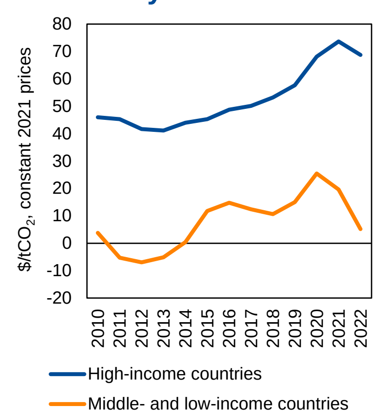
Figure 17. Illustrative Calculation of the New Collective Quantified Goal on Climate Finance



Sources: Aligishiev, Bellon, and Massetti 2022; and IMF staff.
Note: All figures are annual in 2022 US dollars. *2023 figures are interpolated based on a fixed assumed share for grants/other and adaptation/mitigation from 2020 actuals.

However, the new global finance target could be framed as a joint goal, with the increase above $100 billion being conditional on strong mitigation action by developing countries. Incentives and hence private investment into mitigation in developing countries remain low, with effective carbon prices being much lower in developing countries than developed countries (Figure 18). Over 2010-12, the effective carbon price in high-income countries was about $50 per ton of CO2. In middle- and low-income countries rates are much lower and have decreased since 2020. Further, the failure to achieve the $100 billion target has been a major source of discontent at COP, overshadowing discussions. Given the need for domestic policies to accelerate private finance to developing countries and the need for scaled-up public finance from developed countries, the new goal could be framed as a joint goal between developed and developing countries. This would be in keeping with the spirit of global collaboration on mitigation.[27] The new target could also be specified as being conditional on policies in developing countries, with more action yielding a higher target. For example, the target could be flat at $100 billion in the unconditional case and higher than $100 billion conditional on developing countries' enacting strong mitigation policies (for example, raising their effective carbon price; note this excludes increases in adaptation finance which be unconditional).

Figure 18. Effective Carbon Prices by Income Level



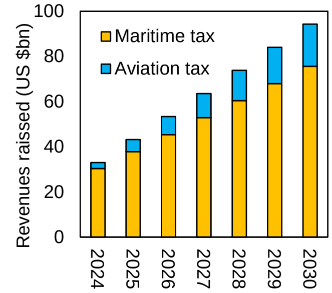
Sources: IMF staff.

[26] Assuming global climate finance accounts for at least 10 percent (currently 13 percent) of the $1.2 trillion needed by 2030 $120 billion. Adding on top current finance for adaptation and cross-cutting needs of about $42 billion in 2030 (assumes adaptation and cross-cutting finance in 2020 levels scales proportionately to the $100 billion target met in 2023) and the above mentioned grant component for LICs and SDSs of about $38 billion yields a total global finance target of $200 billion per year by 2030.
[27] As represented in, for example, the Just Energy Transition Partnerships (JETPs) – see Box 2.

New Global Sources of Revenue

The above target implies a tripling of climate grants to about $56 billion in 2030. However, this is small relative to potential revenues from pricing and could be funded, for example, from a tax on international aviation and maritime, raising nearly $100 billion by 2030 (Figure 19). For illustration: the $41 billion increase in grants would account for just 6 percent of the $670 billion revenues that would be raised if all HICs implemented an additional carbon price of $75 per ton of CO_2 (on top of existing policies) by 2030. Alternatively, African countries recently called for a tax on international aviation and maritime[28], which are not under the jurisdiction of the UN Framework Convention on Climate Change and are currently not covered under any explicit pricing mechanism. These are an attractive potential source of climate finance, especially given that emissions are released in international airspace/waters.[29] Such a tax could raise substantial revenues. For maritime, a carbon levy of $75 in 2030 would raise about $75 billion per year in 2030 (Parry and others 2022a). For aviation, assuming the International Civil Aviation Organization's emissions projections[30] and the same carbon price, revenues would amount to nearly $20 billion in 2030. Total revenues would be about $93 billion in 2030.

Figure 19. Potential Revenues from Global Charge on International Aviation and Maritime



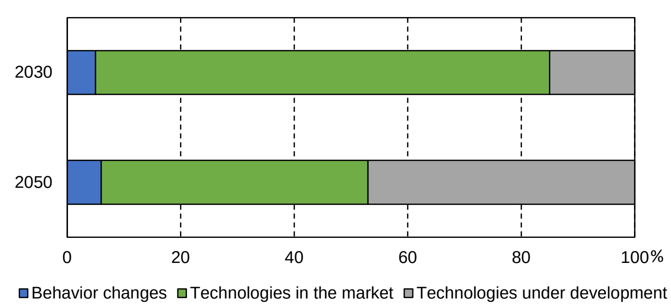
Sources: Parry and others 2022b; and IMF staff. Note: Figures are annual in 2021 US dollars. Levy is assumed to start at $25 in 2024 and grow linearly to $75 in 2030. Aviation tax assumes the midpoint of the International Civil Aviation Organization's passenger projections (ICAO 2023). Estimates account for behavioral responses.

Getting Technology on Track

Background

Decarbonizing the global economy requires a rapid diffusion of proven LCT[31] combined with investment in new technologies (Figure 20). According to the International Energy Agency, about 85 percent of CO_2 emissions cuts out to 2030 can be achieved from commercially proven (not necessarily cost-competitive) technologies. However, diffusion is not proceeding fast enough: global mitigation investment needs to rise sixfold. In addition, new technologies will be required to achieve decarbonization: by 2050, almost half of emissions reductions will need to come from technologies currently under development or yet to be invented (IEA 2021). Hence, investments in newer but essential technologies for 1.5C will be required, though only a handful of countries have clear plans for them (Powis and others 2023). Metrics of technological progress to be assessed include trade, costs, and the development and production of new technologies.

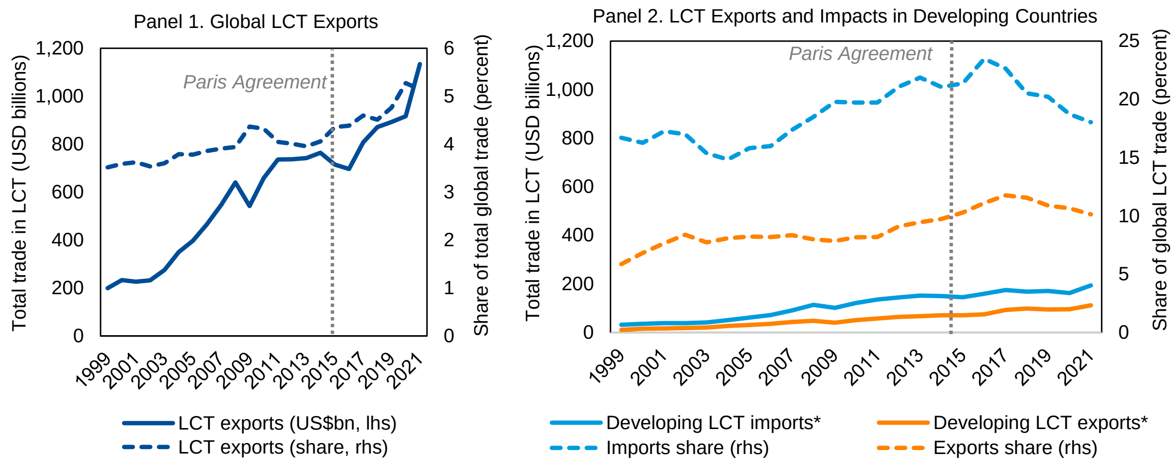
Figure 20. CO_2 Emissions Reductions in the NZE by LCT Development Stage



Source: IEA 2021.

[28] See https://www.ft.com/content/5dccf6be-eeee-4fab-b536-dffa748cecd0.
[29] International aviation has an offsetting mechanism (CORSIA) but, as noted in 0, offsetting is not explicit carbon pricing.
[30] See ICAO (2023). Note estimated revenues are likely overestimated here as the calculation excludes behavioral responses.
[31] LCTs can be considered products or technologies that produce fewer GHGs (including but not restricted to CO_2) than incumbent technologies (on a lifetime basis) or are critical for the low-carbon transition. See Howell and others (2023).

Figure 21. Growth in Low-Carbon Technology Trade Globally and in Developing Countries



Sources: Howell and others 2023; and IMF staff. Note: excludes China.

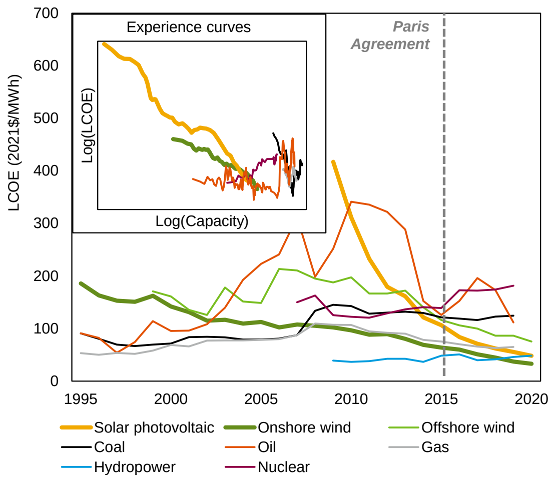
On <u>trade</u>, LCTs continue to flow globally at a growing pace (Figure 21, panel 1). Trade in LCT products—such as solar panels, electric vehicles, and wind turbines—has been growing steadily both in absolute terms and as a share of total trade. Between 1999 and 2021, trade in LCTs grew from $200 billion (a 3.5 percent share of total trade) to $1.1 trillion (a 5.1 percent share), growing at about 8 percent per annum. This trend has continued since the Paris Agreement, despite a slowdown in global trade (goods trade grew by just 2 percent per annum from 2015 to 2021).[32]

However, trade in LCT to and from developing countries has not kept pace with developed countries and trade patterns remain concentrated. Between 2015 and 2021, developing countries excluding China grew their LCT exports by 8 percent per annum and imports by 4.9 per annum. However, their share in LCT exports remains flat at about 10 percent and their share of imports has declined from about 21 to 18 percent. This is disappointing given the need to rapidly diffuse LCT in developing countries. Moreover, more than 60 percent of green patents during 1980-2000 were filed in just nine countries (G7 plus China and Korea)[33]. Additionally, production stages of LCT are concentrated in a small number of countries, notably advanced economies plus China. China is the largest trader in LCT followed by Germany, Japan, Korea, and the United States. The top 10 exporters of LCT[34] collectively account for 34 percent of global exports and 27 percent of imports, shares of which have barely changed since 2000. In UNFCCC discussions developing countries have long called for 'technology transfer' – interpreted here as both the physical transfer of LCTs ('adoption') as well as transfer of the know-how to use and produce them ('production'). If developing countries are to both adopt and produce LCT, domestic policy efforts will be required.

On <u>costs</u>, some progress has been made, notably the rapid decline in the costs of renewables (Figure 22; refer to Annex 7 for a case study). Solar and wind costs have declined precipitously, by about 90 percent from 2010 to 2020, with solar becoming the 'cheapest source of electricity' in history.35 For solar, domestic policies in multiple countries (for example, subsidization regimes in Europe combined with green industrial policies in China) combined with the critical role of trade allowed solar panels to be produced at rapidly declining costs (which simulations suggest can be expected to continue, albeit at slower absolute pace—see Annex 7).

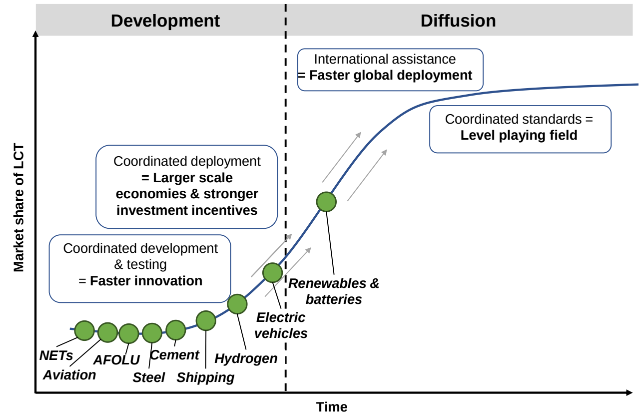
[32] See https://www.wto.org/english/news_e/news23_e/tfore_05apr23_e.htm.
[33] See Hasna and others 2023.
[34] In descending order (from 2021 exports): China, Germany, Japan, USA, Korea, UK, Italy, Hong Kong, France, and Singapore.
[35] See https://www.iea.org/reports/world-energy-outlook-2020/outlook-for-electricity

Figure 22. Historical Costs and Learning Curves for Power Generation



Sources: IRENA 2023; Way and others 2022; Ziegler and Trancik 2021a, 2021b; and IMF staff.
Note: LCOE = levelized cost of electricity; mwh = megatwatt hour.

Figure 23. Key New Low-Carbon Technologies and the Role of Global Cooperation



Sources: IEA, IRENA, and UNCCC 2022; Victor, Geels, and Sharpe 2019; and IMF staff.
Note: The technologies listed refer to the LCT variants (for example, green steel, green cement, green hydrogen, etc.). AFOLU = agriculture, forestry, and land use; NETS = negative emissions technologies.

However, there are several other technologies that need accelerating to achieve net-zero emissions in the long-term, necessitating international collaboration (Figure 23). Technologies essential to global net-zero include green cement, steel, hydrogen, shipping, aviation; negative emissions technologies (NETs) like direct air capture; and technologies for addressing agriculture, forestry, and landuse (AFOLU) emissions. These essential technologies are at early stages of development or have small market shares, so accelerating them down learning curves to accelerate their adoption will be critical. For this, global collaboration is needed. This could include coordinating over R&D (through global partnerships which can minimize duplication of research efforts), deployment (through joint targets or subsidies which can enhance policy certainty for firms), and standards (to minimize costs and maximize scale economies). Such actions can send powerful signals to the private sector, create markets and incentives for investment, while leveling the playing field to allow for competition. However, beyond international collaboration, domestic policies will be needed to accelerate the development of LCT.

Overall, the current global pace of development and diffusion of LCTs is insufficient: acceleration in all parts of the innovation chain is required.

Development of New Technologies

At a domestic level, the development of LCTs requires concerted policy effort. Recent evidence helps elucidate impacts of policies on innovation. Several studies have examined the impacts of carbon pricing on innovation, with some finding substantive effects (Prest, Burtraw, and Palmer 2021) such as moving firms to the technological frontier (Böhmelt, Vaziri, and Ward 2017; Fried 2018), while others find less substantive impacts, with strong disagreement within systematic reviews (Lilliestam, Patt, and Bersalli 2020, 2022; van der Bergh and Savin 2021).[36] On subsidies, two recent IMF studies find that feed-in tariffs, research and development subsidies, and other

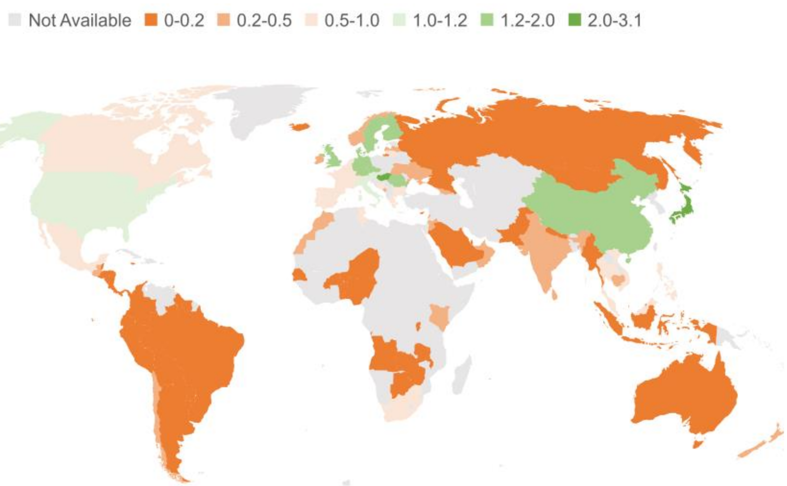
[36] Expectations of future carbon prices are critical for shifting investment patterns of firms (see, for example, Ohlendof and others 2022). Hence, governments implementing carbon pricing should ensure that the future pathway is clear and credible (for example, in carbon tax rate changes written into law or with an emissions trading scheme with a robust and rising floor price).

technology support instruments can have strong effects on accelerating green patents37,38 and hence innovation (Hasna and others, forthcoming; Bettarelli and others 2023). Lastly, beyond mitigation policies, exogenous technical change could affect the rate of low-carbon technologies development: artificial intelligence, for example, could accelerate LCTs as they absorb more positive innovation spillovers (Andres, Dugoua, and Dumas 2022).

The policy challenge is to optimally allocate scarce resources across this innovation chain: governments should target resources for LCT development carefully. In general, support should be targeted towards identified market failures in technology markets.[39] Technology experts suggest that subsidies for basic research may be especially beneficial[40]. However, governments need to be cognizant of ensuring that finance is available for intermediate stage technologies. Though carbon pricing can be beneficial throughout the innovation cycle, it becomes especially important at deployment stages. Additionally, deployment subsidies can help provide a bridge (for example, where new technologies are especially expensive for early adopters). In cases where costs of subsidies are high, governments may consider revenue-neutral options such as "feebates" (which combine fees on incumbent, high-carbon technologies which are used to subsidize subsidies or rebates on the newer, low-carbon technology).

Lastly, an increasing number of countries are seeking to develop green industries via 'green industrial policy'. However, developing such expertise is not easy, and starting positions vary (Figure 24). If the world gets on track to 1.5-2C, trade in these technologies can be expected to rise rapidly, presenting an opportunity for export-led growth. Countries that can integrate into global value chains for LCTs may see increases in their manufacturing sectors' output and, more speculatively, total factor productivity. However, doing so requires substantive increases in capacity at all levels of society, including the state, labor, and firm level. Human capital deepening through a general improvement in educational performance may be especially important in helping countries accelerate adoption and export of LCT (Pigato and others 2020). Additionally, countries' starting positions vary: a small number of countries have a relative comparative advantage in LCTs, mostly developed countries plus China.

Figure 24. Relative Comparative Advantage for LCTs, 2021



Sources: Howell and others (2023).
Note: No data was available for countries in grey. LCTs = low-carbon technologies. The boundaries, colors, denominations, and any other information shown on the maps do not imply, on the part of the International Monetary Fund, any judgment on the legal status of any territory or any endorsement or acceptance of such boundaries.

Countries are increasingly adopting green industrial policies (GIP) to produce LCT, though caution is warranted and core principles should be followed (refer to Annex 8). GIP is a form of

[37] A one standard deviation increase in policy stringency raises green patent filings 10 percent in five years (Hasna and others 2023)
[38] International climate policies such as the Paris Agreement are also found to have had a large impact on green patent filings.
[39] See, for example, Armitage, Bakhtian, and Jaffe (2023) for a discussion.
[40] See, for example, Newell (2015), and Cervantes and others (2023).

targeted (or 'vertical') policies to support domestic innovation and production. Recent examples include China's Five-Year Plans (refer to Annex 7), the United States' Inflation Reduction Act[41], and the European Union's Green Deal[42]. However, some caution is warranted. GIPs are subject to similar concerns as traditional industrial policy, including government failure, political risks, and high fiscal costs. Provisions such as domestic content standards are costly for the global economy and can undermine free trade principles.[43] Transparency about policy objectives and its design and duration as well as regular monitoring of costs and benefits against available fiscal space is warranted (Rodrik, 2004, 2014; Cherif and Hasanov, 2019; Cherif and others, 2022).[44] Lastly, not all countries can subsidize as it relies on available fiscal space and pre-existing national capabilities and infrastructure. While a world of increasing green subsidization can help accelerate LCTs down learning curves, they could also leave many developing countries behind (if middle income countries become producers of green technologies).

Diffusion of Existing Technologies

For transferring LCTs via their physical movement (in trade) and the know-how needed to operate them (in FDI and patent transfers), domestic mitigation policy is critical. By implementing substantive mitigation policies such as carbon pricing, countries can rapidly accelerate the rate at which they adopt LCTs. International economic policies also matter, notably policies on trade, FDI, and intellectual property (the latter two are beyond the scope of this note). For developing countries, implementing climate policies raises imports of LCTs and leads to higher levels of green FDI inflows, while lowering tariffs can significantly raise imports of LCTs[45]. For all countries, lowering tariffs on LCTs[46] as well as human and financial capital controls[47] can accelerate the flow of knowledge such as through patents transfers as well as imports of physical products.[48]

Though there is no "carbon subsidy" in global trade (Figure 25 and Figure 26), there is space to lower trade barriers further, and countries could consider a new LCT free trade agreement. Previous studies suggested a "carbon subsidy" exists in global trade policy (Shapiro 2021), whereby more carbon intensive products faced lower tariffs. However, when looking at LCT products specifically, tariffs tend to be *lower* than on other goods across.[49] Additionally, nontariff barriers such as regulations and standards on products are generally lower for LCT products (except for UMICs). Nonetheless, in both cases there is space to lower barriers even further. Doing so could accelerate

[41] See https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/

[42] See https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

[43] Some argue that global competition, though second-best to cooperation, could nonetheless achieve global mitigation as countries race to develop green industries, thereby lowering costs – see, for example, Kirkegaard 2023

[44] General economic development appears important for green innovation, while green innovation itself can support development. For example, growth in GDP per capita, human capital, organizational capital, institutional capital, physical capital, and financial capital are all associated with growing levels of LCT imports and exports (except financial capital which was not statistically significantly associated with LCT exports; Pigato and others 2020); larger and growing markets receive larger transfers of LCT patents (a 1 percent increase in GDP per capita is associated with a 1.2 percent increase in patent transfers from both high-income and developing economies; Pigato and others 2020) and have larger shares of LCT patents (Hasna and others 2023); and, lastly, more innovative countries tend to export more LCT. This suggests that, alongside 'vertical' policies designed to accelerate the production of LCT, broader economic development can support a country's efforts to innovate and produce LCT. Lastly, green innovation can help yield medium-term growth, supporting development efforts (Hasna and others 2023).

[45] A one standard deviation change in the stock of climate policies is estimated to increase bilateral green FDI inflows by 15 percent (Hasna and others 2023)

[46] An increase of one standard deviation in tariff barriers decreased LCT patent transfers from developed countries by 15 percent and transfers from developing countries by 26 percent. However, nontariff barriers may, counterintuitively, lead to higher patent transfers as they may encourage firms to interact with foreign markets through FDI instead of trade (Pigato and others 2020)

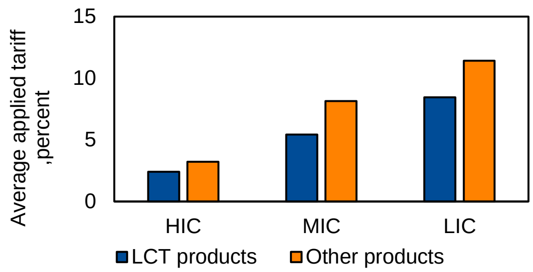
[47] An increase of one standard deviation in FDI restrictions reduced transfers of LCT patents from high-income economies to developing countries by 23 percent and transfers from developing countries by 41 percent (Pigato and others 2020)

[48] A one standard deviation reduction in import duties (about 1.5 percentage points) increase imports of LCT by about 5 percent (Hasna and others 2023)

[49] This contrast is due principally to the different definitions of goods: whereas 'clean' goods could include products with low carbon intensity but are not relevant for low-carbon transition (for example, primary crops), LCTs include technologies needed for global climate mitigation, and hence are a preferable set for examining obstacles to 1.5-2C.

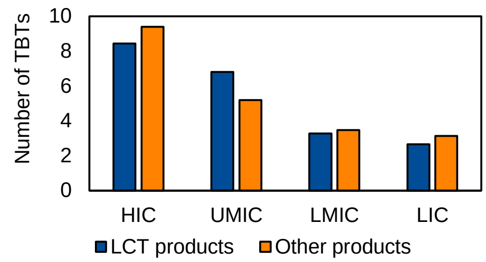
the diffusion of LCTs, especially in developing countries (by about 20 to 30 percent in developing countries[50]). Previous attempts to achieve a free trade agreement on a broader set of products have not been successful: the World Trade Organization's Environmental Goods Agreement talks collapsed in 2016, partly over the definition of an environmental good.[51] However, it may be easier to reach an agreement on a narrower set of products needed for the transition (this is, LCTs). Lastly, tariffs are higher in developing countries, and hence import duties can be significant for some countries. Agreement on lowering them may require complementary transfers.

Figure 25. Applied Tariffs Across Income Groups (2015-–21 average)



Sources: Hasna and others, forthcoming; Howell and others 2023; and UNCTAD, TRAINS database.

Figure 26. Number of Technical Barriers to Trade for LCT Products and Other Products

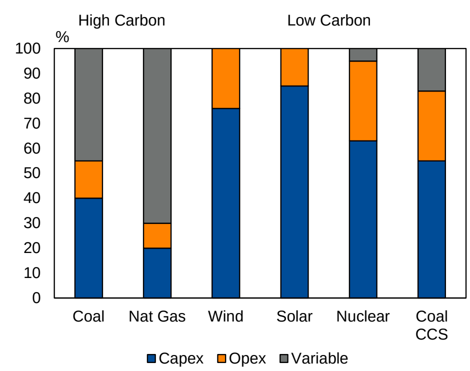


Source: Howell and others (2023); UNCTAD's TRAINS database.

Beyond domestic mitigation and trade policy, there are other barriers to scaling the technologies at the pace required. Such factors include the level of absorptive capacity (for example, human capital, firm- and state-level organizational capital), the need for enabling infrastructure (for example, in grid technology to facilitate scaleup of renewables), and financing constraints (from high cost of capital for non-climate reasons). These other constraints require targeted policies, such as public investments in enabling infrastructure and de-risking instruments to address the high cost of capital for LCTs in developing countries.

A major obstacle to scaling up LCT diffusion, especially in developing countries, is the high cost of capital. It has long been known that many (but not all) LCTs like renewables tend to have larger up-front costs compared with high-carbon incumbents like coal or gas plants (see Figure 27). Though operating expenditures can be significantly lower over time, high capital expenditures (due to the more expensive nature of the newer technology combined with high borrowing costs to finance its purchase) can be prohibitive for LCTs. As a result, borrowing costs can be major barriers to LCT adoption. This problem is especially pervasive in developing countries where perceived and actual political and currency risks yield significantly higher interest rates. For example, the International Energy Agency compared capital costs between advanced and emerging markets and found that the cost of renewables could be reduced by around 35 percent in emerging markets (excluding China) if they had access to capital at the same rate as advanced economies (Figure 28). This problem may have become worse given the higher interest rate environment.

Figure 27. Relative Costs of Power Generation Technologies

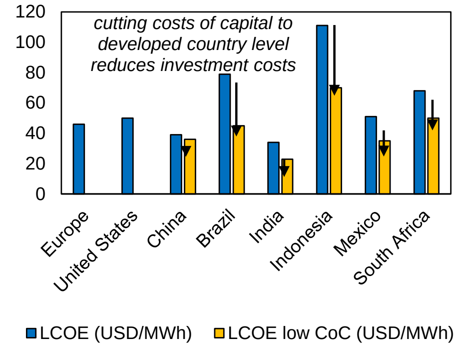


Source: Hirth and Steckel (2016). Note: variable costs are included in opex.

[50] Based on an assumed import elasticity with respect to tariffs of 3.5 to 4 – see footnote 45
[51] For a history, see https://www.csis.org/analysis/environmental-goods-agreement-new-frontier-or-old-stalemate

Structural policies in developing countries alongside new and reinforced instruments to reduce the costs of capital for LCTs in developing countries should therefore be considered. Predictable carbon prices are crucial for sending signals to investors but needs complementing with additional policies to lower capital costs. Structural policies aimed at strengthening macroeconomic fundamentals, deepening financial markets, improving policy predictability, and fostering institutional and governance frameworks, are key to lowering the cost of capital, mobilizing domestic financial resources, and improving credit ratings in developing countries (see Budina and others 2023). Expanded use of guarantees by multilateral development banks and donors could be an effective instrument to reduce real and perceived risks in developing countries, while blended finance (public and private finance combined) structures could improve the risk–reward profile of investment opportunities and broaden the range of private sector investors (see IMF 2023a and 2023b for details).

Figure 28. Cutting Capital Costs Reduces Investment Costs



Source: IEA (2021b).
Note: CoC = Cost of capital.

Conclusion

Overall, eight years on, the Paris Agreement is making progress on climate mitigation. Ambition has been enhanced moderately, though mostly by HICs which account for a shrinking share of emissions. Some progress has been made on climate finance, though the $100 billion target was missed. And diffusion of LCTs continues to grow gradually.

But global ambition and implementation falls far short of what is needed, while investment, finance, and technology are not progressing quickly enough. A robust response to the GST that scales up mitigation action in this decade is required.

Specifically, <u>getting climate ambition on track requires</u>:

- **Revising 2030 targets in NDCs to be Paris-aligned and equitable.** For example, ambition could be enhanced by setting targets depending on countries' per capita income levels, with more ambitious targets for more developed countries. Many options are possible, but it is critical to narrow the gap between countries' aggregated ambition and what's needed for 1.5 to 2°C.

Getting <u>policy implementation</u> on track requires:

- **Implementing policies needed for Paris-aligned NDCs.** Policy packages are needed, ideally including a robust and rising carbon price, reinforcing instruments in hard-to-abate sectors, and further measures to address impediments to clean technology and investment. These reforms can be equitable (for example, reducing poverty), improve fiscal balances, and have substantial domestic welfare co-benefits, even before considering climate benefits.

- **Scaling-up and reinforcing international cooperation and coordination.** This could include new instruments such as an international carbon price floor (ICPF) among major emitters.

Getting <u>finance and investment</u> on track requires:

- **Significantly increasing total mitigation investment and the private sector's share of it.** A sixfold increase in global clean energy investment is needed by 2030. To substantially raise the private sector's share in investment especially in developing countries, incentives are needed, notably a robust, rising carbon price or equivalent policies.

- **Setting a new collective quantified goal on climate finance, framed as a joint target for developed and developing countries.** A transparent methodology for the target beyond $100 billion is needed, for example, linked to investment needs (as in the illustrative calculation) as well as policy in developing countries. In addition, given the critical role of policy in developing countries for attracting private finance, the new target should be a joint target and policy-based climate finance should be scaled up.
- **Considering new sources of funding, such as a global tax on international aviation and maritime transport.** The need to decarbonize aviation and shipping deserves more focus and can also serve as a source of revenues for global mitigation and adaptation investment. A carbon tax on aviation and maritime of $75 per ton by 2030 could raise up to $100 billion by 2030.

Getting technology on track requires:

- **Accelerating the development of early-stage LCTs.** Almost half of the technologies needed for achieving NZE by midcentury are in early stages of development. Countries with capacity to lead in this area should consider targeted support, ideally in a collaborative manner across countries.
- **Pursuing international collaboration, such as a new free trade agreement on LCTs.** Cooperation can accelerate LCT development and diffusion. Though LCT trade barriers are not higher than on other goods, they could be lowered and standards harmonized.
- **Cutting capital costs in developing countries through structural reforms and financial instruments** such as multilateral guarantees and blended finance.

Annex 1. A Stocktake of G20 Mitigation Effort

Countries are increasingly adopting a sectoral approach in mitigation strategies. Annex Table 1.1 shows sectoral mitigation policies and targets in Group of Twenty (G20) countries as of 2022.

Annex Table 1.1. Sectoral Mitigation Policies and Sectoral Targets, G20 Countries as of 2022

	Instrument/coverage (Augest 2023, 2030 prices, US $/ton)[a]	**Power** generation shares, % Renewables		Coal		**Industry**	**Transport** CO2/km		% EVs in vehicle sales		**Buildings**
		2021	Future target (year)	2021	Future target (year)		2021	Future target (year)	2021	Future target (year)	
Argentina	Carbon tax for all emissions (5,5)	0	20 (2025)[d]	1							
Australia		0	68 (2030)	51		Reduce the energy intensity of industry 30 percent between 2015 and 2030.			1	30 (2030)	
Brazil		0	[e]	5			125	119 (2022)	<1		
Canada	Carbon tax/ETS for power, industry, transport, buildings (40, 140)	0	90 (2030)	4	0 (2030)		123	100 (2026)	4	100 (2035)	All new buildings net zero emissions by 2030.
China	ETS for electricity to be expanded to industry (9, 9)[b]	0	80 (2060)	56		Peak aluminium and steel CO_2 emissions by 2025, and reduce them 40 and 30 percent, respectively from that peak by 2040.	116	72 (2030)	6	100 (2035)	Green buildings to account for 50% of new urban buildings.
France	EU ETS for power/industry (87,140), domestic tax for industry/buildings/transport (49, 60)	0	40 (2030)[f]	1	0 (2022)	Reduce (all GHG) emissions from industry 37 percent by 2030 relative to 2019.	100	61 (2030)	11	100 (2030)[f]	Reduce building sector emissions 44% below 2020 emisisons by 2030; EU legislation requires all new buildings to be nearly zero energy.
Germany	EU ETS for power/industry (87,140), domestic ETS for buildings/transport (33,55)	0	80 (2030)	17	0 (2030)	Reduce CO_2 emissions 49-51 percent below 1990 levels by 2030	100	61 (2030)	14	100 (2030)[f]	Reduce building sector emissions 43% below 2020 emisisons by 2030; EU legislation requires all new buildings to be nearly zero energy.
India		0	50 (2030)	64			114	112 (2022)	<1	30 (2030)[h]	Reduce energy use for new commercial buildings 50% by 2030.
Indonesia		0	48 (2030)	51	30 (2025)				<1	numeric (2025)[i]	Reduce energy intensity ≥ 1% per year till 2025.*
Italy	EU ETS for power/industry(87,140)	0	55 (2030)	5	0 (2025)		100	61 (2030)	4	100 (2030)[f]	Reduce building sector emissions 25% below 2020 emisisons by 2030; EU legislation requires all new buildings to be nearly zero energy.
Japan	Carbon tax for all emissions (2,2), Subnational ETS schemes	0	36-38 (2030)	36	19 (2030)	Reduce CO_2 emissions 38% below 2013 levels by 2030	106	92 (2030)	<1	100(2035)	Reduce building sector CO_2 emissions 66% below 2013 levels by 2030. All new houses net zero emissions by 2030.
Mexico	Carbon tax for all emissions (0.4-4,0.4-4)[c]. Subnational CT schemes	0	35 (2024)	5			114	85 (2025)	<1	n/a[j]	All new buildings net zero emissions by 2030.
Russia		0	20 (2020)	9						production (2030)[k]	Reduce energy consumption for all buildings 3.7% a year 2031-2050.
Saudi Arabia		0	50(2030)	0						30 (2030)	
South Africa	Carbon tax for all emissions (10, 10)	0	41(2030)	87		Reduce energy consumption of manufacturing 16 percent below 2015 levels by 2030.	138	n/a	<1		All new buildings net zero emissions by 2030.
Korea	ETS for power/industry/buildings (19, 19)	0	30 (2030)	30	0 (2050)		98	84 (2030)	3	numeric (2025)[l]	All new buildings net zero emissions by 2030.
Turkey	National ETS schemes	0	60(2030)[g]	19		Reduce energy intensity by at least 10 percent in each sub-sector by 2023 (2011 baseline)				numeric (2030)[m]	
UK[n]	ETS for power/industry (99), domestic tax for power (24)	0	100 (2035)	2	0 (2024)	Reduce CO_2 emissions 67 percent below 2018 levels by 2035.	100	61 (2030)	11	100 (2030)	Reduce CO2 emisisons for all new buildings 75-80% by 2030.
US	Subnational ETS schemes	0	28(2030)[g]	12			123	100 (2026)	2	50 (2030)	All new buildings net zero emissions by 2030.

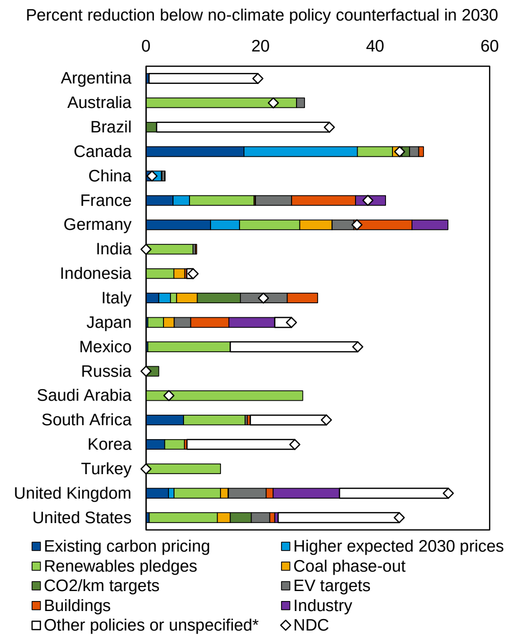
Source. Black and others (2022a).

Notes. [a]Where prices, or caps in ETSs, are not specified in legislation for 2030 they are based on 2022 prices or, as in Germany, the last available year where a price is specified. For the EU ETS, the 2030 price is an estimate based on CPAT. [b]China's ETS takes the form of a tradable emission rate standard. [c]Mexico's carbon price on additional CO_2 emission content compared to natural gas. [d]Argentina's target excludes large hydro, which is included in its generation share. [e]Brazil's latest NDC no longer includes a renewable target. [f]EU wide target. [g]Inferred from numeric targets. [h]Target is for private cars. Target for commercial vehicles=70%, buses=40%, two and three-wheeler sales=80%. [i]Target of 2 million EVs in the passenger vehicle stock by 2025. [j]No federal target but Jalisco, Mexico committed to 100(2030). [k]Annual EV production target of 220,000 units by 2030. lTarget of 1.13 million EVs in the passenger vehicle stock by 2025. [m]Target of 1 million EVs in the vehicle stock by 2030. [n]For the UK, 2030 assumption is that the ETS prices would be comparable to EU ETS.

These sectoral policies and targets can be analyzed in terms of their emissions impacts relative to countries' economy-wide emissions target in NDCs. For example, Black and others (2022a) provides a stocktaking of these policies for G20 countries. The main points include[52]:

- *Economywide:* Carbon pricing schemes are operating in 12 G20 countries.
- *Power generation*: almost all countries have targets for renewables and eight have coal phase out plans. Common policies include renewable subsidies (for example production tax credits, feed-in tariffs providing above market prices) and minimum generation shares for renewables.
- *Transportation*: Aside from fuel taxes, CO_2 emission rate or fuel economy standards for vehicle sellers apply nationally in 9 G20 countries and at the EU level, while 15 countries have targets for phasing in electric vehicles or phasing out internal combustion engine vehicles—feebates apply in some form in nine countries.[53]
- *Buildings*: France, Germany, Italy, and Japan have targets for reducing energy use from the total building stock, while nine other G20 countries have targets for making all new buildings net zero emissions by 2030 or later. Multiple instruments are used to implement these goals such building codes; incentives for insulation, heat pumps, and rooftop solar; and efficiency standards for appliances.
- *Industry*: This sector is generally subject to lighter emissions targets and policies than for other sectors—only five G20 countries have binding emissions targets for industry.

Annex Figure 1.1. CO_2 Impacts of Policies and Sectoral Emissions Targets in 2030, G20 Countries (as of 2022)



Source: Black and others 2022a.
Note: *"Other policies or unspecified" includes policies not quantified in this exercise or not yet specified by the authorities. Does not include policies enacted since the working paper such as the United States' Inflation Reduction Act or the European Union's Green Deal.

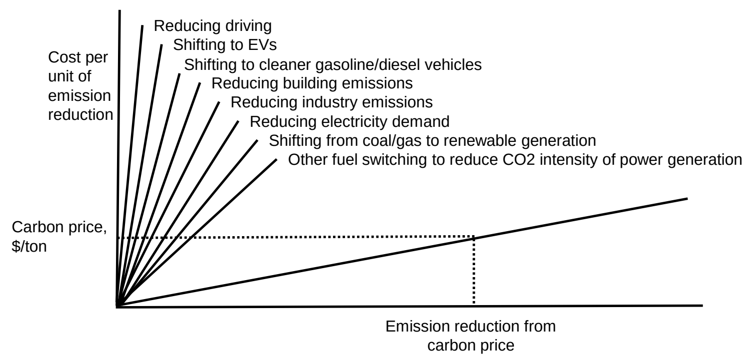
Annex Figure 1.1 **shows estimates of the CO2 emissions impacts of existing and planned mitigation policies and sectoral emissions targets relative to a baseline for 2030 with no carbon pricing.** The combined impacts of these measures would be to cut emissions between 20 and 50 percent in 11 countries but by less than 10 percent in 7 cases. Countries vary significantly in their choice of instrument and relative contribution of sectoral targets, though renewables policies make a significant contribution to reductions in 15 cases and carbon pricing in 8 cases. Countries also vary in the extent to which policies achieve economy-wide mitigation pledges in their NDCs. These targets are not binding, or barely binding, in four cases (including two of the three largest global emitters, China and India), while in another seven cases the economy-wide emissions reductions from specified policies and targets fall well short of the reductions needed for NDCs.

[52] Individual policy impacts are difficult to decompose given overlaps and hence policies should be interpreted as a combination.
[53] Feebates apply a sliding scale of fees to activities or products (like vehicles) with above average emissions intensity and a sliding scale of rebates for products or activities with below average emissions intensity. See Parry (2021).

Annex 2. Why Economists Emphasize Carbon Pricing

Governments have a central role in decarbonization through shifting incentives. Households and firms need to be incentivized to adopt new LCTs while investing in innovation and conserving energy. To maximize the effectiveness of incentives, as many margins of behavior need to be leveraged. For example, if a government is only able to reduce emissions through policies that restrict driving then for a large reduction in emissions social costs will be high. But if the government can also reduce emissions through incentivizing shifts to electric vehicles or more efficient gasoline vehicles then the same emissions reduction can be achieved at a lower cost (Annex Figure 2.1).

Annex Figure 2.1. Illustration of Margins of Behavior and the Costs of Cutting CO_2 Emissions



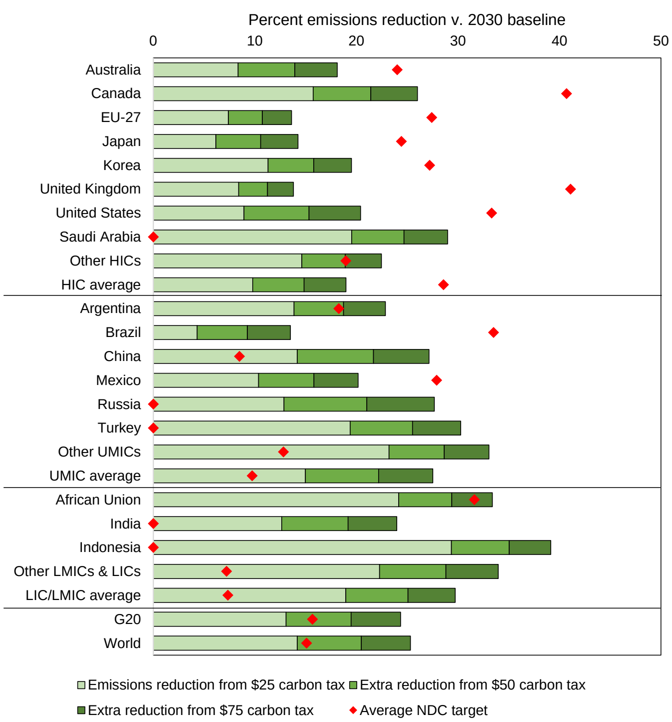
Source: IMF staff.

Among policies, carbon pricing leverages the largest number of behavioral responses, and hence is the most effective (can achieve the largest amount of emissions reduction given some social cost) and efficient (minimizing social costs) single instrument. As a result, it is favored by economists as the most desirable instrument for decarbonization. For example, when comparing current NDCs for G20 countries, a moderate carbon price could make a significant contribution to achieving countries' pledges. Though in several cases more policies will be needed, and in others targets themselves are non-binding or easily achieved (se previous section) carbon pricing can make a large contribution to achieving emissions reductions. Pricing alone cannot achieve the cuts needed at the pace required (see following discussion), but among policies it can make by far the largest contribution.

In addition, the potential medium-term revenues from carbon pricing are sizable (Annex Figure 2.2).

For example, carbon prices of $50 per ton would raise revenues of about 0.5–2 percent of GDP in 2030 (see Figure 8 in Box 1)—revenues are larger in countries

Annex Figure 2.2. CO2 Cuts, NDCs and Carbon Pricing, G20 Countries 2030



Source: IMF staff using CPAT. Note: NDCs assume CO_2 emissions are reduced in the same proportion to pledged reductions in GHGs.

with higher emissions intensity of GDP—and would cut emissions substantively across countries cost (Annex Figure 2.2) . New sources of fiscal revenues are especially appealing in countries where revenue mobilization from broader fiscal instruments is insufficient due to large informal sectors. Ultimately revenues from carbon pricing will need to be replaced by other sources, though this will not be an issue until the latter part of the clean energy transition.

However, it should be noted that there are various other frictions and market failures that, even with carbon pricing, impede LCTs from being adopted at the pace required for net-zero (Annex Table 2.1). As a result, other policies beyond pricing are needed to reinforce incentives and accelerate the development and adoption of these technologies, especially in hard to abate sectors.

Annex Table 2.1. Impediments to the Development and Diffusion of LCTs and Policies to Address Them

Market failure/impediment	Problem(s)	Outcome	Example	Importance	Optimal policies to address
Research: basic research (mostly public)	Knowledge spills over to other firms; commercial applications from scientific discoveries are highly uncertain	Private sector investment essentially non-existent	General scientific research in government labs and academic institutions in novel forms of clean energy	Unknown: could become important to decarbonization in later decades (e.g. fusion)	Subsidization/grants of universities and research labs, prizes
Innovation: applied R&D (mostly private)	Spillovers to other firms that may imitate technology or use embodied knowledge to further their own research	Under investment by private sector even with robust carbon price	Focused research on monetizable innovations such as solid state batteries	High: likely to hold back investment in critical technologies (e.g. CCS, batteries, green aviation)	Intellectual property, R&D subsidies, prizes (where technologies identified in advance)
Deployment: learning-by-doing externalities & scale economies	Firms get better at producing technologies over time (cost curve shifts downwards); average unit costs decline as firms/industries scale	Slow deployment of LCT	Producers of EVs get better through e.g. automation and average costs decline with firm/industry scale (given fixed costs of e.g. factories)	High: LCTs (e.g. renewables, batteries, EVs) have shown large learning-by-doing and scale economies	Deployment subsidies (declining with production levels), advance market commitments, carbon contracts for difference
Deployment: high financing costs	Key low carbon technologies (e.g. renewables) have high up-front investment costs and low marginal costs, increasing importance of costs of capital	Low investment in LCT where costs of capital are high	Capital costs inhibit private investments in solar and wind projects in developing countries	High: major impediment in developing countries, less in developed countries	International climate finance: grants, de-risking instruments, blended finance
Deployment: network externalities	Marginal benefits to producers/users increase with cumulative deployment; one system relies on existence of a network	Under investment in enabling infrastructure by private sector and/or zero output of LCT	Renewables require high-voltage transmission lines at high penetration levels	Medium: Key LCTs rely on infrastructure (e.g. grids for electrification) but public investment needs are moderate	Public investment in enabling infrastructure (e.g. smart grids, charging stations, public transportation)
Deployment: slow capital turnover	Some energy consuming goods have long economic lives and are expensive to replace or retrofit	Lock-in of high-carbon consumption and/or delayed action until infeasible	Buildings turn over at a slow pace and there are hard constraints on pace of retrofits (e.g. 2% max per year)	Medium: major impediment in some sectors (e.g. buildings, power) but less in others (e.g. industry)	Targeted subsidies for e.g. retrofitting buildings, accelerated depreciation, and low-carbon, long-life capital goods

Source: IMF staff.
Note: CCS = carbon capture and storage.

Lastly, it is important to note what carbon pricing is not – offsets are not considered here to be explicit carbon pricing mechanisms. Explicit carbon pricing includes carbon taxes and ETSs and does not usually include ‘offsetting’ mechanisms. This includes trading in voluntary carbon credits, Clean Development Mechanism ‘certified emissions reductions units’, or the exchange of ‘internationally traded mitigation outcomes’ under the Paris Agreement. Offsets, in general, do not add an additional price on new carbon emissions but rather monetize existing or avoided emissions, and hence their role in decarbonization is heavily contested, while the potential for offsets to be a revenue-raising mechanism is highly uncertain (refer to Annex 6). Though elements of offsetting could be incorporated into explicit carbon pricing systems (though their desirability is questionable), the central policy challenge of carbon pricing is to implement an additional price on emissions through a carbon tax or an ETS.

Annex 3. Comparison of Climate Mitigation Policies

Policymakers have several options to choose from when designing mitigation strategies. Annex Table 3.1 presents a typology of mitigation instruments, depending on whether they are market-based (i.e. focus on price incentives) or non-market based (regulations, subsidies, and investments). Additionally, policies can be further delineated between those that seek to cut GHGs and those which cut emissions as a byproduct (non-climate polices).

Annex Table 3.1. Typology of Climate Mitigation Instruments

	Market-based instruments		**Non-market based instruments**	
Type / Objective	***Price-based***	***Quantity-based***	***Regulations***	***Subsidies & investments***
Climate Mitigation Policy (main motivation is emissions reductions)	• Carbon taxes • Feebates • Vehicle CO2 intensity taxes	• Emissions trading systems (ETSs) • Tradeable performance standards (TPSs)	• Emissions intensity standards • Technology mandates • Energy market reform	• Subsidies for LCT development and deployment • Public investment in enabling infrastructure • Feed-in tariffs & subsidies
Non-climate Policy (other motivation but relevant for climate)	• Implicit carbon pricing: fuel excise taxes • Negative carbon pricing: explicit fossil fuel subsidies	• Electricity excise taxes and subsidies • Some industrial/ agricultural subsidies	• Air pollution standards • Fertilizer regulations • Fuel efficiency regulations	

Source: IMF staff.

These policies have varying attributes in terms of their desirability, feasibility, and effectiveness. Annex Table 3.2 below compares policies and lists complementary instruments to overcome impediments to decarbonization, such as knowledge spillovers and household impacts.

Annex Table 3.2. Comparison of Climate Mitigation Policies

Mitigation Instruments		Desirability and feasibility				Environmental effectiveness by sector						
Coverage	Instrument	Economic efficiency	Revenue mobilization	Administrative practicality	Political acceptability	Power	Industry	Transport	Buildings	Forestry/ land use	Extractives (CH4)	Livestock (CH4, NOx)
Economy-wide: carbon pricing	Carbon taxes					✓✓✓	✓✓✓	✓✓	✓✓	✓	✓✓✓	✓✓✓
	Emissions trading systems (ETSs)					✓✓✓	✓✓✓	✓✓	✓✓	✓	✓✓	✓✓
Sectoral	Feebate (fees/rebates for dirty/clean firms/ products/activities)					✓✓	✓✓	✓✓✓	✓✓	✓✓	✓✓	✓✓
	Tradable performance standards					✓✓	✓✓	✓✓			✓	✓
	Abatement subsidies					✓	✓	✓✓	✓	✓	✓	✓
	Requirements for green technologies/ activities					✓	✓	✓✓	✓✓	✓	✓	✓

Complementary policies		Impediments to investment/innovation		Equity/acceptability	
	Issue	Network externalities for clean technologies	Spillovers from new knowledge/technologies	Burdens on households	Burdens on firms
	Instruments	Public investments	R&D incentives, timebound technology subsidies	Targetted assistance, equitable revenue use	Output-based rebates, tax relief, border adjustments

Key:

Declining efficiency/revenues/practicality/acceptability

✓ = somewhat environmentally effective
✓✓ = effective
✓✓✓ = very effective

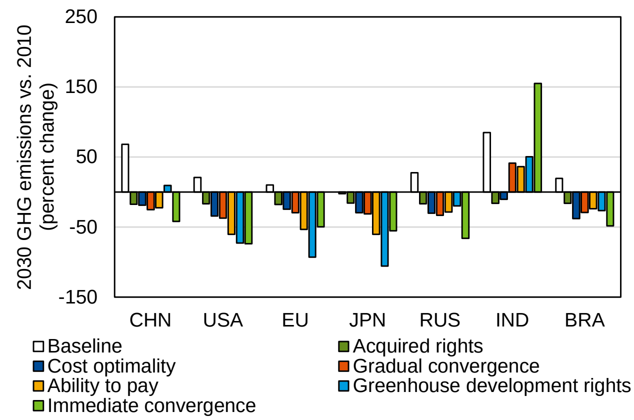
Source: IMF staff. Note: CH4 = methane; NOx = nitrogen oxide.

Annex 4. Perspectives on Equitable Ambition Scenarios

Climate change and equity are intrinsically linked and central to discussions how quickly different countries should decarbonize. 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 (see van der Berg and others 2020) [54]:

1. **Acquired rights** ("grandfathering")—countries cut emissions proportionate 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 cuts 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;
6. **Greenhouse development rights (GDR)**—emissions cuts are based on a mixed measure of historical responsibility and capability which includes GDP per capita and carbon intensity.

Annex Figure 4.1. Emissions Reductions under Six Equity Allocations



Source: van der Berg and others (2020).
Note: uses International Organization for Standardization (ISO) codes.

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 4.1). Acquired rights and cost-optimal paths lead to fewer emissions reductions in 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 MICs and 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 percent for Japan under GDR, i.e. requiring carbon removals) and much smaller reductions in developing countries (for example, above BAU for India under GDR).

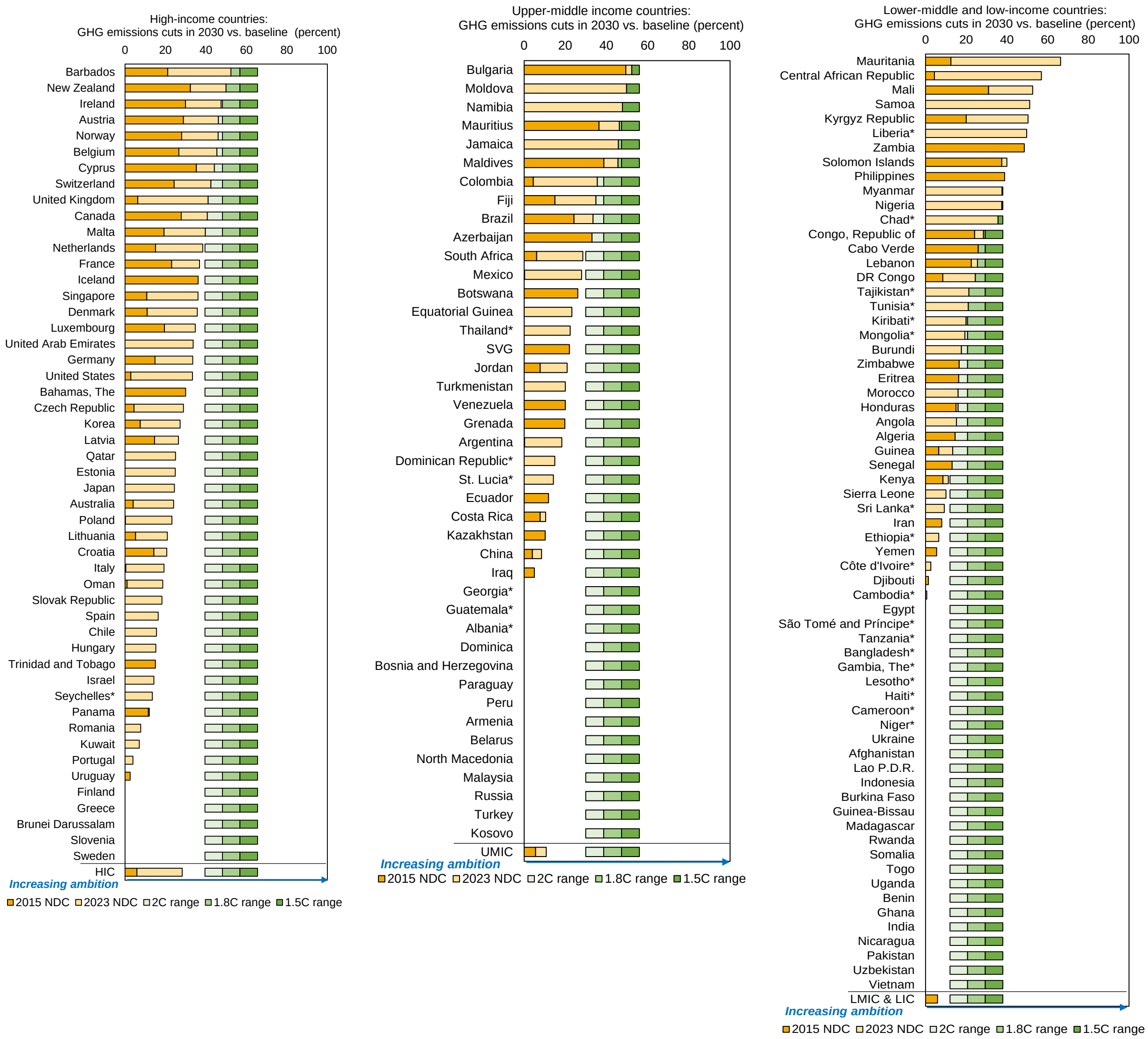
Given these differences, one approach to estimating a relatively high equity case is "trimming": excluding the least and most equitable approaches (acquired rights and GDR, respectively) and taking an average of the four remaining scenarios (cost optimality, gradual convergence, ability to pay, and immediate convergence). Emissions reductions targets for 2030 compared with BAU 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). 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.

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

Annex 5. Country Mitigation Ambition in NDCs for All Countries

Annex Figure 5.1 present estimates of country ambition in NDCs for 156 countries using the IMF-World Bank Climate Policy Assessment Tool. It does so for countries by income group (HICs, UMICs, LMICs/LICs) and compares to the Paris-aligned cuts estimated (refer to Equitable and Paris-Aligned Emissions Reductions).

Annex Figure 5.1. Country Mitigation Ambition (in NDCs) and Ambition Gaps for All Countries



Source: IMF staff using CPAT.
Note: Where no NDC is shown, the target is nonbinding and is assumed achieved in the baseline or is nonquantifiable (for example, Bahrain, Bhutan, Saudi Arabia, and others). Countries with asterisks (*) decreased ambition in 2023 NDCs relative to 2015 NDCs, so the figure shows only 2023 NDCs. NDCs for EU countries are inferred using national allocations for non-ETS sectors (in effort-sharing regulations) and an assumed similar reduction in EU ETS sectors. NDCs average over conditional and unconditional targets where both are specified.

Annex 6. The Uncertain Promise of Carbon Credits for Finance and Mitigation

Under the Kyoto Protocol, developing countries were expected to mitigate principally through the sale of carbon credits which would then be used in regulated markets (like ETSs) in developed countries. Additionally, some (mostly Eastern European transition) countries could sell excess allocations in their national targets to developed countries.[55] The experience of these mechanisms on behalf of both developed and developing countries was mixed:

- Developed countries that accepted offsets in compliance markets (for example, regulated entities using offsets in lieu of permits) became concerned about their additionality and banned them in many cases. A report for the European Union found that 85 percent of the credits used in lieu of official ETS permits were non-additional, and hence their use *increased* global emissions (Cames and others 2016).
- Developing countries expected large sources of climate finance from credit sales, and set up complex monitoring, reporting, and verification systems. But they were disappointed when demand disappeared, prices dropped sharply, and the expected climate finance did not emerge.

Today, in an apparent repeat of the Kyoto experience, several developing countries remain expectant that carbon credits can be a source of climate finance, either through firm-to-firm exchanges of carbon credits, revenues on those exchanges, or direct sales of sovereign credits to developed country governments (in the form of "internationally-traded mitigation outcomes" under Article 6 of the Paris Agreements). However, developed countries appear hesitant to purchase these credits given the experience of the Kyoto mechanisms. Crucially, these mechanisms may be exacerbating the policy gap problem: if developing countries can sell credits for emissions below their NDC then they are disincentivized from enhancing (that is, lowering the target in) their NDC. Lastly, rules and procedures governing carbon credit exchanges are still – eight years on – not fully clarified. This may be leading to costly delays in implementation as governments wait for clarity.

The purpose of the offset is not to reduce total emissions but rather to promote a more cost-effective balance of mitigation between sectors that are, and are not, covered by formal pricing schemes. Offset programs might however end up increasing emissions for various reasons.

- Offsets may not always be additional (that is, a project might have gone ahead anyway even without the offset payment).
- The offset may not be permanent (for example, forests may subsequently burn down, releasing the sequestered carbon).
- Governments of both the buyer and the seller of the offset may count it towards meeting their mitigation pledges.

Some of these concerns might to some degree be addressed through, for example, third-party verification of offsets and incentives to address risks that offsets are not permanent (such as requiring sellers of forestry offsets to take out insurance in case they become liable for repayment in the event of forests being destroyed).

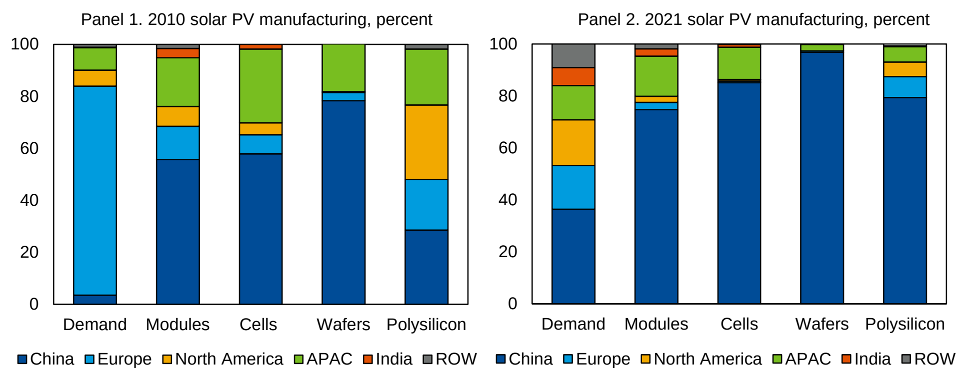
[55] These two mechanisms were known as the Clean Development Mechanism and the Joint Implementation mechanism. Their respective carbon credits are known as Certified Emissions Reductions and Emissions Reductions Units – the latter were converted from national 'Assigned Unit Amounts' through projects. For a more detailed history refer to Black 2018.

Annex 7. Accelerating LCTs: Solar and Wind Example

For global decarbonization, it's essential that LCTs be made cheaper. Photovoltaics (PVs), alongside wind, provides a potentially instructive example (Annex Figure 7.1, panel 1). The pace of adoption of solar and wind continues to rise, with renewables rising from 16.6 percent of global power generation in 2015 to 40.9 percent in 2022 (Energy Institute 2023). Renewable technologies are critical to decarbonizing both the production and consumption of energy, as renewables will need to account for the majority of power production by midcentury[56] and can help decarbonize hard-to-abate sectors like industry through the provision of green hydrogen.

Renewables have declined in cost rapidly, facilitated by a mix of: early stage subsidization in renewables, late-stage subsidization and carbon pricing in key adopting countries, and trade linkages. For solar and wind, subsidies for deployment (in Western Europe and US), combined with green industrial policy (in China), and global production facilitated by trade can combine to support global decarbonization (though at some cost to production diversification). Though these policies were not coordinated globally, they provide an illustrative example to the channels that governments should leverage as they seek to develop and diffuse other essential LCTs.

Annex Figure 7.1. Solar Photovoltaic Manufacturing Capacity by Country and Region, 2010 and 2021



Source: IEA 2022. Note: The figure shows the composition of solar PV by country and region in 2010 and 2021 in terms of global demand and the respective, concurrent manufacturing stages: modules, cells, wafers, and polysilicon, respectively. APAC = Asia-Pacific region excluding India.

There has been exponential growth in innovation and deployment of solar PV technology since the 2000s. Green subsidies, feed-in tariffs, tax credits, loan guarantees, grants, and favorable regulations have been effective in promoting the growth of the solar panel industry, notably in China, Germany, Japan, and the United States. These policies have helped reduce manufacturing costs dramatically, allowing for a 35-fold increase in new solar power capacity in 2015 relative to 2006 (IEA 2016; Gerarden 2023). As a result, solar PV has become the most affordable electricity generation technology in history (IEA 2023b), making it cheaper than fossil fuels in most countries.

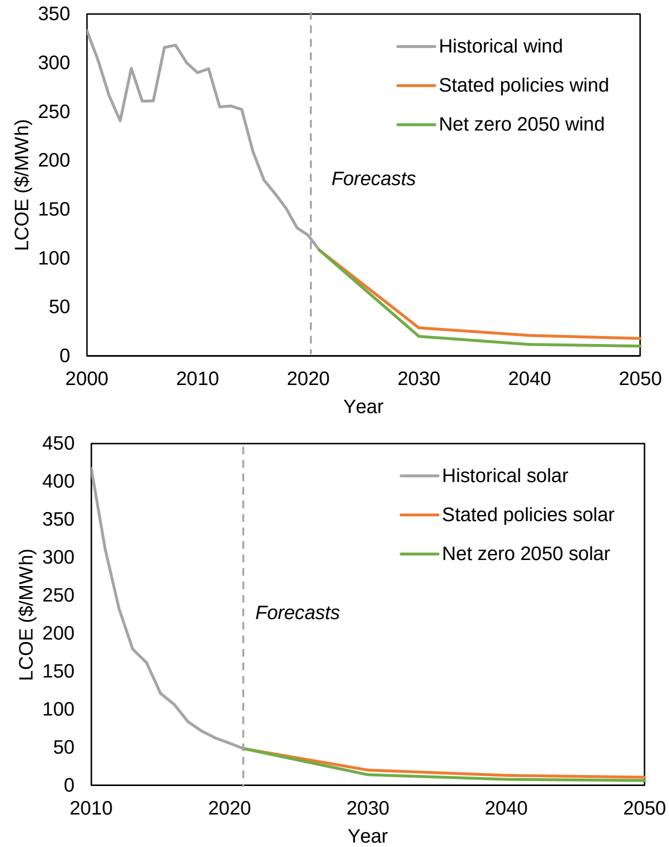
Subsequently, China became the world's largest producer of solar panels (Annex Figure 7.1). In the mid-2000s, China began implementing strong government policies to support the domestic solar industry via subsidies (for example, a multi-tiered feed-in tariff system across different regions in China), tax incentives, favorable land use policies, and low-interest loans, enabling economies of scale, supporting continuous innovation, and shaping the global supply chain, demand, and price of solar PV. Since 2011, China has invested 10 times more than Europe ($50 billion) in new PV supply

[56] In the IEA's NZE scenario, renewables plus nuclear account for 80 percent of all power production in 2050, up from less than 20 percent in 2021 (IEA 2023a)

capacity, and it now has more than 80 percent of global manufacturing capacity (IEA 2022).57 These government policies have contributed to a cost decline of more than 80 percent and made China the home of the world's top 10 suppliers of solar PV equipment, boosting the clean energy transition.

As renewable adoption continues and firms reap scale economies, simulations suggest that these declines can be expected to continue (Annex Figure 7.2), albeit at a slower absolute pace. The cumulative production of solar and wind technologies are regressed on levelized costs of electricity. This is then combined with International Energy Agency scenario forecasts of capacity additions (stated policies and net zero-aligned scenarios) suggests that costs for renewables could decline even further in coming decades. Such a continued decline in costs would make adoption and hence decarbonization easier (though not guaranteed) for all countries.

Annex Figure 7.2. Forecasts of Future Renewables Costs (Wind and solar; to 2050)



Source: IMF staff.

However, increasing concentration in supply chains for renewables also creates risks. China's green subsidies and predominant role have led to supply-demand imbalances in the solar PV supply chain, while its share of global key manufacturing stages (polysilicon, ingot, and wafer) production will soon reach almost 95 percent, with a single province in China (Xinjiang) accounting for more than 40 percent of global polysilicon. Given the importance of global decarbonization, and the role of renewables in it, this geographical concentration in the global supply chain is likely sub-optimal. Diversification of the global supply chain for renewables may therefore help reduce risks and vulnerabilities of the energy transition.

57 International Energy Agency (2022). Special Report on Solar PV Global Supply Chains.

Annex 8. IMF Guiding Principles for Green Industrial Policies

GIPs broadly refers to government efforts to promote LCTs through targeted measures, such as subsidies and tax incentives, on specific domestic firms, industries/sectors, or regions. In implementing GIPs, governments should follow these principles:

1. **GIPs should address environmental externalities, particularly for nascent technologies.** They should be clearly aimed at addressing market failures that hinder decarbonization rather than other considerations such as competitive advantage, domestic employment, and national security. Innovation and research in new green technologies that are underinvested due to a high risk and cost with positive social spillovers could instead be supported by R&D grants and tax credits.
2. **GIPs should complement core decarbonization policies (notably carbon pricing)** by accelerating the innovation, adoption, and production of LCTs. While carbon pricing remains a critical tool in decarbonization, political difficulties mean that emissions are not sufficiently priced in many countries, and technology market failures prevent its development and adoption at the needed rate. Fiscal support for innovation, adoption, and production of LCTs can therefore play a supporting role in the green transition. While research and development incentives help overcome innovation externalities, support for technology diffusion and adoption can help overcome learning-by-doing externalities as well as the high up-front capital costs of adopting green energy. GIPs can facilitate early deployment of LCTs through investment and output subsidies or tax incentives, energy procurement policies, or financial support.
3. **Policies should be time-bound, cost-effective, and transparent while limiting fiscal burdens.** They should be designed to be temporary, with clear end or review dates specified from the outset. Policymakers also need regular re-assessment on (1) the fiscal costs and benefits relative to available fiscal space; (2) the nature and magnitude of the targeted market failures and whether intervention is still warranted; and (3) the risks related to government failure and weak governance.
4. **GIPs should be conducted within an appropriate institutional framework to minimize implementation risks.** Transparency is critical to ensure effective tax compliance and administration. Green policy goals need to be clearly identified, whether for development of new green technologies, their rapid deployment, or stimulation of consumer demand. Transparency can also help facilitate international coordination, allowing data on green industrial measures (especially subsidies) to be collected and shared through international institutions.
5. **Policies should be consistent with World Trade Organization legal obligations, minimize adverse spillovers, and avoid barriers on technology transfers, especially to developing countries.** Uncoordinated policies, particularly those that lead to a “subsidy war” or result “beggar-thy-neighbor” effects, are an ineffective way to address climate change and undermine the core rationale for interventions. A global approach with coordinated, nondiscriminatory subsidies can achieve decarbonization faster with less resources. Measures along these lines could include data sharing, sectoral agreements, harmonization of regulations, and patent pools.

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PUBLICATIONS

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