INTERNATIONAL MONETARY FUND

RESEARCH DEPARTMENT

Economic and Environmental Benefits from International Cooperation on Climate Policies

Prepared by Jean Chateau, Florence Jaumotte, and Gregor Schwerhoff

DP/2022/007

2022
MAR

DEPARTMENTAL PAPER

INTERNATIONAL MONETARY FUND

RESEARCH DEPARTMENT

DEPARTMENTAL PAPER

Economic and Environmental Benefits from International Cooperation on Climate Policies

Prepared by Jean Chateau, Florence Jaumotte,
and Gregor Schwerhoff

Cataloging-in-Publication Data
IMF Library

Names: Chateau, Jean, 1969-, author. | Jaumotte, Florence, author. | Schwerhoff, Gregor, author. | International Monetary Fund. Research Department, issuing body. | International Monetary Fund, publisher.
Title: Economic and environmental benefits from international cooperation on climate policies / prepared by Jean Chateau, Florence Jaumotte, and Gregor Schwerhoff.
Other titles: Departmental papers (International Monetary Fund).
Description: Washington, DC : International Monetary Fund, 2022. | March 2022. | Departmental Paper Series | Includes bibliographical references.
Identifiers: ISBN 9781616358303 (paper)
Subjects: LCSH: Climate change mitigation. | Climatic change -- Law and legislation. | Carbon taxes.
Classification: LCC TD171.75 C43 2022

Acknowledgments
Jaden Kim provided outstanding research support for this paper. The authors thank Shekhar Aiyar, Oya Celasun, Ian Parry, and Antonio Spilimbergo for very helpful comments. Daniela Rojas provided editorial assistance.

Publication orders may be placed online or through the mail:
International Monetary Fund, Publication Services
P.O. Box 92780, Washington, DC 20090, U.S.A.
T. +(1) 202.623.7430
publications@IMF.org
IMFbookstore.org
elibrary.IMF.org

Contents

BOXES

FIGURES

TABLES

Executive Summary

Despite the new commitments made at the 26th United Nations Climate Change Conference of the Parties, there is still an ambition and a policy gap at the global level to keep temperature increases below the 2°C agreed upon in Paris. Avoiding the worst outcomes of climate change requires an urgent scaling up of climate policies. The current environment of high and volatile energy prices highlights another benefit from a low-carbon energy transition, namely less reliance on volatile fossil fuel markets and greater energy independence. This paper discusses and analyzes various international mechanisms for scaling up global action on climate mitigation and the low-carbon transition and addressing the policy gap in this area.

Recent policy proposals include the idea of common minimum carbon prices. The IMF's international carbon price proposal (Parry, Black, and Roaf 2021) and the climate club proposal of the German government are based on this idea. While global carbon prices are not a new idea, new elements include the use of carbon price floors—which allow countries to do more if they wish—and the differentiation of carbon price floors by level of development.

Countries with ambitious climate policies are also considering introducing a border carbon adjustment mechanism. Such a tax on the carbon embodied in imports from nonacting countries would prevent domestic producers from being at a competitive disadvantage owing to more ambitious domestic climate policies. An interesting question from the global perspective is whether border carbon adjustment could deliver substantial additional emissions reductions or provide incentives for other countries to join a carbon price floor agreement.

Multiple obstacles have hindered international coordination on climate policies. Low- and middle-income countries (LICs and MICs) are concerned that decarbonization would compromise their development prospects and ask that high-income countries (HICs) bear a larger burden of the global mitigation effort (including through climate finance), given their responsibility for historical greenhouse gas emissions. In contrast, HICs are concerned that ambitious climate policies on their part would put their producers at a competitive disadvantage in both domestic and international markets, possibly leading to a reallocation of emission-intensive economic activity to other countries with laxer policies and negating part of their emissions reductions. Yet international cooperation that motivates climate action across all groups of countries, and especially LICs and MICs, is key to reaching climate goals, as HICs alone cannot reduce global emissions sufficiently to stay below the 2°C temperature increase.

To advance the debate and international policy discussions, this paper provides a comprehensive analysis. The paper includes a comparison of the emissions, economic, burden-sharing, and competitiveness effects of the various international policy mechanisms being discussed. Given the substantial policy changes considered and the international dimension of the policy proposals, it uses a newly developed state-of-the-art global general equilibrium model to quantify the effects of the various policies.

The study highlights four main findings:

- First, relative to a business-as-usual scenario, international carbon price floors substantially enhance global climate mitigation at small macroeconomic costs, provided needed energy investments materialize.

- Second, a differentiated international carbon price floor—which allows a lower carbon price floor for MICs and LICs—contributes to improving the international burden sharing of mitigation relative to a uniform carbon tax, at small efficiency costs: it shifts emission reductions and GDP costs from LICs to HICs. And this comes without necessarily creating substantial competitiveness impacts for HICs, because the emission intensity of production is significantly higher in MICs and LICs than HICs.
- Third, in the case of unilateral climate action by HICs, a border carbon adjustment mechanism helps limit competitiveness losses for energy-intensive and trade-exposed industries and reduces international carbon leakage. But it does not deliver a strong additional reduction in global emissions, nor does it provide sufficient incentives for nonacting countries to join the carbon price floor.
- Fourth, a sectoral carbon pricing agreement for energy-intensive and trade-exposed industrial sectors, that applies minimum carbon prices differentiated by level of development to these sectors, could be preferable to a border carbon adjustment for LICs and MICs. While such an agreement—like a border carbon adjustment—does not scale up global emissions reductions substantially, it would allow HICs to implement ambitious mitigation policies without concern for carbon leakage and loss of competitiveness, introduce limited carbon pricing in EMDEs, and have EMDE governments acquire revenues. Subsequently, the coverage and level of carbon pricing would gradually need to be aligned with global mitigation requirements.

1. Introduction

There is an urgent need to scale up action on climate mitigation in order to avoid the worst outcomes of climate change. When they signed the Paris Agreement, all countries in the world committed to keeping the global temperature increase well below 2°C above preindustrial levels, and since then many countries have reinforced this commitment by announcing plans to reduce emissions to net zero by midcentury. Unfortunately, there remain both an ambition and a policy gap (Black and others 2021). Countries' current commitments for 2030 (Nationally Determined Contributions, or NDCs) under the Paris Agreement cut emissions only by one- to two-thirds of the emissions reductions needed for emission pathways consistent with 1.5–2°C increases. In addition, current policies are not sufficient to stop the projected increase in global emissions, let alone meet the temperature target. The High-Level Commission on Carbon Prices (2017) found that staying below the 2°C increase would require policies equivalent to a global carbon price between $50 and $100 by 2030, but the explicit global average carbon price is currently only $3.

Obstacles to enhanced international climate action are concerns about compatibility of decarbonization with continued robust growth, fairness of international burden sharing, and risks of competitiveness losses. For low-income countries (LICs) and middle-income countries (MICs), the resistance to more climate action is rooted in the concern that decarbonization would compromise their development prospects by making energy more expensive, given their fast-growing energy needs. Increasing the consumer price of fossil fuels might also increase energy poverty and slow down the process of increasing energy access for poorer households, although there are ways to address this (for example, subsidies for subsistence level of electricity consumption). They also highlight that high-income countries (HICs) should bear a larger burden of the global mitigation effort, including by providing climate finance to LICs, given their responsibility for the large majority of historical greenhouse gas (GHG) emissions which have caused the problem of global warming. In contrast, high-income countries want to move ahead with ambitious climate policy but are concerned about competitiveness losses for their energy-intensive and trade-exposed (EITE) industries and carbon leakage if they adopt more stringent carbon-pricing policies than their partners. To offset these competitiveness losses, high-income countries are considering the use of border carbon adjustments (BCAs) (see, for example, European Commission 2021 for the European proposal). However, international cooperation to motivate action by all country groups is key to controlling climate change. HICs alone cannot reduce global emissions sufficiently, given their declining projected share in future emissions. And MICs and LICs have a strong interest in a successful global effort to limit climate change, as they are highly vulnerable to climate change, and there can be large domestic environmental and health benefits from reducing fossil fuels (so-called co-benefits).

As a way forward, several institutions have been calling for introducing global minimum carbon prices, including to avoid the implementation of BCAs. For example, the IMF recently proposed introducing an international carbon price floor (ICPF) arrangement among a smaller number of large emitters covering the bulk of global emissions to scale up action on mitigation. The proposal of Parry, Black, and Roaf (2021) is organized around carbon pricing but also allows for alternative policy approaches with similar effects on emissions. To improve the fairness of burden sharing across countries, the proposal uses carbon price floors that are differentiated by the level of development of countries and includes the possibility of complementing the price floors with financial and technology assistance to LICs. Another example is Germany's recent proposal for forming a climate club among countries with similarly ambitious climate policies. Such a club would entail coordination on a joint minimum carbon price high enough to prevent carbon leakage and would initially be focused on the energy and industrial sectors. The idea of using global carbon prices is not new, but what differentiates some of these recent proposals is the idea of using carbon price floors—which allow more ambitious countries to do more—and to differentiate these by income levels. The agreement on joint minimum carbon prices would dispense with the need for a BCA among the participating countries, although the agreement could still be supported by a BCA on nonparticipants.

This paper analyzes and compares various international mechanisms proposed to enhance global climate action, discussing their emission, economic, burden-sharing, and competitiveness impacts. It assesses five main policy scenarios going up to 2030 in line with the horizon of NDCs. The first policy scenario is an international carbon price floor similar to that proposed by Black and others (2021), in which high-, middle- and low-income countries introduce carbon price floors of $75, $50, and $25, respectively, and countries implement the maximum of their carbon price floor and the carbon price implicit in their Nationally Determined Contribution. The use of price minima allows the arrangement to complement the Paris Agreement—countries can still set higher prices than the floor price if this is needed to help meet their Paris pledge. One difference between this scenario and that in Black and others (2021) is that the carbon price floors are applied worldwide and not just to a subset of large emitters, in the spirit of global minimum carbon prices and to minimize competitiveness concerns.[1] The second scenario calculates the uniform global carbon price which delivers cumulative emissions reductions similar to those of the international carbon price floor arrangement (the carbon price in 2030 is about $56, close to the midpoint of the carbon price floors) and assumes all countries implement this price. The third and fourth scenarios consider the case of fragmented action, in which only high-income countries implement ambitious climate policies, and examine the impacts both without and with border carbon adjustment of various designs. Finally, in a last scenario that assumes that MICs and LICs do not want to implement an economy-wide international carbon price floor, the paper explores whether they could nevertheless be amenable to an international carbon price floor arrangement limited to energy-intensive and trade-exposed sectors in order to avoid the imposition of border carbon adjustments.

This paper builds on previous IMF analysis to compare in one framework the various international mechanisms that are being considered to scale up global action on climate mitigation and assess their broader economic impacts. First, it provides a fuller assessment of the performance of the IMF's international carbon price floor arrangement proposal. Previous IMF analysis (for example, IMF 2019a, 2019b; Black and others 2021; Parry, Black, and Roaf 2021) estimated the emissions and welfare impacts of international carbon price floors for Group of Twenty (G20) countries using a reduced form closed economy model (the Carbon Pricing Assessment Tool). This study uses a newly developed dynamic computable general equilibrium model (IMF-ENV) that is well suited for analyzing large and simultaneous policy changes across the global economy, including by integrating trade impacts and induced changes in global energy prices, and for providing a broader assessment of economic impacts on GDP, employment, investment, competitiveness, and burden sharing. Second, the paper compares in a common framework the performance of the international carbon price floor arrangement, global uniform carbon tax, and border carbon adjustment policy options and examines interactions among them, such as whether border carbon adjustments could be an incentive for nonacting countries to adopt an economy-wide or sectoral international carbon price floor arrangement.

The paper's findings can be summarized as follows. The international carbon price floor arrangement performs relatively well from environmental, economic, and equity perspectives. In the case of unilateral action by high-income countries, border carbon adjustment mechanisms address issues related to carbon leakage and loss of competitiveness in energy-intensive and trade-exposed sectors of acting countries, but they are not a game changer in regard to global emissions reductions. A sectoral international carbon price floor arrangement for energy-intensive and trade-exposed sectors would be a better alternative to border carbon adjustments, as it would offer a cooperative solution for addressing competitiveness concerns and lay the groundwork for carbon pricing in other countries, rather than creating the risk of escalating trade tensions. More specifically, the study finds that:

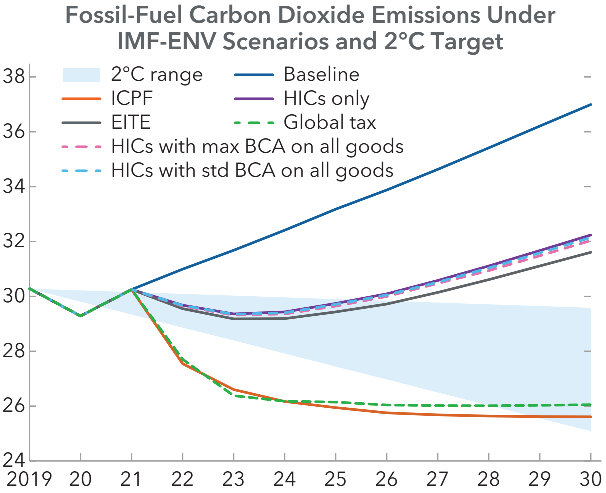
---

[1] In practice, the carbon price floors could be designed by several large emitters, and then others would follow.

- International carbon price floors are essential for scaling up climate mitigation in line with the temperature target of the Paris Agreement. The carbon price floors considered reduce global carbon dioxide (CO_2) emissions by 29 percent below baseline[2] and about 13 percent from current (2019) levels, consistent with keeping temperature increases below 2°C (for all GHG emissions the corresponding reductions are 26.6 percent and 9 percent). Figure 1 provides an overview of the impact of the various scenarios on the path of CO_2 emissions and how they compare with the range compatible with limiting temperature increases to 2°C. Most high-income countries reduce emissions by more than implied by the carbon price floor of $75, reflecting the fact that their Nationally Determined Contributions are very ambitious (see also Black and others 2021 and Parry, Black, and Roaf 2021). For other countries (mostly MICs and LICs), the price floors imply a scaling up of emission reductions relative to the countries' Nationally Determined Contributions. Scaling up action in MICs and LICs is essential to control climate change, as the bulk of current and projected emissions are located in these countries.

Figure 1. Emission Reductions Compared with the 2°C Target

($GtCO_2eq$)



Sources: UNEP (2020); and IMF-ENV model.
Note: For a detailed description of scenarios, see Chapter 2, section B. "ICPF" denotes the international carbon price floor scenario; "Global tax" assumes all countries implement a uniform carbon price that achieves the same global emission reductions as in the ICPF scenario; "HICs only" is a scenario in which only high-income countries implement an ICPF; "HICs with std (max) BCA on all goods" is a scenario in which high-income countries implement an ICPF and impose a border carbon adjustment (of varying stringency) on other nonacting countries; "EITE" is an ICPF for energy-intensive and trade-exposed sectors only (albeit HICs apply the ICPF to all sectors). The 2°C range refers to the likely range of emissions that permits the global temperature increase to be kept to 2°C. $GtCO_2eq$ = gigaton(s) of carbon dioxide equivalent.

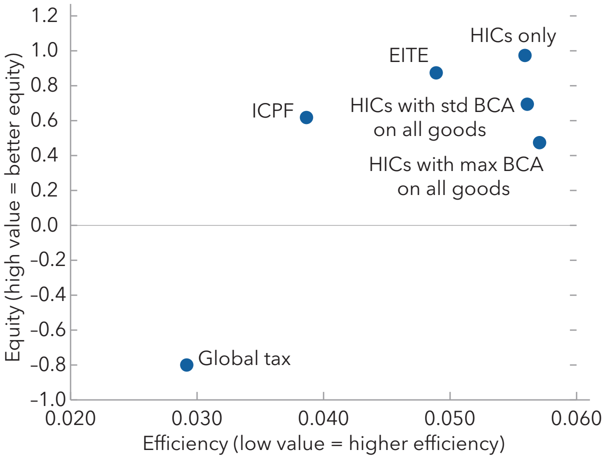
- International carbon price floors scale up climate mitigation at relatively small macroeconomic costs and are compatible with continued economic development, provided needed energy investments materialize. Assuming that carbon-pricing revenues are used productively (for example, to reduce labor income taxes), GDP growth remains very robust under the international carbon price floors and is only slightly lower than under the baseline. Growth projections for LICs in the decade 2021–30, for example, would be reduced from a cumulative 58.3 percent in the baseline to 57.3 percent under the international carbon price floors. Although economic costs imposed by mitigation depend on the energy and fossil-fuel intensity of a particular economy, most countries have a GDP within 1 percent of baseline GDP projections in 2030. In addition, MICs and LICs can expect sizable co-benefits, for example, through reduced local air pollution (Köberle and others 2021; Parry, Mylonas, and Vernon 2021). Underlying this continued growth, however, is a scaling up of investment in the energy sector over this decade and a substantial reallocation of energy-related investment from fossil fuels to non-fossil-fuel technologies. Investment in non-fossil-fuel power needs to increase by 168 percent from 2019 levels, and investment in fossil-fuel power to contract by 64 percent, by 2030.

- Differentiated carbon prices under the international carbon price floor arrangement allow for more international burden sharing than a uniform carbon price, at a small efficiency cost. The international carbon price floor arrangement appears progressive in terms of emissions reductions, as countries with a higher

---

[2] Global reductions in CO_2 emissions from fossil-fuel use in an ICPF scenario are given as 24.6 percent in Parry, Black, and Roaf (2021, Table 1). The comparable number in this paper is 29 percent. The difference arises because the ICPF is applied in this paper to all countries, not only to G20 countries, and also because of revision of the emissions levels in 2019 and the use of the latest NDCs.

Figure 2. Equity versus Efficiency: Scenario Comparison



Source: IMF-ENV model.
Note: The efficiency measure on the horizontal axis shows the average GDP cost per unit of emission reduction, and a lower value corresponds to higher efficiency. The vertical axis shows the difference between the GDP cost for high-income countries (HICs) and the GDP cost for low-income countries. A higher value reflects a higher relative cost for HICs and thus a more progressive distribution of costs. For scenario descriptions, see Figure 1 and Table 2.

income generally reduce their emissions proportionally more (with a few exceptions in which reductions are especially large, including China, Indonesia, and South Africa). This is also true for reductions in emissions per unit of GDP and emissions per capita. Compared with a uniform global carbon price, it shifts part of the emissions reductions and of the economic cost of mitigation from LICs to HICs. The economic efficiency, measured by the global GDP cost per unit of emission reduction, is a bit worse than under a uniform carbon price because the lowest-cost abatement options are in MICs and LICs, but only marginally so (Figure 2). However, despite much higher carbon prices and proportionally larger emissions reductions, HICs typically incur moderate mitigation costs, reflecting their very low emission intensity. Given that there are limits to how much more high-income countries can reduce emissions in the short term, this suggests the need to complement the international carbon price floor arrangement with cross-country financial and technology transfers to increase further the international burden sharing.

- If middle- and low-income countries do not initially participate in an international carbon price floor arrangement, border carbon adjustments are useful for protecting domestic industries of acting countries from carbon leakage and competitiveness losses, but they do not deliver substantial additional reductions in global emissions. The macroeconomic cost of climate mitigation by HICs is not, for these countries, much larger when they act alone than under the international carbon price floor arrangement, but the competitiveness of their energy-intensive and trade-exposed industries can be substantially affected. A strong form of border carbon adjustment, including the use of the foreign carbon intensity to determine the tariff and (to a lesser extent) the inclusion of export subsidies, would help curb substantially losses in energy-intensive and trade-exposed industries' output and market shares and reduce carbon leakages. Emission reductions of HICs alone would, however, not be sufficient at the global level to stay within the 2°C target of the Paris Agreement (see Figure 1).

- If an international carbon price floor arrangement cannot be agreed upon, a sectoral international carbon price floor arrangement focused on energy-intensive and trade-exposed industries could in the short term provide a preferable alternative to border carbon adjustments to address competitiveness concerns. Border carbon adjustments are not sufficient to provide incentives for most other countries to join the international carbon price floor arrangement. Indeed, the international carbon price floor arrangement is more costly than the border carbon adjustment for these countries, as the carbon price applies to their entire economic activity (except CO_2 emissions from land use, land use change, and forestry, or LULUCF), but only to exports with the border carbon adjustment. But a strong form of border carbon adjustment could provide incentives for MICs and LICs to impose a carbon price on their energy-intensive and trade-exposed sectors, rather than being exposed to a border carbon adjustment. This could help pave a path forward for high-income countries to move ahead with ambitious climate policy without concerns about competitiveness impacts and without having to resort to a border carbon adjustment. Avoiding the use of a border carbon adjustment has advantages, because such a mechanism is an administratively demanding policy and can be considered an unfriendly interference with international trade by trade partners. It would also be a first step toward the implementation of carbon pricing in nonacting countries. Even a sectoral international carbon price floor arrangement, however, does not increase global emissions reductions sufficiently, and ultimately the goal should be for global minimum carbon prices to be applied to the entire economy.

This paper contributes to the literature on international coordination of climate mitigation policies. It relates to studies examining the international burden-sharing effects of various coordination mechanisms (for example, van den Berg and others 2020; Clarke and others 2014; and Leimbach and Giannousakis 2019). This literature finds that international burden sharing with a uniform carbon price would either require substantial cross-country transfers (in the case of a carbon tax) or generate large and politically sensitive capital flows (in the case of a global emissions-trading system with permit allocation based on level of development). Compared with these studies, this study finds that the international carbon price floor arrangement is a relatively effective way of improving burden sharing, as the differentiation of carbon prices by development level makes the distribution of economic impacts more progressive with only limited efficiency costs. It may not go far enough, however, in reaching desired levels of burden sharing and may need to be complemented by cross-country transfers, albeit of smaller magnitude than in the case of a uniform carbon price.

This paper also contributes to the literature examining fragmented climate mitigation and the role of border carbon adjustment in reducing carbon leakage and competitiveness losses for acting countries. The paper confirms a number of conclusions of this literature, namely that (1) a border carbon adjustment helps reduce competitiveness losses of energy-intensive and trade-exposed sectors (Böhringer and others 2022); (2) border carbon adjustments are not a perfect instrument for entirely restoring output levels of energy-intensive and trade-exposed industries (see survey in Nachtigall and others 2021); and (3) a border carbon adjustment shifts a small part of the burden of mitigation toward the noncoalition countries and sectors (Böhringer, Balistreri, and Rutherford 2012). Compared with the existing literature, this paper adds two new findings: first, that an ICPF can be as effective as border carbon adjustment mechanisms at preserving competitiveness of high-income countries in energy-intensive and trade-exposed sectors. In addition, stronger forms of border carbon adjustments could offer incentives for the introduction of international carbon price floors by MICs and LICs in energy-intensive and trade-exposed sectors, in which concerns about losses of competitiveness for acting countries are the greatest.

The paper is structured as follows. Chapter 2 presents the model and introduces the scenarios. Chapter 3 discusses the effects of the international carbon price floor arrangement and compares them with a uniform global carbon tax. Chapter 4 shows the effects of introducing a border carbon adjustment in the context of uncoordinated climate policy and compares them with an international carbon price floor arrangement and a sectoral agreement for energy-intensive and trade-exposed sectors. Chapter 5 concludes.

2. Modeling and Scenario Design

The analysis of this paper is based on model simulations with the IMF-ENV model. This model is a global dynamic computable general equilibrium (CGE) model newly developed by the IMF Research Department (see Box 1 for an overview of the model). Dynamic CGE models are well adapted for the analysis of policies implying structural changes (that is, changes in the sectoral composition of economies) like those resulting from ambitious decarbonization goals. These models are based on a neoclassical framework, dealing only with real values and with almost-perfect markets for goods and production factors. They focus on the long-term reallocation of resources across the different sectors and allow simulation of impacts of climate mitigation policies on emissions, macroeconomic variables, sectoral economic activity, and international trade patterns. They feature vintage capital stocks and short-term adjustment costs for the capital stock but tend to underestimate some of the short-term costs of the transition, for example, those resulting from rigidities in labor reallocation. Given their focus on the real economic flows and potential output dynamics, they are not adapted to either the study of the business cycle or the assessment of financial and monetary consequences of climate policies. For the sake of exposition, the 25 regions and countries considered in the model are grouped into four categories in most of the paper's figures, namely, HICs, MICs, and LICs (following World Bank classification) and oil exporters (Table 1).

Table 1. Country Groups in IMF-ENV Model

High-income countries	Middle-income countries	Low-income countries
Australia	Argentina	India
Canada	Brazil	Other Africa (OAF)
France	China	Other East Asia and New Zealand (ODA)
Germany	Indonesia	Other Eastern Europe and Caspian countries (OEURASIA)
Italy	Mexico	
Japan	South Africa	
Republic of Korea	Other Latin America (OLA)	**Oil exporters**[1]
Rest of European Union and Iceland (RESTEU)	Turkey	Russian Federation
United Kingdom		Saudi Arabia
United States		Other oil-exporting countries (RESTOPEC)

[1] Oil exports are separated for convenience. In terms of the economic development classification, Saudi Arabia belongs to the high-income countries group, the Russian Federation to the middle-income countries group, and "Other oil-exporting countries" to the low-income countries group.

A. The Baseline Scenario

The baseline scenario is a projection of economic development to 2050 under the assumption that climate mitigation is limited to the current actual climate and energy policies. The macroeconomic projections for this scenario are based on April 2021 *World Economic Outlook* (IMF 2021) projections up to 2025. For the period 2025–50, projections are used[1] from a long-term growth model in which potential GDP is decomposed into its primary components: labor supply, the ratio of physical capital to GDP, and total factor productivity (TFP). Each of these components is projected based on conditional convergence assumptions, to build (with a standard Solow decomposition) projections for real GDP (see Dellink and others 2017). This projected macroeconomic scenario[2] is then used as input to calibrate the baseline projection of the IMF-ENV model (following a methodology described in Fouré and others 2020). TFP is not endogenous in the model. Sectoral TFP and labor efficiency are calibrated exogenously in the baseline. When a policy is implemented, the reallocation of capital, labor, etc., across sectors changes the apparent TFP and labor efficiency, since sectors have different TFP in the baseline.

Other assumptions in the baseline scenario are chosen to project realistic changes in sectoral production and demand patterns. Nonhomothetic preferences ensure that when GDP per capita grows, final demand shifts away from necessary goods. Income elasticities are assumed to conditionally converge toward the preferences of more advanced countries.[3] Similar assumptions are made for conditional convergence toward the production structure and sectoral productivity of more advanced economies. Additional assumptions of structural change are a more intensive use of service inputs into production processes to reflect trends toward "servitization" and the increasing use of information technology. The baseline also incorporates sectoral autonomous energy efficiency improvements, which are assumed to follow the latest historical trends. The evolution of regional energy systems mimics the energy projections of the Stated Policies Scenario (STEPS)[4] of the World Energy Outlook (IEA 2020). STEPS considers all policies that have been put in place, taking into account both existing policies and those that are under development. Based on industry expectations, this study assumes that changes observed during the COVID crisis in demand patterns for leisure and tourism are not permanent. Further, the study assumes that the expected increase in teleworking has no major effect on changes in production modes and preference patterns in the long term.

Without climate action, emissions are expected to increase strongly, driven by robust GDP growth. The baseline features global GDP growth on the order of 2.6 percent per year over 2019–30—the decade of focus in this paper—reflecting economic convergence of lower-income countries and their growing labor force. GDP growth is faster in less-developed economies, with LICs, MICs, and HICs growing respectively at 4.3, 4.1, and 1.3 percent per year. With current trends extrapolated, the baseline projects reductions in energy and emission intensity due to a combination of "electrification" of the energy system, progressive increase in importance of renewable energy in the electricity mix, and improvements in sectoral energy efficiency. But these trends are very insufficient to offset the effects of strong GDP growth on emissions (Figure 3). Over 2019–30, CO_2 emissions[5] are projected to grow by 23 percent in the baseline and the emissions of all greenhouse gases by 23.7 percent. Emission intensity (defined as CO_2 emissions per unit of GDP) has been declining for a long time, and this trend is expected to continue (Figure 3). CO_2 emissions per capita, however, would increase by 11 percent at the global level, reflecting strong increases in GDP per capita among LICs and MICs. As populations continue to grow, increasing GDP per capita causes a strong increase in absolute emission levels as well.

---

[1] In some cases, like those of China and the United States, projections provided by IMF country desks are available and used instead of the model projections.

[2] The macroeconomic projections used to feed the CGE model are based on projections for GDP, population, employment rates, and capital-to-GDP ratios as well as other assumptions for fiscal-balance-to-GDP ratios, government-consumption-to-GDP ratios, or current accounts. GDP and investment are endogenous variables of the IMF-ENV model, so other variables are calibrated to reproduce the targeted real GDP and investment trajectories. For GDP, the calibration variables are sectoral labor efficiencies, which are uniformly adjusted, conserving the original relative sectoral productivity differences. For the investment-to-GDP ratio, the calibration variable is the household saving rate.

[3] See Chateau and others (2020) for further details on the calibration of projected structural change in dynamic CGE models.

[4] The baseline scenario assumes that no "new" climate or energy policies are implemented. The projections of energy systems assume constant levels for feed-in tariffs, other energy subsidies, and taxes, as well as a given constant carbon price of $15/ton CO_2 for the sectors covered by the European Union emissions-trading system and $10/ton CO_2 for the power sector in China.

[5] Unless mentioned, CO_2 emissions from LULUCF are not taken into account in the numbers shown for CO_2 emissions but are taken into account in the calculations of total GHG emissions.

Box 1. An Overview of the IMF-ENV Model

The IMF-ENV model[1] is a recursive dynamic neoclassical, global, general equilibrium model, built primarily on a database of national economies and a set of bilateral trade flows. The model describes how economic activities and agents are interlinked across several economic sectors and world countries or regions. The central input of the model is the data of the Global Trade Analysis Project version 10 database (Aguiar and others 2019). The database includes country-specific input-output tables for 141 countries and 65 commodities and real macro flows. It also represents world trade flows comprehensively for a given starting year. The currently used version 10 is based on data from 2014. The model is based on the activities of the key actors: representative firms by sector of activities, a regional representative household, a government, and markets. Firms purchase inputs and primary factors to produce goods and services, optimizing their profits. Households receive the factor income and in turn buy the goods and services produced by firms; household demands result from standard welfare optimization under households' budget constraints. Markets determine equilibrium prices for factors, goods, and services. Frictions on factor or product markets are limited, except as described elsewhere in this box.

The model is recursive dynamic: it is solved as a sequence of comparative static equilibria. The fixed factors of production are exogenous for each time step and linked between time periods with accumulation expressions, like the dynamic of a Solow growth model. Output production is implemented as a series of nested constant-elasticity-of-substitution functions to capture the different substitutability across all inputs. International trade is modeled using the so-called Armington specification, which posits that demands for goods are differentiated by region of origin. This specification uses a full set of bilateral flows and prices by traded commodity. In contrast to intermediate inputs, primary factors of production are not mobile across countries.

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

The model also links economic activity to environmental outcomes. Emissions of greenhouses gases (GHGs) and other air pollutants are linked to economic activities either with fixed coefficients, such as those for emissions from fuel combustion, or with emission intensities that decrease (nonlinearly) with carbon prices—marginal abatement cost curves. This latter case applies to emissions associated with non-energy-input uses (for example, nitrous oxide emissions resulting from fertilizer uses) or with output processes (like methane emissions from waste management or carbon dioxide emissions from cement manufacturing). In the very long term, the model may overestimate the cost of decarbonization,

---

[1] The IMF-ENV model has been operational for a few months at the IMF, but some aspects are still under development, including a draft of the documentation. Meanwhile, readers interested in the model can consult the documentation of the twin models. The current model is built on the ENVISAGE model (van der Mensbrugghe 2019) and the OECD ENV-Linkages Model (Chateau, Dellink, and Lanzi 2014).

Box 1. An Overview of the IMF-ENV Model *(continued)*

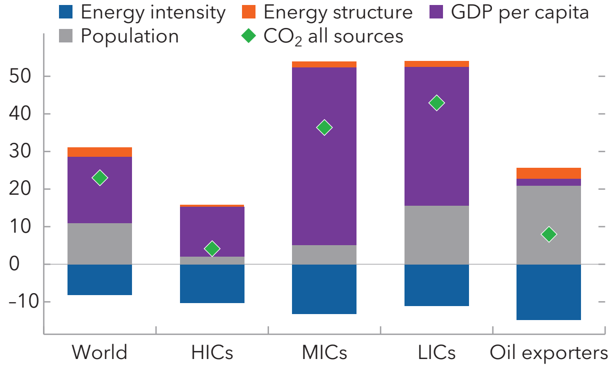
since it does not take into account radical technology innovations that could materialize at this longer horizon (hydrogen, second generation of nuclear and biofuel technologies, carbon capture and storage technology). While some of these new technologies are at an experimental stage, it is difficult to include them in the model at the moment because of a lack of information about the future costs of these technologies if they were deployed at industrial scale.

The model can be used for scenario analysis and quantitative policy assessments. For scenario analysis, the model projects up to 2050 an internally consistent set of trends for all economic, sectoral, trade-related, and environmental variables. In this context, the model can be used to analyze economic impacts of various drivers of structural changes like technological progress, increases in living standards, and changes in preferences and in production modes. A second use for the model is quantitative economic and environmental policy assessment for the coming decades, including scenarios of a transition to a low-carbon economy. In this case the model assesses the costs and benefits of different sets of policy instruments for reaching given targets like GHG emission reductions.

Figure 3. Baseline Emission Projections by Aggregate Groups

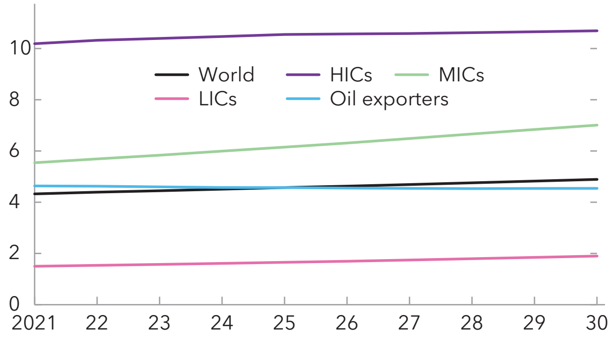
1. Drivers of Changes in CO_2 Emissions Changes under the Baseline, 2019–30

(Percent deviation from 2019)



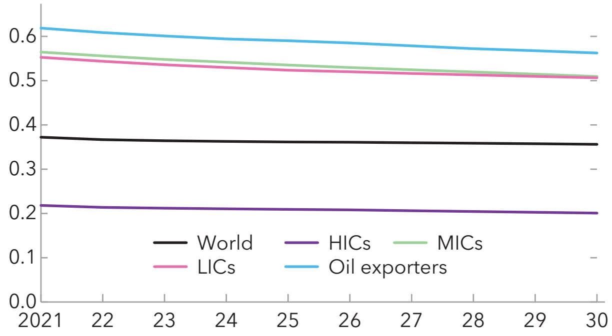
2. CO_2 Emissions per Capita

(Tons per person)



3. CO_2 Emissions per GDP

(Tons per US dollar)



Source: IMF-ENV model.

Note: CO_2 = carbon dioxide; Energy structure = CO_2 emissions-to-total primary energy demand ratio; HIC = high-income country; LIC = low-income country; MIC = middle-income country.

B. Policy Scenario Overview

The paper analyzes the ICPF proposal and compares it with a global uniform carbon price and partial-action scenarios with BCAs. The ICPF scenario assumes carbon price floors differentiated by income level ($75 per ton of CO_2 equivalent [tCO_2eq] for HICs, $50 for MICs, $25 for LICs, and prices according to income levels for oil exporters), and countries implement a carbon price equivalent to the maximum of the carbon price floor and the carbon price implicit in their NDC commitment as of November 2021.[6] The ICPF scenario provides a macroeconomic analysis to complement the analysis of the ICPF in Parry, Black, and Roaf (2021). A major difference, however, is that the current paper considers the implementation of the ICPF at the global level and not just for the main G20 emitters. In addition, the coverage of carbon price is comprehensive across sectors, sources of emissions, and GHGs, except for CO_2 emissions from traditional biomass combustion and from LULUCF. To assess efficiency and burden-sharing properties, the ICPF scenario is then compared with a global tax scenario in which the same global emissions reductions are achieved by a uniform carbon price of $55.8/$tCO_2eq$ for all countries. Next, the study considers partial-action scenarios in which only HICs (including Saudi Arabia) implement their ICPF carbon price, while other countries continue with baseline policies. In a first partial-action scenario, HICs do not take any action to reduce losses in competitiveness. In another set of scenarios, they introduce BCAs with different designs. Specifically, the paper considers (1) varying coverage of goods (BCAs on all goods versus only on EITE goods) and (2) varying stringency of BCAs, distinguishing between a "standard" BCA, in which acting countries introduce a countervailing tariff on imports from nonacting countries based on domestic carbon content, and a "maximum"

---

[6] The emission reduction targets for 2030 proposed in NDCs are expressed in terms of total GHGs in megatons of CO_2eq for all sources of emissions (including LULUCF); the NDC targets are calculated using ClimateWatch data (https://www.climatewatchdata.org/) as of November 29, 2021. For most countries the NDC target is expressed as a percentage reduction in emissions relative to a base year (generally 1990 or 2005), and therefore the translation into the model is straightforward. For some countries, like China and India, the NDC targets are expressed in reduction of emission intensity relative to a given year; for these countries the baseline GDP projections are used to translate the emission intensity into absolute targets. Finally, some countries, like Indonesia and Mexico, provide two kinds of NDCs, namely, a "conditional NDC," which is conditional on other countries' support, and an "unconditional NDC." For these countries, the target is the conditional NDC. Dollar amounts in this paper refer to 2018 $.

Table 2. Scenario Overview

Name	Description
Baseline	Countries do not implement additional climate policies.
ICPF	Global ICPF in which countries gradually implement a carbon price up to 2030 to reach the maximum of their carbon price floor and the carbon price implicit in their NDC. Carbon price floors are \$25/tCO_2eq for LICs, \$50 for MICs, and \$75 for HICs.
Global tax	Global carbon tax, uniform across all sources and countries, to meet exactly the same global GHG emissions reduction target as in ICPF.
HICs only	Only the HICs country group and Saudi Arabia are acting, implementing their carbon price in the ICPF scenario; MICs and LICs do not implement additional climate policies.
HICs with BCA	As in the HICs-only scenario, but HICs implement a BCA in addition. Various designs are considered.
EITE	As in the HICs-only scenario, but MICs and LICs countries adopt their carbon price in the ICPF scenario only for EITE industries.

Source: Authors.

Note: BCA = border carbon adjustment; EITE = energy intensive and trade exposed; GHG = greenhouse gas; HIC = high-income country; ICPF = international carbon price floor; LIC = low-income country; MIC = middle-income country; NDC = Nationally Determined Contribution; tCO_2eq = ton(s) of carbon dioxide equivalent.

BCA, in which the countervailing tariff is based on the foreign carbon content and complemented by an export subsidy to level the playing field on international markets as well. This analysis provides a complement to the analysis of BCAs in Keen, Parry, and Roaf (2021). Finally, in a last scenario assuming that MICs and LICs do not want to implement an economy-wide carbon price, the study examines whether a scenario in which carbon price floors are limited to EITE sectors for MICs and LICs (but in which HICs implement the full ICPF) could provide a preferable alternative to being subjected to a BCA for these countries. Table 2 provides an overview of the scenarios.

In all policy scenarios, the revenue from carbon pricing is assumed to be used to reduce distortionary labor income taxes, as is standard in the double-dividend literature.[7] This keeps the tax burden equal and government revenues constant. The move away from more distortive taxation provides a boost to GDP, partly offsetting the costs from mitigation. If (and only if) the preexisting tax system is not optimal and for small increases in the carbon tax, such a tax reform can yield a double dividend, meaning that GDP could increase while emissions are reduced at the same time (Goulder 2013). The reductions in the labor income tax could be targeted toward low-income households to ensure that the reform as a whole is progressive (Klenert and others 2018), but since this model has a representative household, this aspect is not explored.

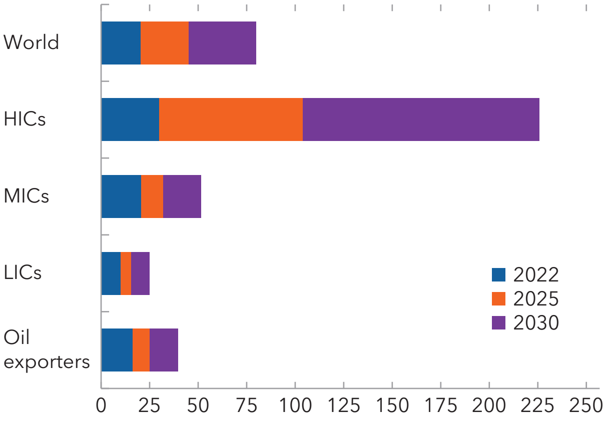
---

[7] Given that the focus of this paper is on the comparison of various forms of international mechanisms for scaling up global actions rather than the composition of the domestic mitigation policy mix, a common standard assumption is made for the policy mix (carbon tax and recycling of revenues as a reduction of the labor tax). See, for example, IMF (2020) and IMF and G20 (2021) for a discussion of the design of the mitigation policy mix.

3. The International Carbon Price Floor

In the ICPF scenario, all countries introduce a carbon price that is the maximum of their carbon price floor and the implicit carbon price required to reach their NDC. The level of the carbon price floor in 2030 depends on the level of development: \$25/tCO_2eq for LICs, \$50/tCO_2eq for MICs, and \$75/tCO_2eq for HICs and Saudi Arabia. If the corresponding carbon price floor is not sufficient to reach the country's NDC, the carbon price for the country is adjusted to reach GHG emissions in 2030 consistent with the country's NDCs. The carbon price is phased in gradually between 2022 and 2030. Figure 4 provides an overview of the carbon prices for the model regions over time. The carbon prices in some MICs (Argentina, Brazil, and Mexico) and all HICs except Australia are higher than the carbon price floor for their country groups.

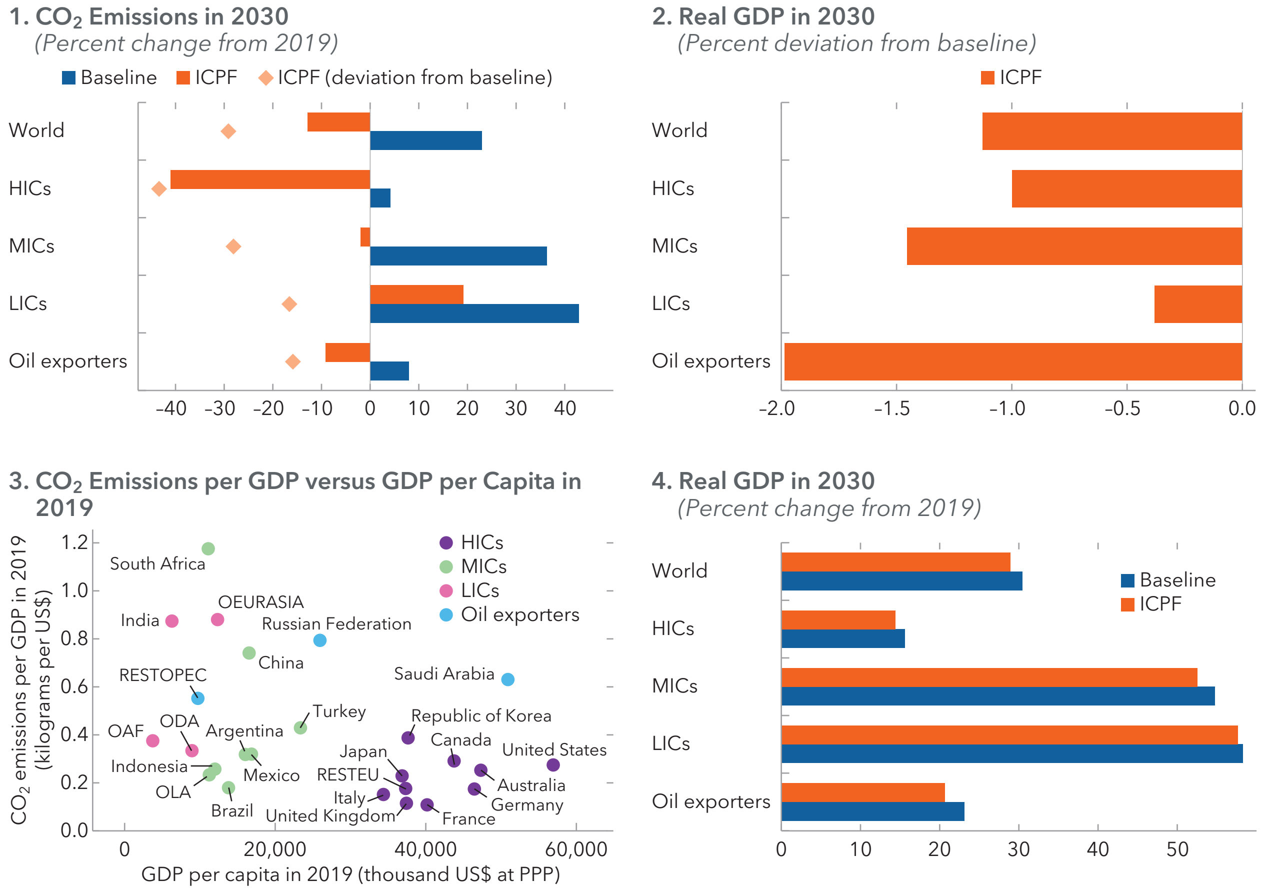
Figure 4. Carbon Prices under the ICPF Scenario, by Aggregate Country Groups
(2018 US dollars per tCO_2eq)



Sources: Price floors from Parry, Black, and Roaf (2021); Nationally Determined Contribution (NDC) targets from Climate Watch (2021); and IMF-ENV model for endogenous carbon price to reach NDC target.
Note: HIC = high-income country; LIC = low-income country; MIC = middle-income country; tCO_2eq = ton(s) of carbon dioxide equivalent.

The study estimates that achieving NDCs with carbon prices alone could require very high carbon prices by 2030 in some countries, but these prices could be reduced substantially with a more comprehensive policy package and technology improvements. Reaching NDCs requires carbon prices close to \$225 in HICs, reflecting the high ambition of their commitments. Carbon prices measure marginal abatement costs, that is, the cost of removing the last unit of carbon, which is typically higher for countries with very ambitious NDCs (for example, the United States) and for countries with very low current levels of emissions (for example, France). This is because to reach their ambitious targets, they must decarbonize hard-to-abate sectors such as industry and transportation. As shown later in the paper, though, even very high carbon prices do not translate into very large aggregate GDP costs for these countries, because most of the abatement options are cheaper than the last unit of emission abated. The high prices are also a reflection of using carbon pricing as the only policy instrument in this analysis. Other policy instruments, such as regulations or targeted research and development to develop low-carbon technologies for hard-to-abate sectors (for example, to produce steel with green hydrogen or to improve carbon capture and sequestration technologies) could strongly reduce the need for high carbon prices. The international carbon price floor proposal allows for the use of alternative policies to carbon pricing and mixed approaches, which will be the focus of future work. Finally, anticipation effects—in which forward-looking agents front-load their adjustment to expected future carbon price increases—also reduce the need for high up-front carbon prices (IMF 2020). In a review of model estimates of carbon prices consistent with the 2°C target, the High-Level Commission on Carbon Prices (2017) found estimated carbon prices in 2030 ranging from \$50 to \$100. The corresponding uniform carbon price in this study's global tax scenario (presented later in the paper) is \$55.80, well within that range.

Figure 5. ICPF Scenario: Changes in CO_2 Emissions and GDP in 2030, by Aggregate Country Groups



1. CO_2 Emissions in 2030
(Percent change from 2019)

2. Real GDP in 2030
(Percent deviation from baseline)

3. CO_2 Emissions per GDP versus GDP per Capita in 2019

4. Real GDP in 2030
(Percent change from 2019)

Source: IMF-ENV model.
Note: CO_2 = carbon dioxide; HIC = high-income country; ICPF = international carbon price floor; LIC = low-income country; MIC = middle-income country; OAF = other Africa; ODA = other East Asia and New Zealand; OEURASIA = other Europe and Asia; OLA = other Latin America; PPP = purchasing power parity; RESTEU = rest of European Union and Iceland; RESTOPEC = other oil-exporting countries.

A. The Effect of the ICPF on Projected GHG Emissions

In the ICPF scenario, future emissions fall strongly compared with the baseline, putting the global economy on a path consistent with the 2°C target. Results in panel 1 of Figure 5 show that in 2030, global emissions of CO_2 fall by 29 percent and global GHG emissions by 26.6 percent,[1] relative to their baseline levels. However, because emissions are projected to increase strongly in the baseline, this translates into more modest reductions from 2019 levels, at respectively 13 percent and 9 percent, for CO_2 and GHG emissions. These emissions reductions are compatible with keeping temperature increases below 2°C and putting global emissions on a declining trend in a context of robust global growth would be a major achievement.

Emission reductions in HICs are the largest, followed by those in MICs and then those in LICs and oil-exporting countries. HICs reduce CO_2 emissions by 43 percent (and GHGs by 45 percent) in 2030 compared with the baseline (Figure 5, panel 1). This reduction is higher than that in other countries, because as Figure 4 shows, the NDCs of most HICs imply emission reductions beyond the $75/t$CO_2$eq required by the carbon price floor. MICs reduce CO_2 emissions by about 28 percent relative to their baseline (and GHGs by 25 percent). There is considerable within-group variation, as a given carbon price reduces emissions more

---

[1] Figures report CO_2 emissions (excluding CO_2 LULUCF emissions), but other environmental indicators, like all GHG emissions or emissions detailed by GHG and air pollutant, can also be extracted from the model (see Annex Figures 2.1 and 2.2).

among countries with a higher carbon intensity. China, Indonesia, and South Africa have a high carbon intensity and drive the relatively high emission reductions of MICs (Figure 6, panel 1). LICs and oil producers reduce their CO_2 emissions less than the other groups, by 16.6 percent and 16 percent, respectively, relative to their baselines, reflecting their low carbon price floors. Despite reductions of emissions relative to the baseline, all LICs experience rising emissions relative to 2019 under the ICPF. Among LICs, India is playing a central role, since it accounts for 45 percent of CO_2 emissions of this group in 2030. Specifically, CO_2 emissions in India decline by 22 percent compared with the baseline in 2030 and increase by 17 percent compared with 2019 emissions. The share of global CO_2 emissions for India would increase from 7 percent to 10 percent between 2019 and 2030 (under the ICPF).

B. The Effect of the ICPF on Economic Development

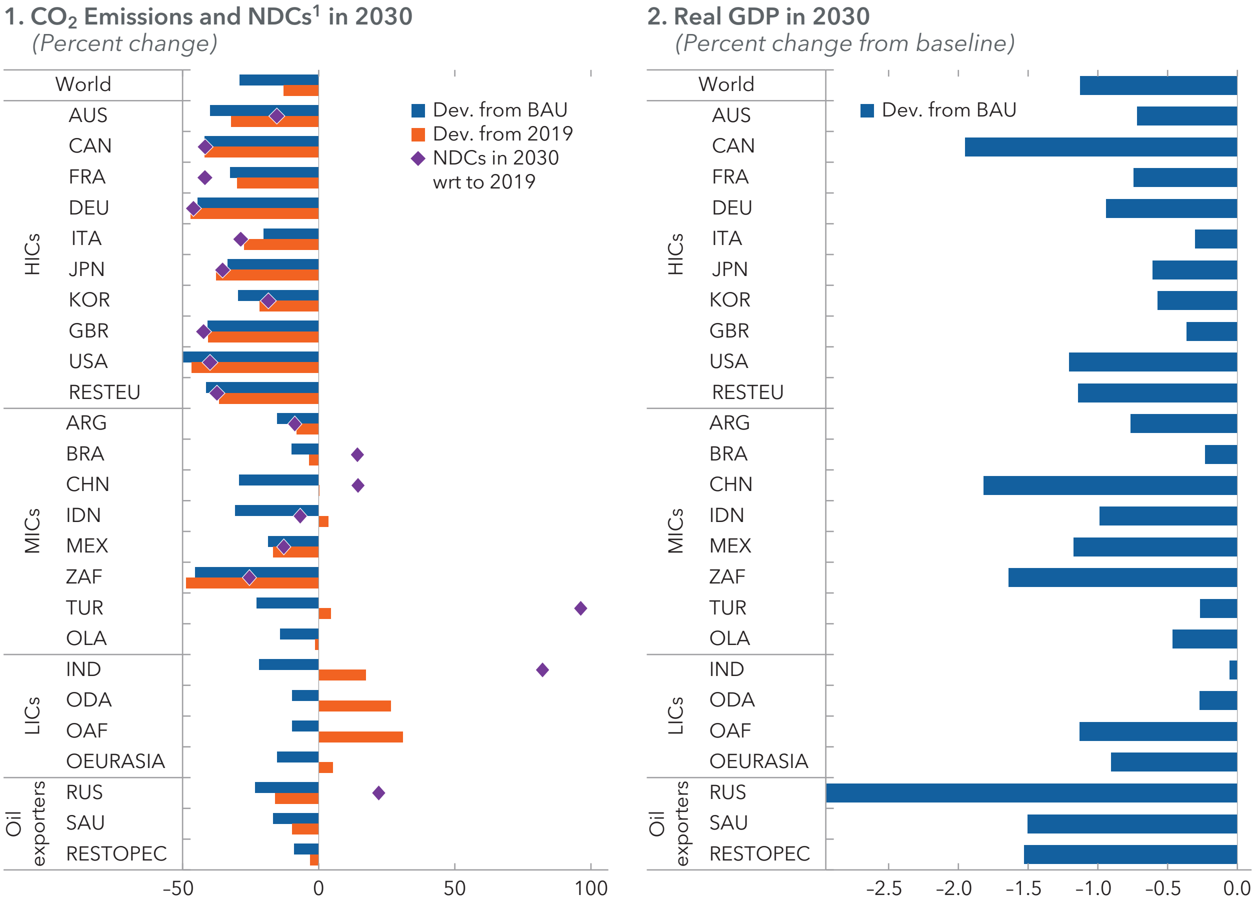
The aggregate economic costs under the ICPF are small, considering the large emission reductions from baseline. The model projects a decrease in global real GDP of about 1.1 percent in 2030 compared with its baseline level, against global CO_2 emissions reductions of 29 percent from baseline in the same year (Figure 5, panel 2). GDP costs for HICs are generally moderate, despite the fact that their NDCs imply higher proportional emission reductions and that abatement opportunities are more expensive in these countries. This in turn reflects the fact that HICs are on average less carbon intensive than MICs and LICs, as shown by CO_2 intensities reported in Figure 5, panel 3. Hence, for a given carbon price increase, the corresponding increase in production costs is mechanically lower in HICs than in other countries. These lower relative economic costs of climate mitigation for HICs, compared with those for developing countries, which are characterized by higher growth of GDP and higher reliance on fossil fuels, are a seminal and conventional result of modeling studies with either CGE models (OECD 2009) or integrated assessment models (Clarke and others 2014). Detailed results presented in panel 2 of Figure 6 show that countries with large fossil-fuel sectors, like Canada, member countries of the Organization of the Petroleum Exporting Countries, the Russian Federation, and South Africa, record GDP losses of more than 1.5 percent, which is higher than the global average. Losses in these countries are relatively high even with modest climate ambition, because of the strong decline in their export incomes. However, the losses are still moderate, at 3 percent of GDP, compared with the baseline for the Russian Federation, the most-affected region.[2] Among other countries, GDP costs range from 0 (India) to 1.8 percent (China) and increase with the carbon intensity of the country and the level of the carbon price. MICs have on average larger GDP losses, but this masks different situations across countries of this group. China, which currently has a carbon-intensive economy, has a relatively high cost of 1.8 percent of GDP. Mexico and Indonesia have a historically important reliance on fossil fuels and record GDP losses of about 1.2 percent and 1 percent, respectively. But other countries in this group show GDP losses well below 1 percent. LICs as a group have smaller losses than MICs and HICs, reflecting the fact that their emission reductions are more moderate under the ICPF.

Climate policy also generates substantial co-benefits and will help reduce future damages from climate change. The model does not incorporate important economic benefits from climate policy, such as the positive effect of climate policy on labor productivity and health through a reduction in local air pollution (Graff Zivin and Neidell 2012) and the benefits of shifting the tax burden from labor income taxation to carbon pricing in terms of reduced informality of the economy (Bento, Jacobsen, and Liu 2018). In some countries, these effects are projected to offset fully the GDP losses of carbon pricing, for example, because of higher labor productivity under lower air pollution levels (Li and others 2018; Pandey and others 2021) and more efficient tax systems (Liu 2013). In addition, the purpose of climate mitigation policies is to limit the GHG concentration in the long term to avert permanent and severe climate change that would in turn affect

---

[2] The Russian Federation is more affected than other oil-exporting countries for multiple reasons: first, because it faces a higher minimum carbon price floor than the other oil-exporting countries; second, the share of the Russian Federation's manufacturing and energy-intensive industries is higher than that of other oil exporters; and third, the fall in international oil prices under the ICPF scenario (see Figure 9) makes Russian oil extraction less profitable relative to that in the other oil-exporting countries.

Figure 6. ICPF Scenario: Changes in CO_2 Emissions and Real GDP in 2030, by Country



Sources: Nationally Determined Contribution (NDC) targets calculated using November 2021 data from Climate Watch (2021); and IMF-ENV model.

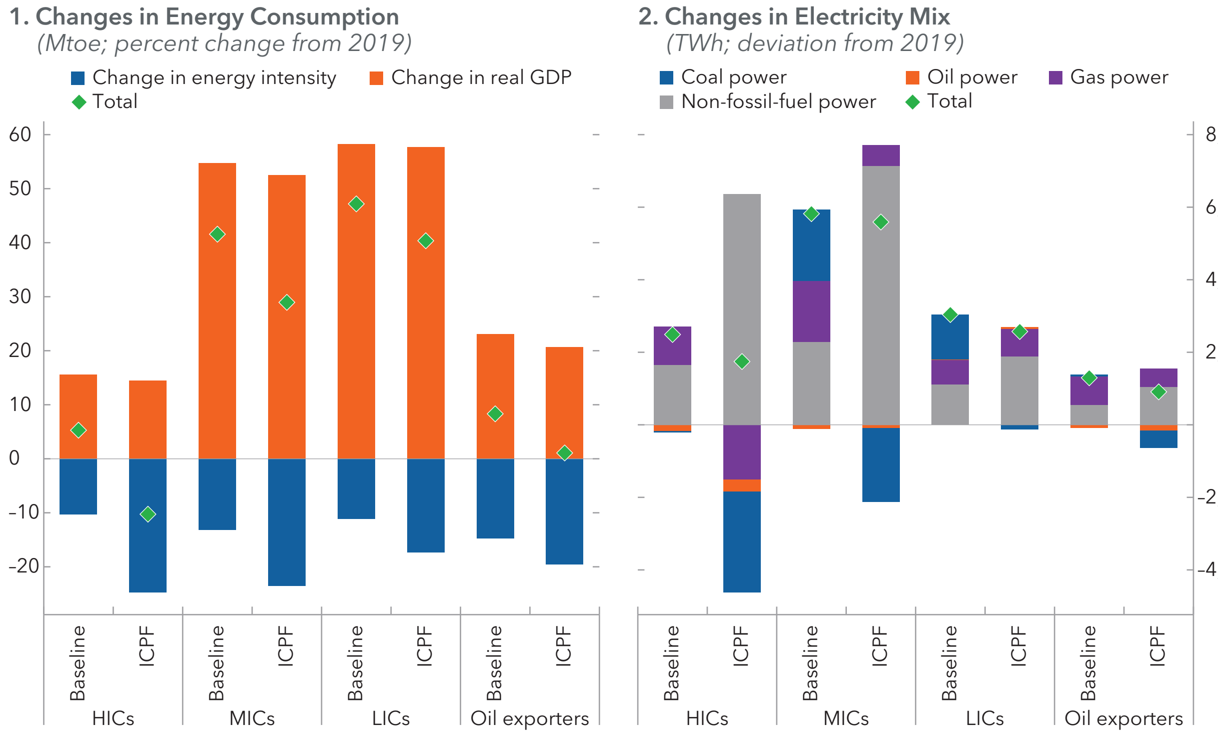
Note: : Data labels use International Organization for Standardization (ISO) country codes. BAU = business as usual; Dev. = deviation; HIC = high-income country; LIC = low-income country; MIC = middle-income country; OAF = other Africa; ODA = other East Asia and New Zealand; OEURASIA = other Europe and Asia; OLA = other Latin America; RESTEU = rest of European Union and Iceland; RESTOPEC = other oil-exporting countries; wrt = with respect to.

[1] The emission reduction targets for 2030 proposed in NDCs are generally expressed in terms of total greenhouse gases in megatons of CO_2 equivalent for all sources of emissions (including land use, land use change, and forestry, or LULUCF). This panel translates these targets for CO_2 emissions only. The result may give the impression that countries targeting NDCs under the international carbon price floor (ICPF) (like Italy and France) do not exactly reach their targets: the diamond does not fit within the orange bar. The reason is that emissions reductions across greenhouse gases (GHGs) are not perfectly proportional when the uniform carbon price of ICPF is implemented. The results for total GHGs including LULUCF are reported in Annex Figure 2.4 showing the right mapping.

economic activity strongly. In this decade, the economic benefits of these averted climate-change-related damages are expected to be small relative to GDP (though they can have considerable effects at a local level). Hence, to avoid any further complexity, they are not incorporated in the current analysis. However, any extension of the current analysis beyond 2030 should consider these averted GDP losses when GDP impacts of climate policy are calculated.

The ICPF is compatible with continued robust growth and development. The panel 4 of Figure 5 puts GDP costs into perspective, by comparing cumulative growth between 2019 and 2030 in the ICPF and the baseline scenarios. GDP is projected to grow substantially in the baseline: for example, GDP in LICs is expected to grow by 58.3 percent, thus converging toward that in higher-income countries. The ICPF changes this picture only marginally: cumulative growth is reduced from 30.4 percent to 29.2 percent at the global level and from 58.3 percent to 57.3 percent for LICs. Effective climate policy is thus not at odds with economic development. Energy consumption keeps growing strongly under the ICPF, especially in MICs and LICs, supporting fast GDP growth (Figure 7). The carbon price provides incentives for an increase in

Figure 7. ICPF and Baseline Scenarios: Changes in Energy Consumption and Electricity Mix in 2030



Source: IMF-ENV model.
Note: HIC = high-income country; ICPF = international carbon price floor; LIC = low-income country; MIC = middle-income country; Mtoe = Megatons of oil equivalent; TWh = Terawatt hours.

energy efficiency, so that less energy input is required to obtain the same level of energy services. More importantly, however, the carbon price causes a higher electrification of energy consumption and a switch to non-fossil-fuel power in the production of electricity.

Continued growth, however, will require a scaling up and substantial reallocation of energy-related investments, which may necessitate government support. Investment, shown in Figure 8, follows the changes in output closely and reflects the energy intensity of the sectors. Relative to the baseline, utilities increase investment strongly and absorb most of the reduction in investment in other sectors, especially in fossil-fuel extraction and EITE sectors. Overall, energy-related investment needs to increase by about 50 percent from current levels by 2030, relative to 25 percent in the baseline. In addition, investments within power generation are reallocated from fossil-fuel to non-fossil-fuel power. These changes are not small: they imply a 168 percent increase in non-fossil-fuel power investment and a 64 percent reduction in investment in fossil-fuel power, from 2019 levels. Non-fossil-fuel power investments are mainly renewable energy and electricity network infrastructure (IEA 2021). While these changes in investment are triggered by carbon pricing in the model, they may require government support in reality, as lack of credibility of policies, imperfect coordination or high degrees of risk and financing cost of low-carbon investment may hinder the investment response. Government interventions could take the form of provision of infrastructure investment or derisking mechanisms to support private investment in low-carbon technologies (Pigato and others 2020).[3]

Carbon pricing triggers and operates through nonnegligible changes in energy prices, on both international and domestic markets, warranting careful management. As shown in panel 2 of Figure 9, the carbon price increases the price of fossil fuels and electricity for consumers, in some cases by more than 10 percent. Electricity prices faced by households and firms increase for two main reasons. The first is the carbon price,

---

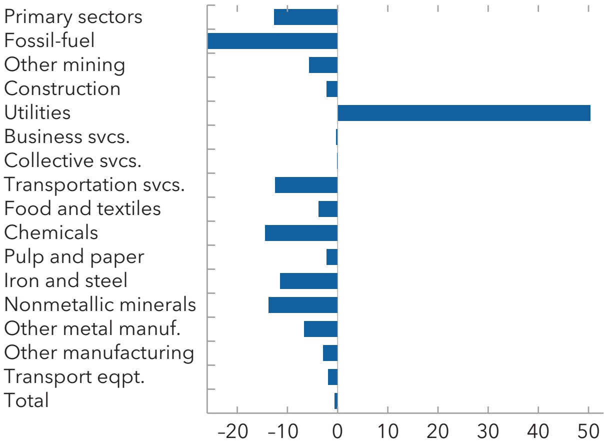
[3] The IMF (2020) and IMF and G20 (2021) discuss the role of public investment in low-carbon infrastructure.

which makes fossil-fuel-powered generation more expensive in the ICPF scenario. This is reflected in the increase in the supply price of electricity (Figure 9, panel 1), especially in countries where renewable electricity is scarce. The second reason is the increasing demand for electricity, which results from the overall shift of the energy mix toward electricity, as discussed earlier. This occurs even in countries with a large reliance on nuclear power and renewables, since the supply of electricity remains sluggish in the short term. The prices of oil and gas also increase for consumers, albeit less for oil than gas, even though the carbon content of refined oil is higher. This reflects the fact that the world oil market is less elastic than the gas market and that the production price of crude oil decreases more than that of gas extraction when the demand for both liquid and gaseous fossil fuels falls (Figure 9, panel 1). Coal markets are more elastic than oil and gas markets, on both the demand and the supply sides. Therefore, the increasing cost of coal (due to carbon pricing) implies a strong reduction in demand and an even larger reduction in coal extraction, which in turn translates into an increase in the supply price for coal. To prevent disruptions in energy markets and stronger price responses, careful monitoring and provision of support—as needed—to expand sufficiently quickly the supply of low-carbon energy will be crucial. In addition, effects of higher energy prices on lower-income households can be addressed through targeted income transfers or subsidies for subsistence levels of electricity consumption.

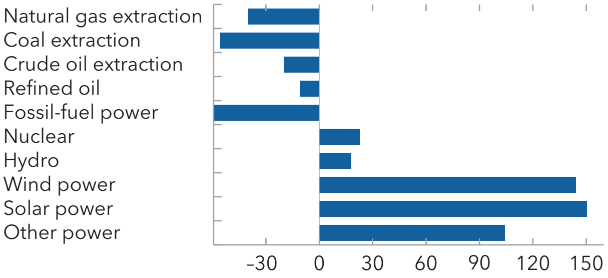
While aggregate GDP changes are moderate, economic sectors are affected very differently by the ICPF, which highlights the need for support measures to ensure a just transition. Figure 10 shows how the ICPF affects real gross output of the different sectors. While most sectors grow compared with 2019, emission-intensive sectors grow less quickly than in the baseline, while low-carbon sectors benefit from the changed incentives. Fossil-fuel production grows only by a few percent. Energy-intensive sectors like transportation services and EITE industries (that is, chemicals, pulp and paper, nonferrous metals, iron and steel, and nonmetallic minerals) also grow considerably more slowly than in the baseline. These sectors could in principle switch

Figure 8. ICPF Scenario: Global Investment in 2030

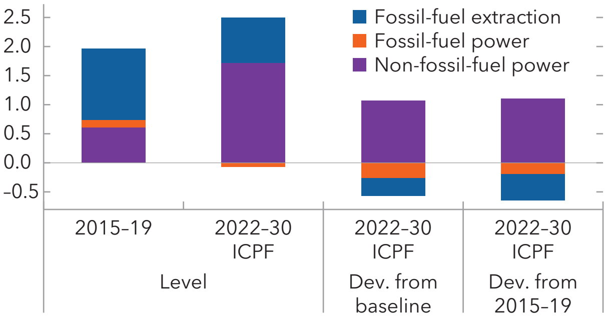
1. Global (Real) Investment in 2030, by Aggregate Sector[1]
(Percent deviation from baseline)



2. Global (Real) Investment in 2030, Energy Sectors Detailed[2]
(Percent deviation from baseline)

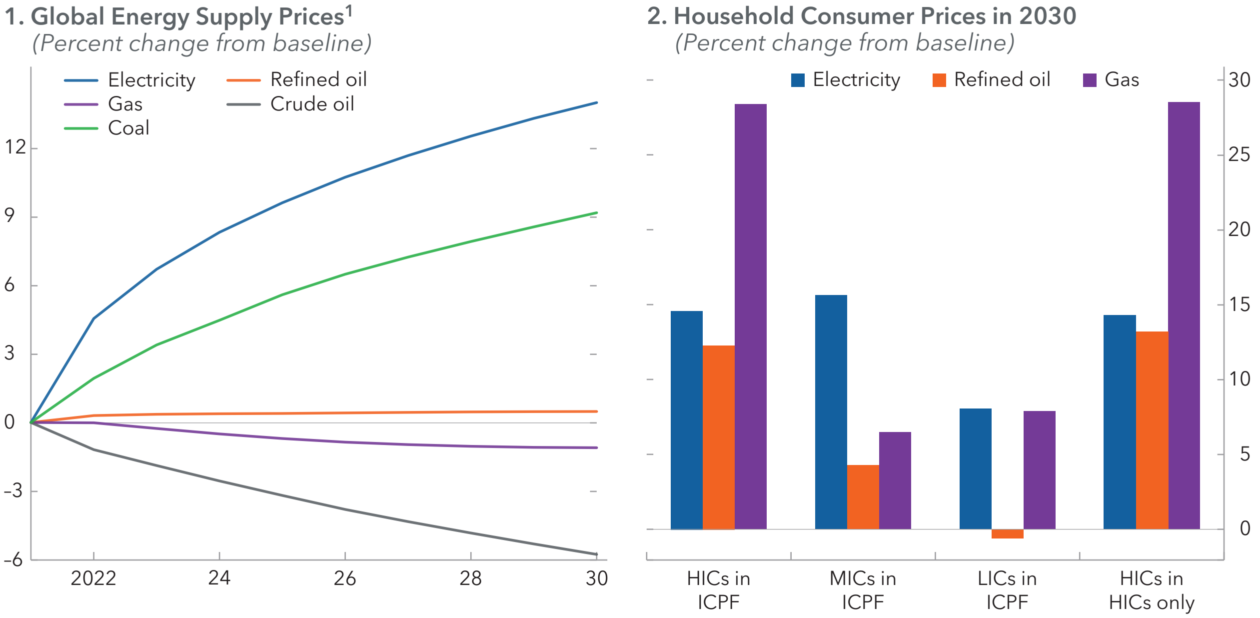


3. Ratio of Global Investment to GDP[3]
(Percent)



Source: IMF-ENV model.
Note: Dev. = deviation; eqpt. = equipment; ICPF = international carbon price floor; manuf. = manufacturing; svcs. = services.
[1] "Primary sectors" include crops, livestock, fisheries, and forestry sectors. "Fossil-fuel" includes natural gas extraction, coal extraction, crude oil extraction, and refined oil. "Utilities" include power generation, electricity distribution and transmission, and waste and water management.
[2] For power sectors the measure reported is change in the capital stock with respect to the baseline and not a change in investment.
[3] "Non-fossil-fuel power" is the sum of wind, solar, nuclear, hydro, and other power. "Fossil-fuel power" is the sum of coal, oil, and gas power.

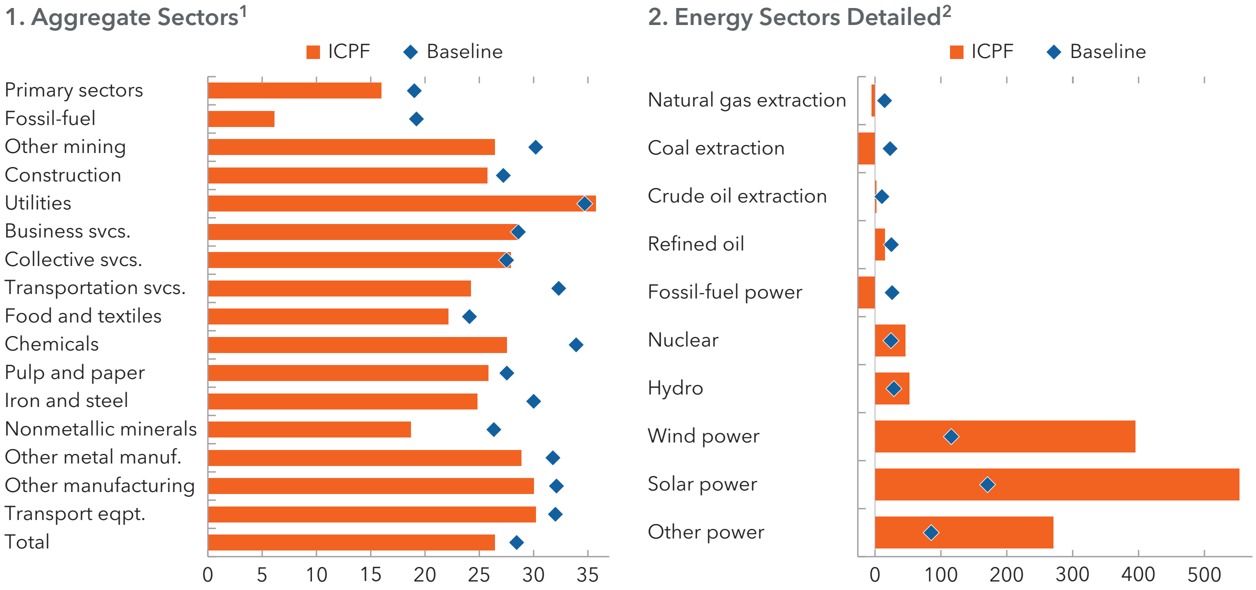
Figure 9. ICPF Scenario: Projected Changes in World Energy Prices



Source: IMF-ENV model.
Note: HIC = high-income country; LIC = low-income country; MIC = middle-income country.
[1] Supply prices are calculated as a world average of production price of the sector.

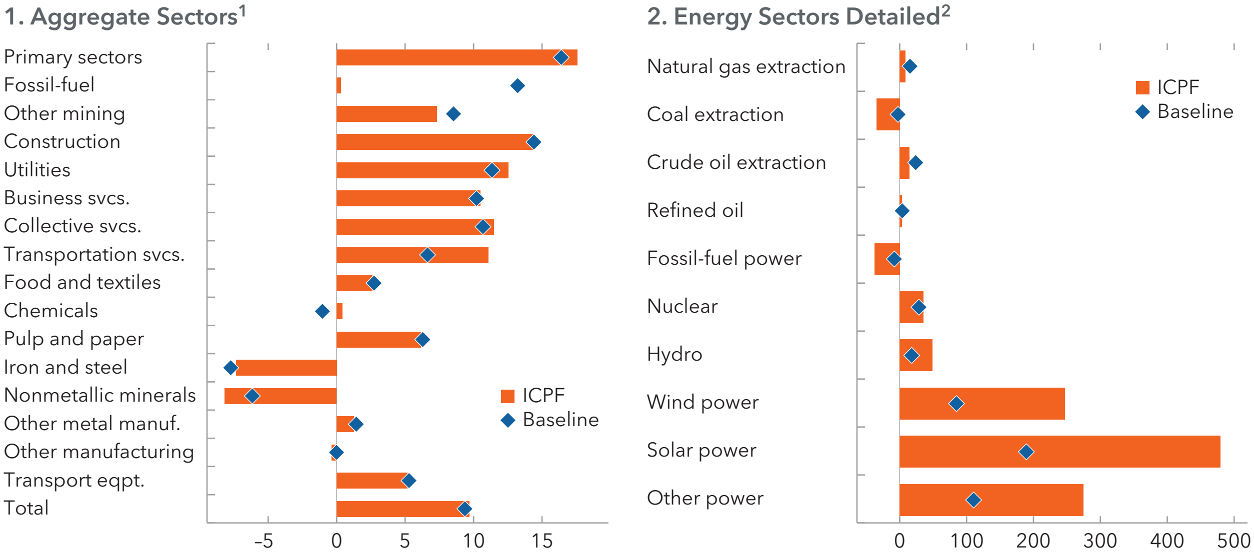
Figure 10. ICPF and Baseline Scenarios: Change in Global Real Gross Output in 2030, by Aggregate Sector

(Percent deviation from 2019)



Source: IMF-ENV model.
Note: eqpt. = equipment; ICPF = international carbon price floor; manuf. = manufacturing; svcs. = services.
[1] "Primary sectors" include crops, livestock, fisheries, and forestry sectors. "Fossil-fuel" includes natural gas extraction, coal extraction, crude oil extraction and refined oil. "Utilities" include electricity generation, distribution and transmission and waste and water management.
[2] "Fossil-fuel power" is the sum of coal, oil, and gas power.

Figure 11. ICPF and Baseline Scenarios: Change in Employment in 2030, by Aggregate Sector
(Percent deviation from 2019)



Source: IMF-ENV model.
Note: eqpt. = equipment; ICPF = international carbon price floor; manuf. = manufacturing; svcs. = services.
[1] "Primary sectors" include crops, livestock, fisheries, and forestry sectors. "Fossil-fuel" includes natural gas extraction, coal extraction, crude oil extraction and refined oil. "Utilities" include electricity generation, distribution and transmission and waste and water management.
[2] "Fossil-fuel power" is the sum of coal, oil, and gas power.

to zero-carbon energy sources and thus become insulated from higher emission prices. In the short term, however, the technologies for this are not ready for large-scale rollout. The utilities sector benefits in the ICPF, as it includes renewable energy. The service sectors—which account for a large share of the economy—also expand relative to the baseline, as they are not very energy intensive and benefit from the reduction in the labor income tax. Panel 2 of FIgure 10 zooms into the energy sector. The extraction of natural gas, coal, and crude oil and fossil-fuel power are expected to contract. Only the refined-oil sector is expected to grow, by a few percent, as some oil will still be needed and oil is also an input, for example, in the production of plastics. Non-fossil-fuel power generation expands to replace fossil-fuel power generation. These sectoral reallocations will create difficult transitions for firms and workers and require careful policy planning, including support measures for affected sectors and regions to ensure the transition is as inclusive as possible.

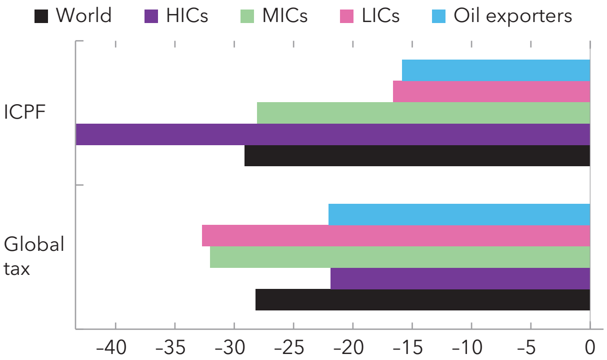
Last but not least, the reduction in labor income taxes financed with the carbon price revenues stimulates labor supply and implies a small net increase in employment, albeit with substantial sectoral reallocation.[4] The small net increase in employment relative to the baseline masks substantial reallocation of employment across sectors. Fossil-fuel sectors are the sectors that lose substantial fractions of employment relative to today, especially coal extraction and fossil-fuel power (Figure 11). Employment in total EITE industries in 2030 is also lower than today, but only by small amounts, and global employment was already projected to fall under the baseline in some of these sectors owing to China's large structural and demographic change. In contrast, employment in the non-fossil-fuel power sector increases by large amounts, following the pattern of output change in Figure 10. Employment also increases in the service sectors, as these sectors are labor intensive and benefit from the reduction in labor income taxes financed by the carbon price. Policy

---

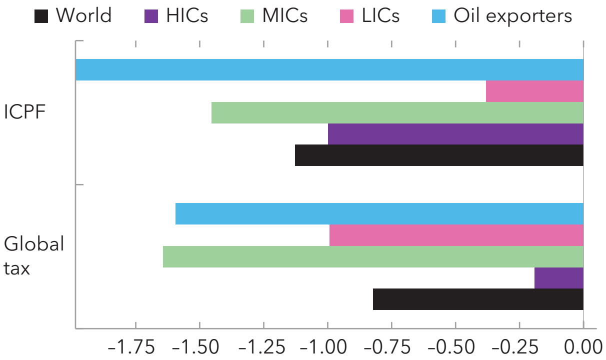
[4] Additional simulations (available on demand) show that alternative ways of recycling the revenues from carbon taxes would affect GDP and employment outcomes. For example, assuming instead that carbon tax revenues are used to provide a lump-sum rebate to households would cause global employment to be 0.6 percent lower in 2030 (relative to the baseline), instead of being 0.2 percent higher with labor income tax recycling. In turn this contraction of employment would imply a global GDP cost of climate policy of 1.8 percent in 2030, higher than the 1.1 percent cost in this study's central scenario.

Figure 12. ICPF and Global Tax Scenarios: Burden Sharing, by Aggregate Country Group

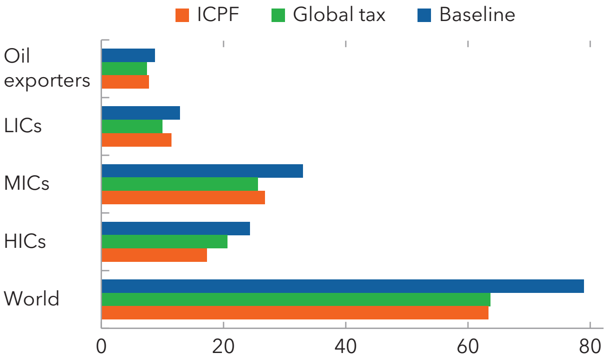
1. CO_2 Emissions in 2030
(Percent deviation from baseline)



2. Real GDP in 2030
(Percent deviation from baseline)



3. Shares of Carbon Budget for the 1.5°C Scenario Used from 2021 to 2030[1]
(Percent)



Source: IMF-ENV model.
Note: HIC = high-income country; ICPF = international carbon price floor; LIC = low-income country; MIC = middle-income country.
[1]This indicator is the cumulative emissions (over 2021–30) as a share of the remaining carbon budget for the 1.5°C target calculated by the IPCCC (2018).

support to facilitate as much as possible the transition of workers from declining to growing sectors and compensatory measures for those most affected will be key to ensuring a just and smooth transition.

C. International Burden Sharing

To illustrate the efficiency and international burden-sharing properties of the ICPF, the study compares it with a global tax scenario. A uniform global carbon tax has long been suggested as the most efficient form of climate change mitigation at the global level. Thus, the study models it to compare it with the ICPF scenario, with its differentiated carbon prices. The global tax scenario is designed by calculating the total CO_2 emission reductions of the ICPF scenario and then setting a global uniform carbon price to match these emission reductions exactly. The endogenous carbon price in this scenario reaches \$55.80/tCO_2eq in 2030 (2018 prices).

The ICPF introduces more burden sharing of climate mitigation across countries than the global tax scenario. Figure 12 compares the emissions and GDP impacts of the ICPF and global tax scenarios across country groups (all measured in deviation from the baseline in 2030). In the ICPF scenario, emission reductions are progressive, meaning that they are highest among HICs and lowest among LICs. In contrast, the global tax scenario implies much higher emission reductions among MICs and LICs than among HICs. The reason for this is that the emission intensity is highest at lower income levels; hence, for a given carbon price, countries reduce emissions by more. Broadly speaking, relative to the global tax scenario, the ICPF transfers a fraction of the emissions reductions and the associated GDP cost from LICs to HICs, with MICs little affected since their carbon price floor under the ICPF is close to the uniform global carbon price.

The greater fairness of the ICPF comes at the cost of less efficiency than the global tax scenario, but the loss in efficiency is small. Panel 2 of Figure 12 illustrates the argument in favor of a uniform global carbon price: uniform pricing would imply lower GDP costs at the global level, at about 0.8 percent compared with 1.1 percent under the ICPF. The reason is that it is most efficient to reduce emissions where abatement cost is lowest (in LICs, for example). The ICPF scenario implies greater GDP losses but a fairer sharing of the mitigation costs burden than the global carbon tax scenario. This illustrates a traditional equity-efficiency trade-off. In principle, it is possible to have full efficiency and a progressive allocation of cost across countries with an additional policy instrument. This would require, for example, complementing a global carbon tax with a transfer from HICs to MICs and LICs. Indeed, the GDP loss among HICs is smaller in the global tax scenario than in the ICPF. This difference could be (partially) used for the transfer. However, implementation of such a transfer system has proven to be politically very difficult. An ICPF is thus a pragmatic approach for combining fairness with a good, though not optimal, level of efficiency.

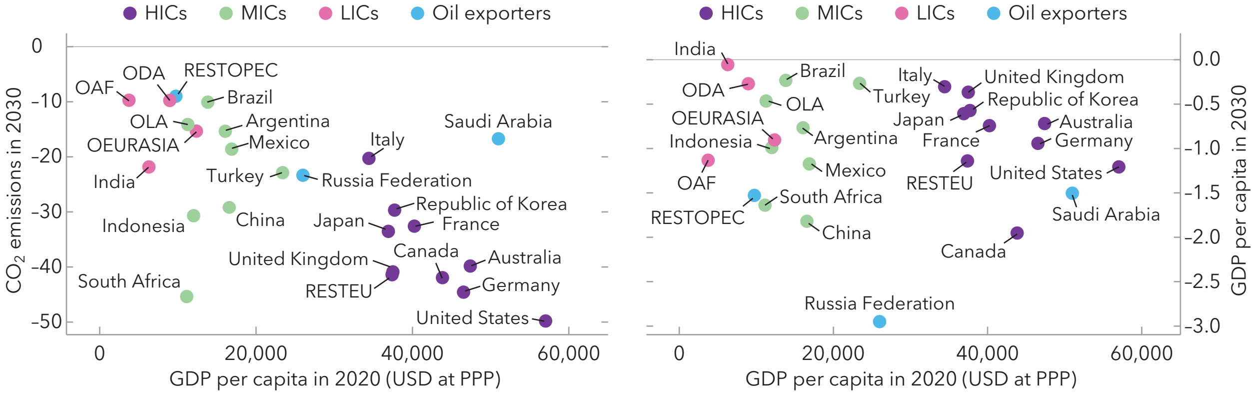
The ICPF also allocates shares of the remaining emissions budget more fairly than a uniform global carbon price. Panel 3 of Figure 12 shows the cumulative emissions by region for the decade 2021–30 as a share of the remaining carbon budget for the 1.5°C target. The ICPF demands more emissions reductions from HICs and less from other groups than a global uniform price would: in the ICPF, the share of the carbon budget used by HICs is lower by about 3 percentage points, offset by increases in the shares of LICs and to a lesser extent MICs. Even the ICPF, however, would already consume about two-thirds of the remaining carbon budget for 1.5°C in this decade.

Looking in more detail at burden sharing within the ICPF, emissions reductions follow a progressive pattern, but the evidence on other indicators is more mixed. Figure 13 shows the distribution of the burden across countries for various measures of the climate mitigation effort in relation to GDP per capita. The simulations point to the following:

- Wealthier countries reduce emissions proportionally more relative to the baseline, whether one looks at percentage reductions in total CO_2 emissions, emissions per capita, or emissions per unit of GDP. The main outliers are Indonesia and South Africa and to a lesser extent China, which reduce emissions more than other countries in their income groups, owing to an especially high carbon intensity for their group level.
- However, the evidence on fair burden sharing is less clear when GDP per capita costs and the carbon-tax-to-income ratio, which do not increase with income level despite a higher capacity to pay among HICs, are considered. As explained earlier, this reflects the low emission intensity of HICs, at about 20 percent of that in other countries. A more comprehensive analysis of costs and benefits should, however, also incorporate important co-benefits that MICs and LICs can expect from reductions in air pollution (see Annex Figure 2.2).
- Finally, despite some convergence, emissions per capita remain higher in HICs than in the rest of the world in 2030. This is entirely due to differences in income per capita, as emissions per unit of income (or GDP) in HICs are much lower than in other regions. The lower emission intensity of production in HICs reflects a different economic structure, most notably a higher share of the service sector, and a higher efficiency in using fossil fuels. The difference in the use of fossil fuels could be reduced as technology is transferred from HICs to other countries.

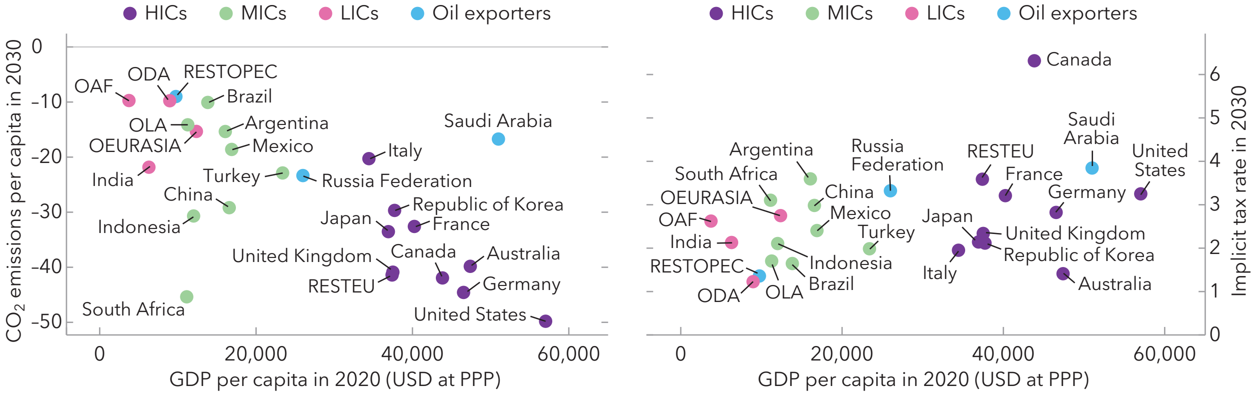
Climate finance and technology transfers are important additional policy tools for improving international equity and also efficiency. Figure 13 shows that an ICPF will not be equitable across all the different possible ways to measure equity. At the same time, the per-unit cost of reducing emissions is currently lowest in LICs. Climate finance is an opportunity to reduce emissions where these reductions are most efficient and also to make climate mitigation more progressive at the global level. The current commitment of advanced economies is to provide $100 billion per year to emerging markets and developing economies (EMDEs). Nevertheless, scaling up international support would have strong benefits and contribute to a just and affordable transition in EMDEs. This should also be combined with technology transfers that ensure that all countries have access to low-carbon technology on affordable terms (Pigato and others 2020).

Figure 13. Burden Sharing under the ICPF Scenario



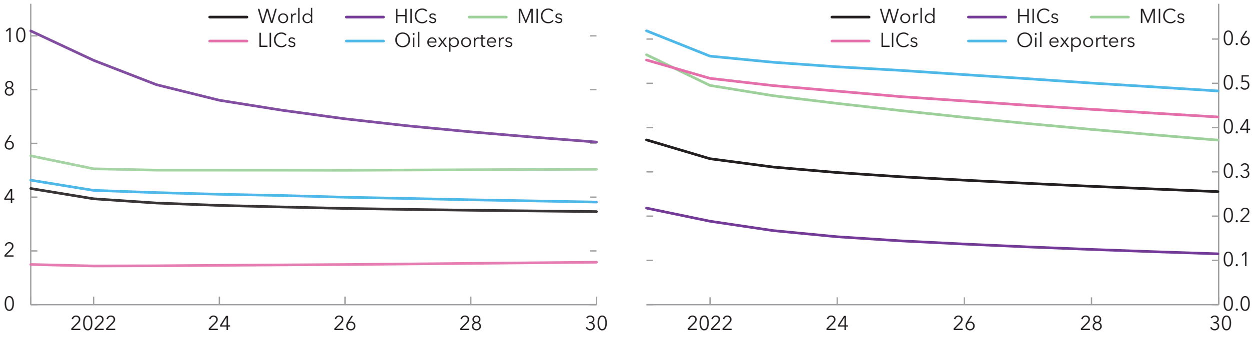
1. CO_2 Emissions Reductions
(Percent deviation from baseline)

2. Real GDP per Capita Cost
(Percent deviation from baseline)



3. CO_2 Emissions per Capita Reductions
(Percent deviation from baseline)

4. Carbon-Tax-to-Income Ratio
(Percent)



5. Level of CO_2 Emissions per Capita
(Tons per person)

6. Level of CO_2 Emissions per GDP
(Tons per US dollar)

Source: IMF-ENV model.

Note: CO_2 = carbon dioxide; HIC = high-income country; ICPF = international carbon price floor; LIC = low-income country; MIC = middle-income country; OAF = other Africa; ODA = other East Asia and New Zealand; OEURASIA = other Europe and Asia; OLA = other Latin America; PPP = purchasing power parity; RESTEU = rest of European Union and Iceland; RESTOPEC = other oil-exporting countries.

4. Incomplete Action and the Role of Border Carbon Adjustment

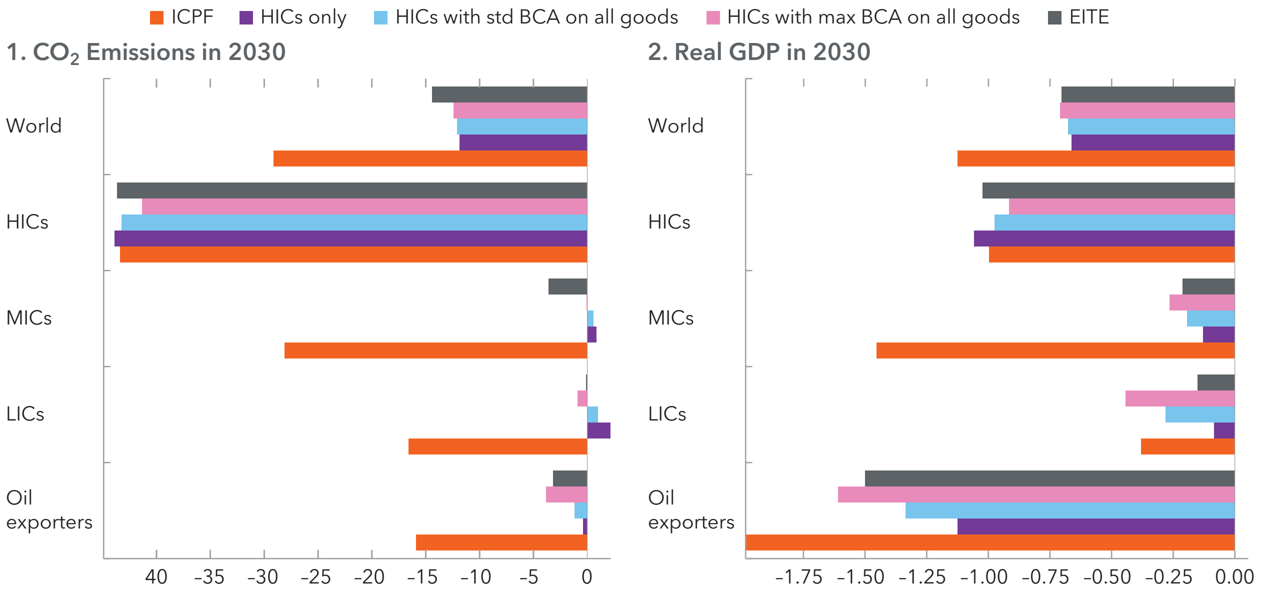
Despite its benefits, an ICPF may not be adopted, and HICs may have to go ahead unilaterally with ambitious climate policy, raising questions about risks of carbon leakage and competitiveness losses. This chapter examines the case of unilateral action by HICs, impacts on competitiveness and carbon leakage, and how they can be addressed with BCAs. The effectiveness of BCAs at addressing competitiveness problems will be compared with that of the ICPF, in which all countries take action, but carbon price floors are differentiated by income level. Finally, the chapter discusses whether BCAs could offer incentives for a scaling up of climate policy in nonacting countries, through participation in an ICPF type of arrangement.

A. Partial Action When Only HICs Adopt a Carbon Price Floor

Even under unilateral climate action, emission reductions and GDP outcomes of HICs are very close to those in the ICPF scenario. HICs are assumed to implement their carbon price from the ICPF scenario, while all other countries continue with their baseline policies. A small amount of carbon leakage occurs among MICs and LICs (Figure 14), but global CO_2 emissions still decrease by almost 12 percent relative to baseline (versus by 15 percent without the carbon leakage to MICs and LICs). This means that carbon leakage does not undermine the efforts of acting countries (HICs). The aggregate carbon leakage rate is about 6.5 percent (Figure 15, panel 1), in the range of estimates found in the literature, which vary between 5 and 25 percent, with a mean of 14 percent (see Branger and Quirion 2014). As explained by Burniaux, Chateau, and Duval (2013), the aggregate carbon leakage is moderate because, as discussed in Chapter 3, section B, the supply of coal is more price-elastic than that of crude oil and natural gas. Emission reductions by HICs make coal relatively more expensive relative to other fossil fuels in international markets (as in the ICPF scenario; see Figure 9) and therefore lead to some emission reductions in nonacting countries as well. Leakage rates also depend on the size of the acting coalition, which is relatively large here (see the discussion in Box 2). When they act unilaterally, HICs experience only slightly higher GDP losses relative to those in the ICPF scenario, reflecting competitiveness losses of their industries on international markets with respect to nonacting countries.

Nonacting countries do not record GDP gains from climate mitigation policies implemented by the HICs. For nonacting countries, the net GDP impact depends on (1) how they are affected (through reduced exports) by the overall lower activity in HICs; (2) how the higher relative prices in HICs affect the terms of trade for nonacting countries (they could either give them some comparative advantage or increase the import prices of goods produced by the coalition); and (3) the lower global energy prices. Simulations show that negative effects generally dominate and that most MICs and LICs experience a minor decrease in GDP relative to the baseline (Figure 14). This counterintuitive result is not surprising. A study done by the Energy Modelling Forum pointed out that most of the 12 models used in its cross-model comparison analysis showed a similar substantial shift of abatement burdens to nonabating countries through terms-of-trade adjustments (Böhringer, Balistreri, and Rutherford 2012). This result calls into question the idea that nonacting countries can draw economic benefits from the mitigation effort of acting countries. However, a few MICs and LICs (Argentina, India, South Africa, and Turkey) record marginal GDP gains relative to the baseline, reflecting either gains in market shares (to the detriment of HICs), benefits from lower international prices for oil and gas, or both. Clearly, oil exporters still experience substantial losses in GDP—even if they don't act on climate themselves (only Saudi Arabia is assumed to act with other HICs), because climate policy in HICs reduces international demand for oil and gas and therefore international prices for these fuels.

Figure 14. Partial-Action Scenarios: Emissions and GDP in 2030, by Aggregate Country Groups
(Percent change from baseline)

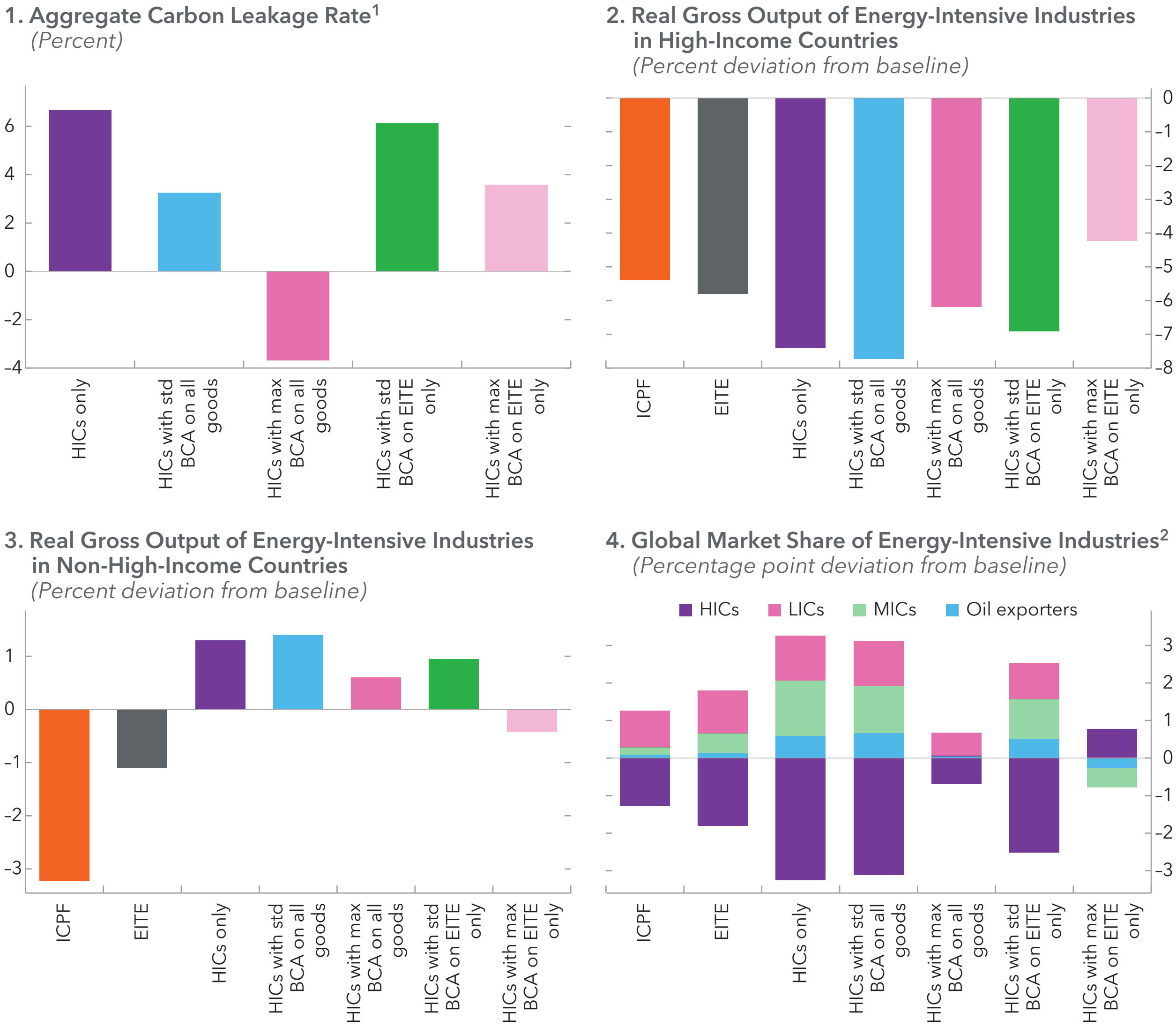

1. CO_2 Emissions in 2030
2. Real GDP in 2030

Source: IMF-ENV model.
Note: BCA = border carbon adjustment; EITE = energy intensive and trade exposed; HIC = high-income country; ICPF = international carbon price floor; LIC = low-income country; max = maximum; MIC = middle-income country; std = standard.

While aggregate GDP losses for HICs are only marginally higher, their EITE industries experience more substantial output and competitiveness losses. Figure 15 shows sectoral output changes for HICs and the rest of the world for the various scenarios. In EITE sectors, most notably chemicals, iron and steel, and nonmetallic minerals, the loss in competitiveness of domestic firms, owing to increased costs with respect to those in nonacting foreign competitors, causes output losses up to one-third higher for HICs than in the ICPF, at about 7.5 percent. The gross output of nonacting countries in these sectors improves by 1.25 percent. HICs' loss of competitiveness in EITE sectors is also illustrated by the reduction of their market share in international markets for these goods by about 2 percentage points, from 56.2 percent in the ICPF scenario to 54.2 percent in the HICs-only scenario (Figure 15, panel 4). Leakage rates for EITE sectors are much greater than the 6.5 percent aggregate leakage rate when HICs are acting alone, as shown in Figure 16. On average for all EITE sectors, the leakage rate reaches 40 percent of the corresponding emission reductions in acting HICs. It ranges from 50 percent for chemicals and for iron and steel to 30 percent for nonmetallic minerals, 15 percent for nonferrous metal manufacturing, and zero for pulp and paper manufacturing. Leakage rates for EITE goods are high for a couple of reasons: first, these goods are carbon intensive; second, they are also heavily traded (at least chemicals and iron and steel); and third, the changes in trade patterns for these goods are very sensitive to changes in relative prices between regions, reflecting the rather homogenous character of these goods.

Global emission reductions are very insufficient when only HICs implement the ICPF. Figure 14 shows a large difference in global emissions between the partial- and the full-participation (ICPF) scenarios. When only HICs implement the ICPF, global CO_2 (GHG) emissions decline by 12 percent (10 percent) below the baseline in 2030, compared with a 29 percent (26.6 percent) reduction of global CO_2 (GHG) emissions under global action. This demonstrates the central role of MICs and LICs in reaching global temperature goals. If only HICs are acting, global emissions in 2030 cannot reach a level consistent with a 2°C scenario. Indeed, while HICs reduce their CO_2 emissions by 44 percent relative to the baseline, global CO_2 emissions still increase by 8.4 percent in 2030 relative to 2019, because HICs only account for 23.5 percent of baseline global GHG emissions in 2030.

Figure 15. Partial-Action Scenarios: Carbon Leakage Rates, EITE Output, and EITE Market Shares in 2030



1. Aggregate Carbon Leakage Rate[1]
(Percent)

2. Real Gross Output of Energy-Intensive Industries in High-Income Countries
(Percent deviation from baseline)

3. Real Gross Output of Energy-Intensive Industries in Non-High-Income Countries
(Percent deviation from baseline)

4. Global Market Share of Energy-Intensive Industries[2]
(Percentage point deviation from baseline)

Source: IMF-ENV model.
Note: BCA = border carbon adjustment; EITE = energy intensive and trade exposed; HIC = high-income country; ICPF = international carbon price floor; max = maximum; std = standard.
[1] Leakage rates are defined as the change (with respect to baseline) in carbon dioxide (CO_2) emissions in nonacting countries expressed as a percentage of the reduction in CO_2 emissions in acting countries (i.e., HICs).
[2] Market share for a given commodity is the value of exports of a country as a percentage of world total exports.

B. The Effect of Border Carbon Adjustment

Countries that are undertaking ambitious climate policies to reduce emissions are considering implementing BCAs to protect domestic industries and reduce carbon leakage. The two phenomena are interrelated, as ambitious climate policies undertaken in a coalition of a few countries lead to production shifts toward nonacting countries that, owing to their less ambitious carbon policies, benefit from comparative advantage on international markets. Increasing production in nonacting countries implies higher energy demand in these countries and therefore generates a carbon leakage. To a lesser extent, carbon leakage could also result from a response of fossil-fuel demand among nonacting countries in response to lower international prices for these fuels as a consequence of the lower fossil-fuel demand by acting countries. The empirical evidence so far points to small aggregate carbon leakage and competitiveness losses, but this could change at higher carbon price levels, and larger losses are already identifiable for EITE sectors—in which international competition is high (see Chapter 4, section A).

The paper considers several possible BCA designs. One important distinction is the coverage of goods subject to the BCA; another is the stringency of the BCA, which depends on how the carbon content used to apply the tariff is calculated and whether the tariff is complemented by an export subsidy.

- Coverage of goods: For the analysis, the BCA will be applied either to all commodities (base assumption) or only to EITE sectors. Restricting the BCA to EITE sectors was suggested by Keen, Parry, and Roaf (2021). It allows the administrative efforts to be focused on the most relevant products. In both cases, the BCA includes only the carbon content of commodities resulting from CO_2 emissions from fossil-fuel combustion. While it is straightforward to model BCAs including the carbon content of other GHGs or that from process-based emissions, in the real world these emission coefficients cannot be determined reliably.
- Stringency of the BCA: The analysis focuses on two main cases, while other possible designs and the role of the size of the coalition are discussed in Box 2. In the most stringent case (maximum BCA), the BCA is designed as both a countervailing tariff, based on the specific carbon content of a given commodity, and an export subsidy.[1] The calculation of the tariff is based on emissions embodied in the commodity of the foreign country, and therefore the countervailing tariffs imposed by acting countries are different across partner countries. The indirect carbon content from electricity used in the production process of the goods is included. The tariff revenue from the BCA is retained by the acting countries, partly to finance the export subsidies. Tariffs and export adjustments are calculated based on the difference between carbon prices of acting and nonacting countries, but the carbon price for most nonacting countries is zero. In the less stringent case (standard BCA), only the tariff part of the BCA is implemented, and these tariffs are calculated based on the carbon content of equivalent goods produced in the domestic (acting) country, so they are the same for all nonacting countries. As in the case of the maximum BCA, the indirect carbon content from electricity used in the production process of the goods is included, and the tariff revenues from the BCA are retained by the acting countries. In all designs of the BCA, the carbon content of (domestic or imported) goods used for the calculation of tariffs and export subsidies is updated each projected year.

BCAs improve the effectiveness of climate policies at reducing emissions and help restore competitiveness of firms in acting countries (HICs), but the magnitude of these effects depends on the BCA design. Using the foreign carbon content of goods to calculate the BCA is in general key for its effectiveness. In contrast, a BCA based on the domestic carbon content of goods does little to restore the competitiveness of EITE sectors in acting countries. The addition of an export subsidy under the maximum BCA also contributes to its greater effectiveness, but to a lesser extent. Finally, the choice of coverage of goods is not innocuous and implies some trade-offs between the two objectives of reducing carbon leakage and limiting competitiveness losses. A BCA on all goods will naturally be more effective at reducing the aggregate carbon leakage of an economy, while a BCA on EITE goods will be more efficacious at protecting EITE sectors. This is because limiting the BCA to EITE goods makes these industries more competitive not only with respect to imported EITE goods, but also with respect to other substitutable goods on domestic markets; in addition, the cost of intermediate (imported) goods in EITE sectors is lower than if those goods were also subjected

---

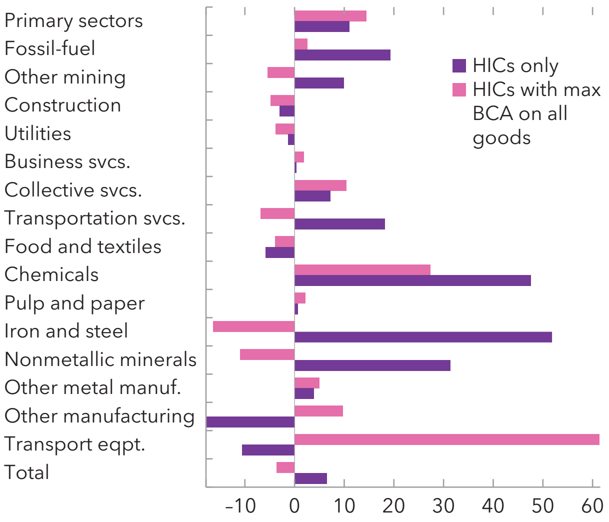
[1] All BCA scenarios assume for simplicity that Saudi Arabia does not adopt a BCA to avoid unconventional results due to higher domestic than foreign carbon intensity.

to carbon tariffs; lastly, the overall price distortion introduced by carbon tariffs is lower, since only a fraction of goods are subject to the extra carbon-based tariffs.[2] These findings are discussed in more detail in the following paragraphs.

BCAs are most effective at reducing aggregate carbon leakage when they are applied to all commodities and calculated with the foreign carbon content. Figure 15 (panel 1) shows that when a BCA is applied to all products, the carbon leakage rate for the total economy falls from 6.5 to 2.7 percent under the standard BCA and turns negative under the maximum BCA. In contrast, reductions in the leakage rate are smaller when the BCA is applied only to EITE goods. A negative leakage rate means that emissions in nonacting countries are lower than in the baseline when those countries face carbon tariffs on their exports. As explained earlier and in Burniaux, Chateau, and Duval (2013), these reverse carbon leakages appear when the supply of coal is more elastic than that of crude oil and natural gas. Emission reductions by HICs make coal relatively more expensive in international markets and therefore lead to emissions reductions in nonacting countries as well.

The effectiveness of a BCA at protecting domestic EITE industries hinges on using the foreign carbon content, with further (but lesser) gains from limiting its applicability to EITE goods as opposed to all goods. A BCA calculated with domestic carbon content, like the standard BCA, fails to reduce leakage rates of EITE industries substantially, as the implied carbon-based tariff rate is small, at less than 1 percent, while it is at least three to five times higher under the maximum BCA. When the foreign carbon content is used, sectoral EITE leakage rates are drastically reduced (Figure 16), on average from 50 to 10 percent. Figure 15 shows that a maximum BCA applied only to EITE goods would reduce output losses in EITE industries of acting countries the most, from 7.5 percent (in the absence of BCAs) to 4 percent. It would also suppress the gross output gains of nonacting countries in these sectors, from 1.25 percent (relative to the baseline) with no BCA to –0.2 percent. Finally, a maximum BCA can achieve a high degree of protection against market share losses in EITE industries, reducing losses to 1 percentage point from the baseline when the BCA is applied to all goods and even generating small market share gains for HICs when the BCA is limited to EITE goods.

Figure 16. Partial-Action Scenarios: Sectoral Leakage Rates in 2030[1]
(Percent)



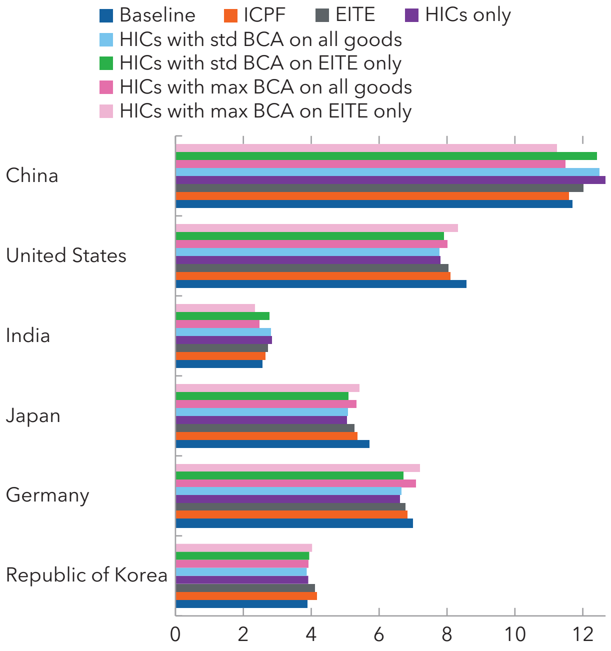
Source: IMF-ENV model.
Note: BCA = border carbon adjustment; eqpt. = equipment; HIC = high-income country; manuf. = manufacturing; max = maximum; svcs. = services.
[1] Leakage rates are defined as the change in carbon dioxide (CO_2) emissions in nonacting countries (for a given sector or at aggregate level) expressed as a percentage of the change in CO_2 emissions in acting countries (i.e., HICs).

Importantly, an ICPF can be as effective as some designs of BCAs at protecting against losses in competitiveness and market shares of HICs. Despite carbon prices differentiated by development levels, the ICPF performs better than the standard BCA and almost as well as the maximum BCA when it comes to limiting output losses of HICs in EITE sectors and changes in world market shares for these industries, as shown in Figure 15 for HICs as a group and Figure 17 for selected countries. Indeed, while MICs and LICs benefit from lower carbon prices than HICs under the ICPF, the carbon intensity of their products

---

[2] At the same time, BCAs do not entirely curb EITE output losses for two reasons discussed in Burniaux, Chateau, and Duval (2013): (1) EITE industries in HICs make important use of carbon-intensive EITE intermediate inputs produced by the nonacting countries, and (2) ultimately, EITE industries are more affected by the domestic carbon price itself than by any changes in comparative advantage.

Figure 17. Partial-Action Scenarios: Market Share in EITE Sectors, Selected Countries, 2030[1]
(Percentage points)



Source: IMF-ENV model.
Note: BCA = border carbon adjustment; EITE = energy intensive and trade exposed; HIC = high-income country; ICPF = international carbon price floor; max = maximum; std = standard.
[1] Market share for a given commodity is the value of exports of a country as a percentage of world total exports.

is higher, evening out the carbon costs per unit of output. This is also the case if a sectoral ICPF arrangement (EITE scenario) is considered, in which HICs move ahead with ambitious policies implementing the ICPF economy-wide, while other country groups implement the ICPF carbon price floor in EITE sectors only—the sectors of most concern to HICs for international competitiveness. The outcomes for EITE sectors in HICs are very close to one another whether MICs and LICs impose the carbon price floor on their entire economies (as in the full ICPF) or on their EITE sectors only (as in the sectoral ICPF scenario).

C. BCA versus ICPF

BCAs imply a considerable administrative effort and might be considered a hostile move by trade partners. As this study has shown, the most effective BCA is one that uses foreign carbon content. Estimating the carbon content of a foreign good—including the indirect carbon content from intermediate goods—is a difficult task, as carbon intensity varies strongly across countries, between sectors, and within sectors. While the domestic carbon content could be used as a proxy for the foreign carbon content, this reduces substantially the efficiency of the BCA, as discussed earlier. In addition, a BCA could be seen as an excuse to introduce a trade barrier for imports. This could threaten international goodwill and lead to retaliatory measures. The effectiveness of a BCA could also be further reduced by adjustments in international trade, such as using the least carbon-intensive products in each sector for export and reserving more polluting ones for domestic use.

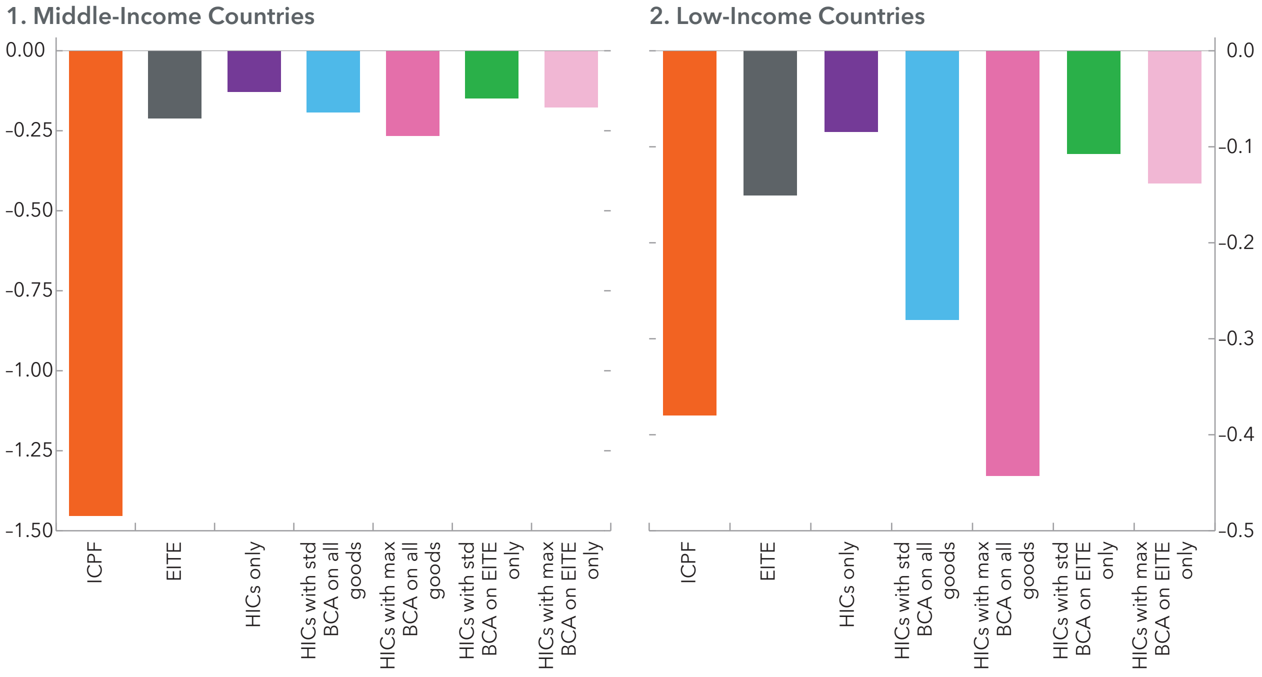
More importantly, contrary to the ICPF, BCAs do not scale up mitigation sufficiently. While BCAs reduce carbon leakage by taxing carbon emissions in embodied imports from nonacting countries, the bulk of nonacting countries' emissions, embodied in domestic absorption, remain untaxed. In contrast, under the ICPF, all country groups introduce domestic carbon pricing or equivalent measures, which leads to substantial reductions in global emissions.

In general, a BCA will not provide incentives for participation of nonacting countries in the ICPF. BCAs extend the burden of emission reductions to nonacting countries by imposing carbon-based tariffs on imported goods. Changes in GDP shown in Figure 14 indicate that HICs are better off when they impose a BCA (relative to unilateral action with no BCA), while nonacting countries are worse off, independent of the design or the goods coverage of the BCA.[3] However, inaction is still preferable to participation in the ICPF for most nonacting countries, as their GDP outcomes are much better in the BCA case than under the ICPF. Again, this is because the BCA taxes only exports, which are a small share of domestic production,

---

[3] For a maximum BCA imposed on all goods, HICs (Australia excluded) are even better off than in the ICPF scenario; this also holds with a standard BCA for the European Union and North America. On the contrary, when the BCA is imposed only on EITE sectors, GDP losses in HICs are always (but only slightly) higher than in the ICPF: the economic gains for curbing EITE output losses with a BCA are smaller than the overall loss of competitiveness of the rest of economy resulting from the unilateral action.

Figure 18. BCA and EITE Scenarios: Real GDP in 2030 for Middle- and Low-Income Countries
(Percent change from baseline)



Source: IMF-ENV model.
Note: BCA = border carbon adjustment; EITE = energy intensive and trade exposed; HIC = high-income country; ICPF = international carbon price floor; max = maximum; std = standard.

while under the ICPF the carbon price would apply to the entire economy. Important exceptions are LICs like India or other developing Asian countries, for which the GDP outcomes are similar under the ICPF and the standard BCA and even slightly worse under the maximum BCA. This reflects their relatively low ICPF carbon price floor (at $25 versus at least $75 under the BCA) and their specialization in EITE goods, which implies they get hurt by the BCA.[4]

If an ICPF proves not to be within reach yet, a sectoral carbon pricing agreement for EITE sectors, that applies minimum carbon prices differentiated by level of development to these sectors, could provide a path forward for avoiding the use of BCAs. MICs and LICs could be more amenable to such a sectoral agreement, in which they would impose a carbon price floor on EITE sectors only—the sectors of concern to HICs—while HICs move ahead with their economy-wide carbon price. Figure 18 shows that GDP costs of MICs and LICs would be broadly similar (or even slightly lower in some cases) with such a sectoral agreement compared with a BCA, because the tax would be lower (albeit it would apply to both exported and domestically sold goods) and they could keep the revenues from the carbon price. While this would not scale up mitigation efforts sufficiently, it would allow avoidance of the use of BCAs and provide a cooperative solution.[5]

Ultimately, a full ICPF—with economy-wide carbon price floors, or equivalent policies, in all regions—provides a reasonable way forward to scale up global climate mitigation. To sum up, an ICPF, if it could be negotiated, would substantially increase global reductions in emissions, provide some degree of burden sharing

---

[4] This does not imply that India would join the ICPF, though, as other countries not joining (for example, China) could affect its GDP outcomes. Other LICs like African countries are better off under a BCA than under the ICPF, mostly because their trade specialization is not in energy-intensive goods, but rather in agriculture, food, and textile products, hence a BCA does not hurt them much. MICs are always better off under the BCA than under the ICPF, under which they would have to implement a $50 carbon tax.

[5] Limiting carbon pricing to traded goods might also be politically easier for MICs and LICs, as EITE sectors are in general only a small share of total economic activity. Such an agreement would not require an increase in the price for transportation fuel, for example, which is politically sensitive.

without creating substantial competitiveness concerns, and avoid the risk of creating divisions and trade tensions that would result from the implementation of a BCA. Such an agreement could accommodate the use of differentiated policy approaches across countries to achieve emission reductions equivalent to those under the carbon price floor. Reaching such an agreement would seriously enhance the world's chances of keeping the global temperature increase to safe levels.

5. Conclusion

An international carbon price floor arrangement would be a very effective mechanism for scaling up global mitigation efforts toward what is required to keep within the temperature targets of the Paris Agreement. Current policies are not sufficient to stop global emissions from increasing, let alone to implement the substantial reductions that are required to reach net zero targets by midcentury. An international carbon price floor arrangement as suggested by Parry, Black, and Roaf (2021) would help the global economy change course and head in the right direction. Key to such a mechanism is the concept of global minimum carbon prices—whether achieved explicitly by a carbon price or implicitly by an equivalent set of alternative policies—and the differentiation of these minimum carbon prices by level of development of countries. Such an arrangement would deliver substantial global emission reductions while improving international burden sharing relative to a uniform global carbon tax. Emissions reductions would be progressive, largest for high-income countries and smallest for low-income countries. However, this arrangement should be complemented by cross-country transfers to further improve burden sharing and support the transition efforts of middle- and low-income countries that have much larger development needs and are still highly reliant on fossil fuels. Further, such an arrangement would broadly preserve the relative competitiveness of country groups in sensitive energy-intensive and trade-exposed sectors, a concern for countries that are moving ahead with ambitious climate policies. The GDP costs associated with the international carbon price floor arrangement pale in comparison to baseline growth, and decarbonization is compatible with continued robust growth, provided it is supported by the right investments. In the longer term, ambitious decarbonization is the only path for ensuring sustained growth.

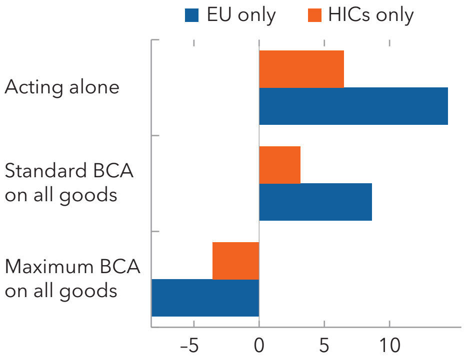
In case of unilateral action by high-income countries, a border carbon adjustment mechanism would be effective at protecting their energy-intensive and trade-exposed industries and limiting aggregate carbon leakage if it is based on foreign carbon content. In the absence of a multilateral effort, high-income countries can still effectively reduce their emissions without much damage to economic activity. Contrary to common intuition, unilateral climate action causes neither substantial losses in aggregate GDP for acting countries, relative to the case of joint action, nor gains in nonacting countries, relative to the case in which no country acts. Furthermore, aggregate carbon leakage is moderate, so that the efforts of the acting countries at reducing emissions are not undermined. However, energy-intensive and trade-exposed industries specifically do experience more substantial competitiveness losses and carbon leakages in the case of unilateral action. A border carbon adjustment mechanism would help reduce carbon leakage and restore competitiveness for these industries by forcing firms in nonacting countries to pay a price for carbon emissions. However, the effectiveness of the border carbon adjustment would depend strongly on measuring the foreign carbon content, which is difficult and administratively cumbersome to implement.

Border carbon adjustment mechanisms are not without drawbacks, and a sectoral international carbon price floor arrangement for energy-intensive and trade-exposed goods could offer a better alternative if the full international carbon price floor arrangement is not yet in reach. In addition to the administrative effort implied by the implementation of a strong border carbon adjustment mechanism, its introduction could be perceived as a hostile and protectionist move by other countries, triggering retaliation and escalating trade tensions. A sectoral carbon pricing arrangement for energy-intensive and trade-exposed sectors—in which countries would introduce a carbon price floor differentiated by income level on their energy-intensive and trade-exposed sectors—would achieve broadly similar outcomes as a strong form of border carbon adjustment (that is, one based on foreign carbon content) in terms of preserving the relative competitiveness of country groups in energy-intensive and trade-exposed sectors. It would also lead to broadly similar or better GDP outcomes for middle- and low-income countries than under a BCA, which could make them amenable to such an arrangement. It would allow HICs to implement ambitious mitigation policies without concern for carbon leakage and loss of competitiveness and without resorting to border carbon adjustments, introduce limited carbon pricing in EMDEs, and allow EMDE governments to acquire revenues. Subsequently, coverage and level of carbon pricing would gradually need to be aligned with global mitigation requirements.

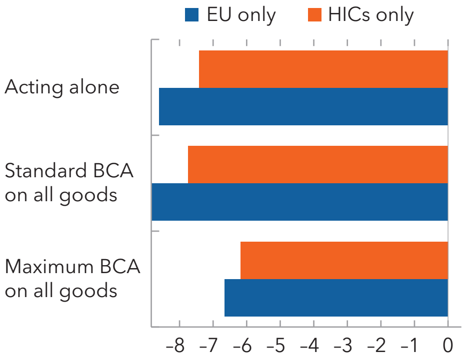
Box 2. The Environmental and Economic Effectiveness of BCAs Depends on the Design

Box Figure 2.1. EU-Only and HICs-Only Scenarios: Leakage Rates and Gross Output of EITE Industries in 2030[1]

1. Aggregate Leakage Rate
(Percent)



2. Gross Output of EITE Industries in Acting Countries
(Percent deviation from baseline)



Source: IMF-ENV model.
Note: BCA = border carbon adjustment; EITE = energy intensive and trade exposed; EU = European Union; HIC = high-income country.
[1] Leakage rates are defined as the change (with respect to baseline) in carbon dioxide (CO_2) emissions in nonacting countries expressed as a percentage of the reduction in CO_2 emissions in acting countries (i.e., HICs or EU).

This box explores how the impact of a border carbon adjustment (BCA) changes with its design and with the size of the coalition of acting countries.

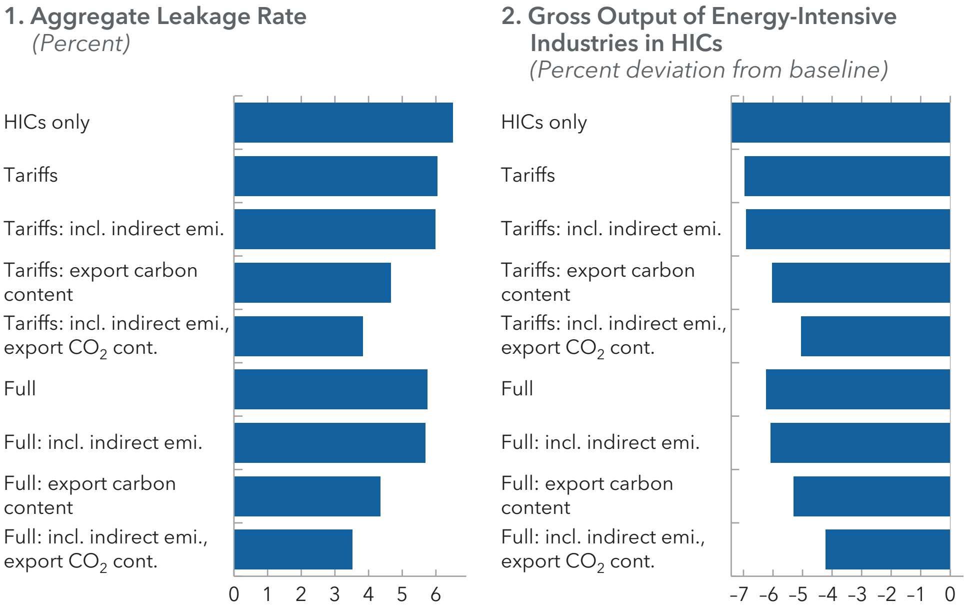
Carbon leakage rates are higher for smaller coalitions of acting countries. To illustrate this, the box compares carbon leakage rates of a larger coalition (high-income countries [HICs]) with those of a smaller coalition (European Union [EU] plus United Kingdom). When HICs are acting alone, the increase in carbon dioxide (CO_2) emissions in nonacting countries represents 6 percent of CO_2 emissions reductions in HICs in 2030, whereas if only EU countries are acting, the leakage rate could reach 17 percent of the EU CO_2 emissions reductions (Box Figure 2.1). The value for the EU is close to the estimate of 15 percent in Misch and Wingender (2021). This confirms the conclusion of Branger and Quirion (2014) that the size of the coalition is an important factor for the extent of carbon leakage. When the coalition of acting countries is small, most of the CO_2 leakage results from the reallocation of production out of acting countries, while when the coalition is large, the former effect phases out, and leakage is instead largely driven by lower international prices of fossil fuels. Similarly, output losses in energy-intensive and trade-exposed (EITE) sectors are larger for EU countries when they act alone than for HICs when all HICs act alone. This is because EU countries face competitiveness losses relative to more countries, accentuated by the fact that other HICs have trade specializations similar to those of the EU. The counterpart of this is that when the coalition is small, BCAs are more efficient at reducing leakage rates and restoring the competitiveness of the acting countries (Burniaux, Chateau, and Duval 2013). A BCA reduces less the leakage rate for larger coalitions because a larger fraction of the leakage is driven by a rebound effect of fossil-fuel demand in other countries as a result of lower international prices for fossil fuels.

The way BCAs are designed greatly affects their effectiveness. Without loss of generality, this box discusses the case in which a BCA is imposed only on EITE goods by HICs. Box Figure 2.2 shows that what really matters for the efficiency of the BCA is the use of the foreign carbon content for the computation of tariffs; adding the export subsidies also improves the efficiency of the BCA, but to a much smaller extent; and last, incorporating the indirect carbon content from power generation into the BCA improves its efficiency only when tariffs are calculated using foreign carbon content. A detailed analysis of BCAs by type of goods would show that they are rather inefficient at reducing out-

Box 2. The Environmental and Economic Effectiveness of BCAs Depends on the Design *(continued)*

put losses for the sectors that make important intermediate use of EITE goods produced in nonacting countries. Additional experiments (not reported here) show that a BCA including process-based CO_2 emissions or non-CO_2 greenhouse gas emissions is slightly more effective at leakage reduction, in line with Monjon and Quirion (2011) or Böhringer, Carbone, and Rutherford (2018).

Box Figure 2.2. Leakage Rates and Gross Output of EITE Sectors for HICs in 2030: Various BCA Designs (on EITE Goods Only), HICs-Only Scenario



Source: IMF-ENV model.
Note: BCA = border carbon adjustment; CO_2 = carbon dioxide; cont. = content; EITE = energy intensive and trade exposed; emi. = emissions; Full = the BCA contains both a tariff and an export subsidy; HIC = high-income country; incl. = including.

Annex 1. Sectoral Model Aggregation

Annex Table 1.1. Aggregate Sectors in IMF-ENV Model

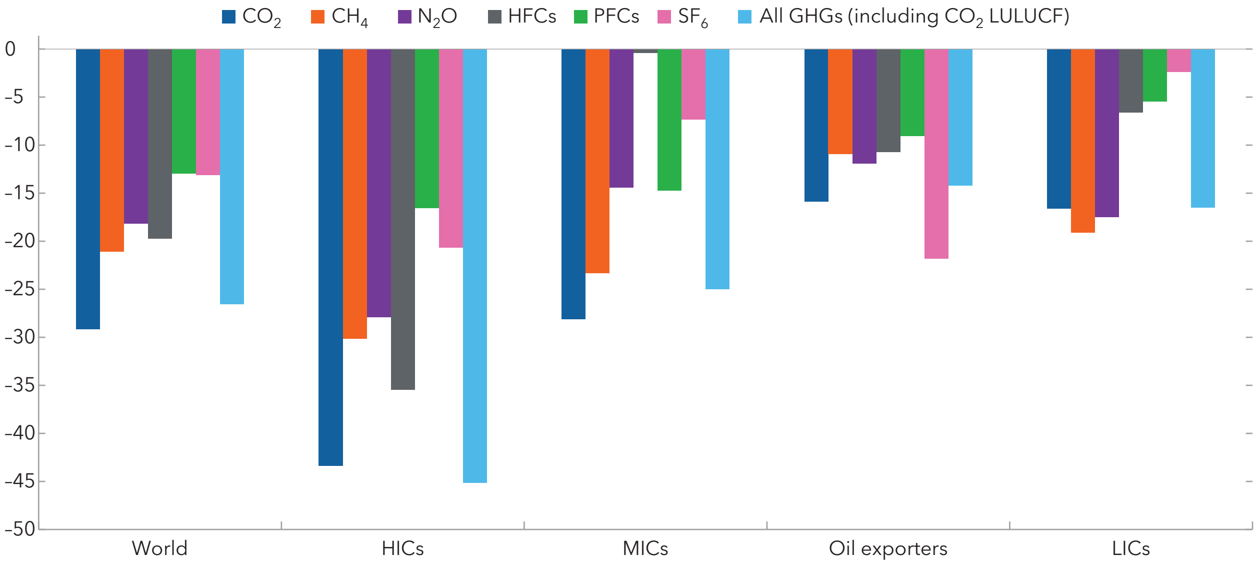
Air transport	Forestry	Other collective services
Chemical products	Gas-powered electricity	Other manufacturing
Coal extraction	Hydro power	Other power
Coal-powered electricity	Iron and steel	Paper and paper products
Collective services	Land transport services	Petroleum and coal products
Construction	Livestock	Solar power
Crops	Mining (non-fossil-fuel)	Textiles
Crude oil extraction	Natural gas: extraction and distribution	Transport equipment
Electricity transmission and distribution	Nonferrous metals	Water supply; sewerage and waste
Electronics	Nonmetallic minerals	Water transport
Fabricated metal products	Nuclear power	Wind power
Fisheries	Oil-powered electricity	
Food products	Other business services	

Annex 2. Supplementary Figures

Detailed GHG and Air Emissions

Annex Figure 2.1. Changes in Global GHG Emissions in 2030 under the ICPF Scenario, by Type of Greenhouse Gas

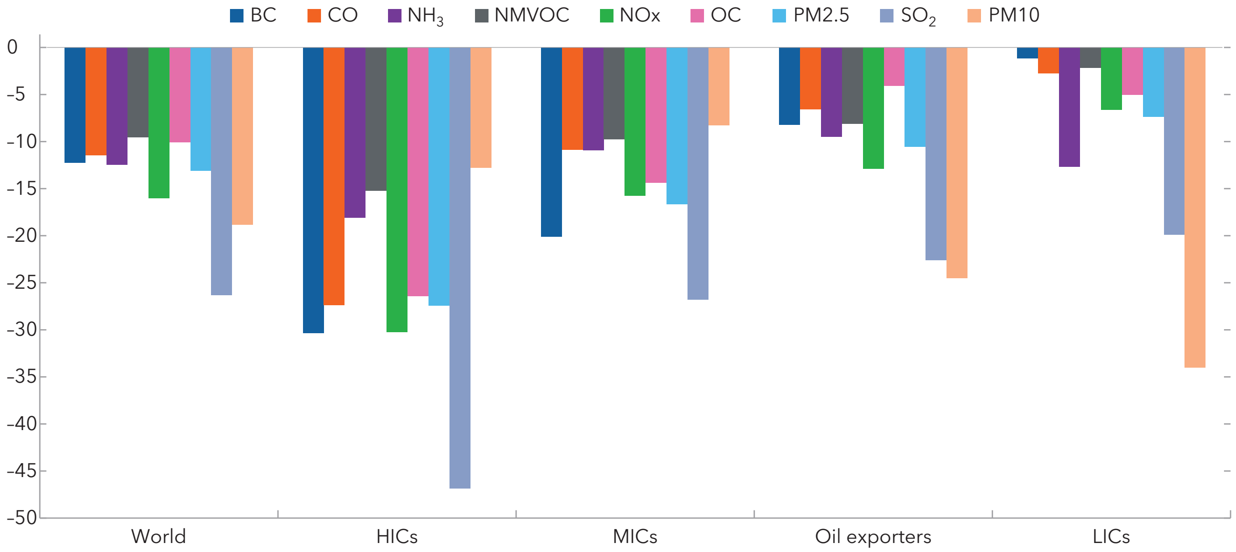
(Percent changes with respect to business as usual)



Source: IMF-ENV model.
Note: CH_4 = methane; CO_2 = carbon dioxide; HFC = hydrofluorocarbon; HIC = high-income country; LIC = low-income country; LULUCF = land use, land use change, and forestry; MIC = middle-income country; N_2O = nitrous oxide; PFC = perfluorocompound; SF_6 = sulfur hexafluoride.

Annex Figure 2.2. Changes in Global Outdoor Air Pollution in 2030 under the ICPF Scenario, by Type of Air Pollutant

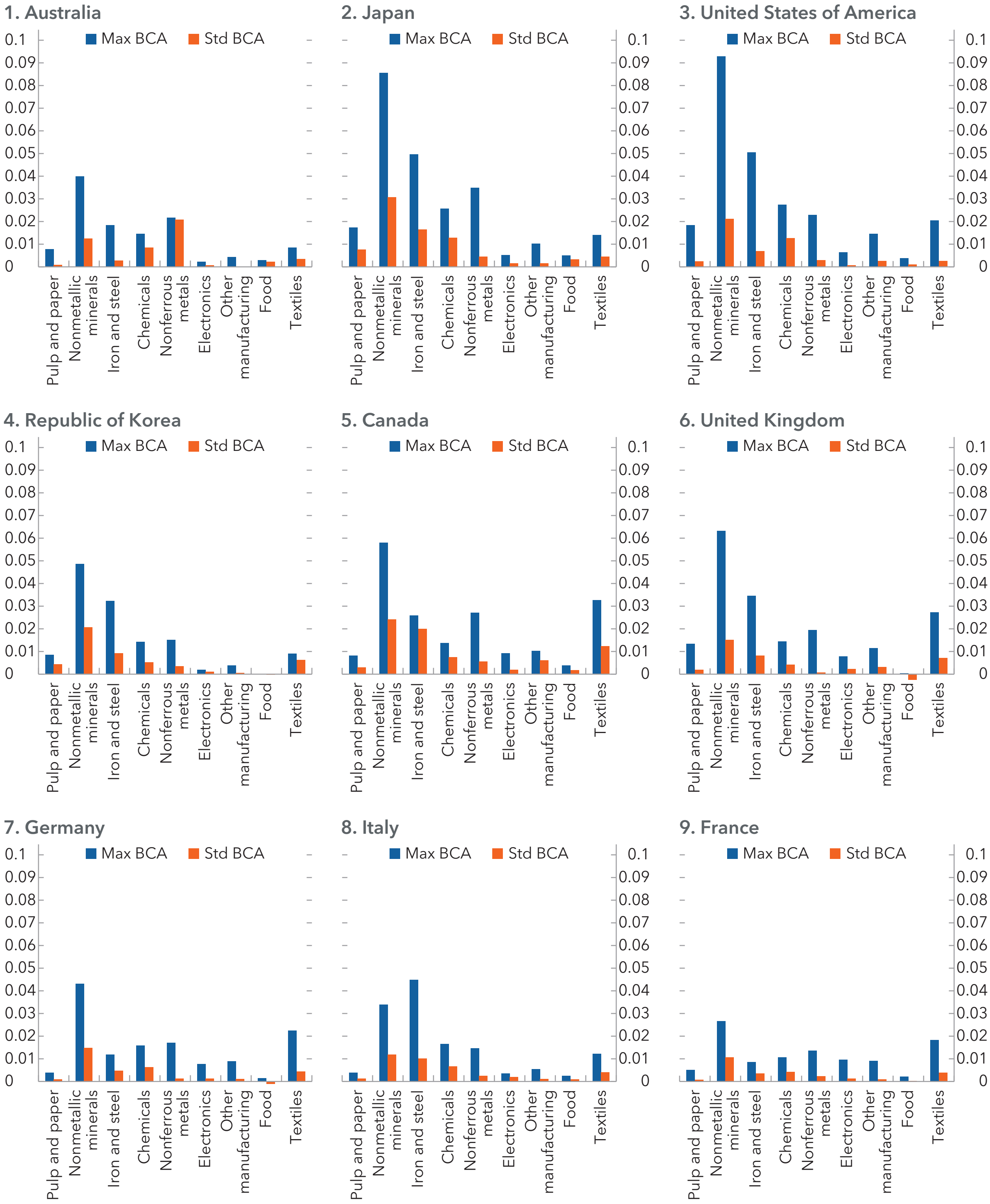
(Percent changes with respect to business as usual)



Source: IMF-ENV model.
Note: BC = black carbon; CO = carbon monoxide; HIC = high-income country; LIC = low-income country; MIC = middle-income country; NH_3 = ammonia; NMVOC = nonmethane volatile organic compound; NOx = nitrogen oxides; OC = organic carbon; PM2.5 = particulate matter (2.5 micrometers and smaller); PM10 = particulate matter (10 micrometers and smaller); SO_2 = sulfur dioxide.

Annex Figure 2.3. HICs-Only Scenarios with BCAs on All Goods: Changes in Tariffs Rates due to BCAs in 2030

(Percentage point changes with respect to initial tariffs; average of tariff rate over trade partners)



1. Australia

2. Japan

3. United States of America

4. Republic of Korea

5. Canada

6. United Kingdom

7. Germany

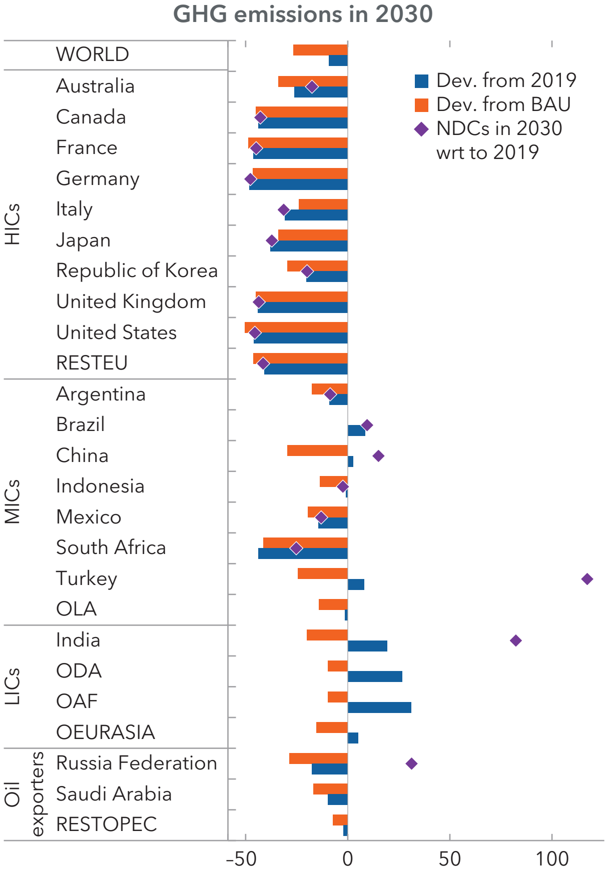
8. Italy

9. France

Source: IMF-ENV model.
Note: BCA = border carbon adjustment; HIC = high-income country; max = maximum; std = standard.

Annex Figure 2.4. ICPF Scenario: Changes in GHG Emissions

(Percent change)



Source: IMF-ENV model.

Note: BAU = business as usual; Dev. = deviation; GHG = greenhouse gas; HIC = high-income country; LIC = low-income country; MIC = middle-income country; NDC = Nationally Determined Contribution; OAF = Other Africa; ODA = Other East Asia and New Zealand; OEURASIA = Other Europe and Asia; OLA = Other Latin America; RESTEU = Rest of European Union and Iceland; RESTOPEC = Other oil-exporting countries; wrt = with respect to.

References

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

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

Black, Simon, Ian Parry, James Roaf, and Karlygash Zhunussova. 2021. "Not Yet on Track to Net Zero: The Urgent Need for Greater Ambition and Policy Action to Achieve Paris Temperature Goals." Staff Climate Note 2021/005 (October), International Monetary Fund, Washington, DC. https://www.imf.org/en/Publications/staff-climate-notes/Issues/2021/10/29/Not-Yet-on-Track-to-Net-Zero-The-Urgent-Need-for-Greater-Ambition-and-Policy-Action-to-494808.

Böhringer, Christoph, Edward J. Balistreri, and Thomas F. Rutherford. 2012. "The Role of Border Carbon Adjustment in Unilateral Climate Policy: Overview of an Energy Modeling Forum Study (EMF 29)." *Energy Economics* 34, Suppl. 2 (December): S97–S110.

Böhringer, Christoph, Jared C. Carbone, and Thomas F. Rutherford. 2018. "Embodied Carbon Tariffs." *Scandinavian Journal of Economics* 120 (1): 183–210.

Böhringer, Christoph, Carolyn Fischer, Knut Einar Rosendahl, and Thomas Fox Rutherford. 2022. "Potential Impacts and Challenges of Border Carbon Adjustments. *Nature Climate Change* 12: 22–29.

Boutabba, Mohamed Amine, and Sandrine Lardic. 2017. "EU Emissions Trading Scheme, Competitiveness and Carbon Leakage: New Evidence from Cement and Steel Industries." *Annals of Operations Research* 255 (1): 47–61.

Branger, Frédéric, and Philippe Quirion. 2014. "Would Border Carbon Adjustments Prevent Carbon Leakage and Heavy Industry Competitiveness Losses? Insights from a Meta-analysis of Recent Economic Studies." *Ecological Economics* 99 (March): 29–39.

Burniaux, Jean-Marc, Jean Château, and Romain Duval. 2013. "Is There a Case for Carbon-Based Border Tax Adjustment? An Applied General Equilibrium Analysis." *Applied Economics* 45 (16): 2231–40.

Chateau, Jean, Erwin Corong, Elisa Lanzi, Caitlyn Carrico, Jean Fouré, and David Laborde. 2020. "Characterizing Supply-Side Drivers of Structural Change in the Construction of Economic Baseline Projections." *Journal of Global Economic Analysis* 5 (1): 109–61.

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

Clarke, Leon, Kejun Jiang, Keigo Akimoto, Mustafa Babiker, Geoffrey Blanford, Karen Fisher-Vanden, J.-C. Hourcade, Volker Krey, Elmar Kriegler, and Andreas Löschel. 2014. "Assessing Transformation Pathways." In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Ottmar Edenhofer, R. Pichs-Madruga, and Y. Sokona. Cambridge: Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter6.pdf.

Climate Watch. 2021. "Nationally Determined Contributions". Washington, DC: World Resources Institute. https://www.climatewatchdata.org.

Dellink, Rob, Jean Chateau, Elisa Lanzi, and Bertrand Magné. 2017. "Long-term economic growth projections in the Shared Socioeconomic Pathways." *Global Environmental Change* 42 (January): 200–14.

European Commission. 2021. "Proposal for a Regulation of the European Parliament and of the Council Establishing a Carbon Border Adjustment Mechanism." Brussels. https://ec.europa.eu/info/sites/default/files/carbon_border_adjustment_mechanism_0.pdf.

Fouré, Jean, Angel Aguiar, Ruben Bibas, Jean Chateau, Shinichiro Fujimori, Julien Lefevre, Marian Leimbach, Luis Rey-Los-Santos, and Hugo Valin. 2020. "Macroeconomic Drivers of Baseline Scenarios in Dynamic CGE Models: Review and Guidelines Proposal." *Journal of Global Economic Analysis* 5 (1): 28–62.

Goulder, Lawrence H. 2013. "Climate Change Policy's Interactions with the Tax System." *Energy Economics* 40 (December): S3–S11.

Graff Zivin, Joshua, and Matthew Neidell. 2012. "The Impact of Pollution on Worker Productivity." *American Economic Review* 102 (7): 3652–73.

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

International Energy Agency (IEA). 2020. *World Energy Outlook 2020*. Paris. https://www.iea.org/reports/world-energy-outlook-2020.

International Energy Agency (IEA). 2021. *Net Zero by 2050: A Roadmap for the Global Energy Sector*. Paris. https://www.iea.org/reports/net-zero-by-2050.

International Monetary Fund (IMF). 2019a. *Fiscal Monitor: How to Mitigate Climate Change*. Washington, DC, October. https://www.imf.org/en/Publications/FM/Issues/2019/09/12/fiscal-monitor-october-2019.

International Monetary Fund (IMF). 2019b. "Fiscal Policies for Paris Climate Strategies—From Principle to Practice." Policy Paper 19/010, Washington, DC. https://www.imf.org/en/Publications/Policy-Papers/Issues/2019/05/01/Fiscal-Policies-for-Paris-Climate-Strategies-from-Principle-to-Practice-46826.

International Monetary Fund (IMF). 2020. *World Economic Outlook: A Long and Difficult Ascent*. Washington, DC, October. https://www.imf.org/en/Publications/WEO/Issues/2020/09/30/world-economic-outlook-october-2020.

International Monetary Fund (IMF). 2021. *World Economic Outlook: Managing Divergent Recoveries*. Washington, DC, April. https://www.imf.org/en/Publications/WEO/Issues/2021/04/06/World-Economic-Outlook-April-2021-50308.

International Monetary Fund (IMF) and Group of Twenty (G20). 2021. "Reaching Net Zero Emissions." G20 Note, International Monetary Fund, Washington, DC. https://www.imf.org/external/np/g20/pdf/2021/062221.pdf.

IPCC, 2018: Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

Keen, Michael, Ian Parry, and James Roaf. 2021. "Border Carbon Adjustments: Rationale, Design and Impact." IMF Working Paper 2021/239, International Monetary Fund, Washington, DC.

Klenert, David, Linus Mattauch, Emmanuel Combet, Ottmar Edenhofer, Cameron Hepburn, Ryan Rafaty, and Nicholas Stern. 2018. "Making Carbon Pricing Work for Citizens." *Nature Climate Change* 8 (8): 669–77.

Köberle, Alexandre C., Toon Vandyck, Celine Guivarch, Nick Macaluso, Valentina Bosetti, Ajay Gambhir, (12): 1035–45.

Leimbach, Marian, and Anastasis Giannousakis. 2019. "Burden Sharing of Climate Change Mitigation: Global and Regional Challenges under Shared Socio-economic Pathways." *Climatic Change* 155 (2): 273–91.

Li, Mingwei, Da Zhang, Chiao-Ting Li, Kathleen M. Mulvaney, Noelle E. Selin, and Valerie J. Karplus. 2018. "Air Quality Co-benefits of Carbon Pricing in China." *Nature Climate Change* 8 (5): 398–403.

Liu, Antung Anthony. 2013. "Tax Evasion and Optimal Environmental Taxes." *Journal of Environmental Economics and Management* 66 (3): 656–70.

Misch and Wingender. 2021. Misch, Florian, and Philippe Wingender. "Revisiting Carbon Leakage." IMF Working Paper 21/207 https://www.imf.org/en/Publications/WP/Issues/2021/08/06/Revisiting-Carbon-Leakage-462148

Monjon, Stéphanie, and Philippe Quirion. 2011. "Addressing Leakage in the EU ETS: Border Adjustment or Output-Based Allocation?" *Ecological Economics* 70 (11): 1957–71.

Nachtigall, Daniel, Jane Ellis, Sonja Peterson, and Sneha Thube. 2021. "The Economic and Environmental Benefits from International Co-ordination on Carbon Pricing." OECD Environment Working Paper 173, Organisation for Economic Co-operation and Development, Paris. https://www.oecd-ilibrary.org/content/paper/d4d3e59e-en.

Organisation for Economic Co-operation and Development (OECD). 2009. *The Economics of Climate Change Mitigation: Policies and Options for Global Action beyond 2012*. Paris.

Pandey, Anamika, Michael Brauer, Maureen L. Cropper, Kalpana Balakrishnan, Prashant Mathur, Sagnik Dey, Burak Turkgulu, and others 2021. "Health and Economic Impact of Air Pollution in the States of India: The Global Burden of Disease Study 2019." *Lancet Planetary Health* 5 (1): e25–e38.

Parry, Ian, Simon Black, and James Roaf. 2021. "Proposal for an International Carbon Price Floor among Large Emitters." IMF Staff Climate Note 2021/001, International Monetary Fund, Washington, DC. https://www.imf.org/en/Publications/staff-climate-notes/Issues/2021/06/15/Proposal-for-an-International-Carbon-Price-Floor-Among-Large-Emitters-460468.

Parry, Ian, Victor Mylonas, and Nate Vernon. 2021. "Mitigation Policies for the Paris Agreement: An Assessment for G20 Countries." *Journal of the Association of Environmental and Resource Economists* 8 (4): 797–823.

Pigato, Miria, Simon Black, Damien Dussaux, Zhimin Mao, Miles McKenna, Ryan Rafaty, and Simon Touboul. 2020. *Technology Transfer and Innovation for Low-Carbon Development. International Development in Focus*. Washington, DC: World Bank.

United Nations Environment Programme (UNEP). 2020. *Emissions Gap Report 2020*. Nairobi.

van den Berg, Nicole J., Heleen L. van Soest, Andries F. Hof, Michel G. J. den Elzen, Detlef P. van Vuuren, Wenying Chen, Laurent Drouet, and others 2020. "Implications of Various Effort-Sharing Approaches for National Carbon Budgets and Emission Pathways." *Climatic Change* 162 (4): 1805–22.

van der Mensbrugghe, Dominique. 2019. "The Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model Version 10.01." https://mygeohub.org/groups/gtap/File:/uploads/ENVISAGE10.01_Documentation.pdf.

PUBLICATIONS

Economic and Environmental Benefits from International Cooperation on Climate Policies

Departmental Paper No. DP/2022/007

ISBN 978-1-6163-5830-3