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Questions:	Ms. Jaumotte, RES (ext. 36191) Mr. Parry, FAD (ext. 39724) Mr. Roaf, FAD (ext. 37360)

Delivering Climate Mitigation under Diverse National Policy Approaches

IMF / OECD report for the G7 Finance Ministers and Central Bank Governors
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Delivering Climate Mitigation under Diverse National Policy Approaches

IMF/OECD paper for the German 2022 G7 Presidency

Delivering Climate Mitigation under Diverse National Policy Approaches

Executive summary

In the face of the huge global challenge of climate change, international cooperation and dialogue are key to achieving substantial progress – effectively and rapidly reducing emissions, in an economically efficient and publicly acceptable manner. Such dialogue needs to be underpinned by hard evidence on policies and their effects.

In spite of progress made to date and the significant long-term ambition announced by many countries, policy actions on climate remain insufficient to meet the Paris Agreement objectives. The difference between 1.5 and 2 degrees is predicated on actions in the next 5-10 years, making the deficit in action from now to 2030 particularly worrisome. In addition, countries' reliance on different combinations of a wide range of price-based and non-price-based policies, to suit country-specific circumstances, hampers the assessment and comparison of policy approaches over time and across countries. Several international initiatives aim to track and monitor climate policies, and through the Paris Agreement the UNFCCC has established a formal framework under which countries are to report progress towards their climate targets from 2024. However, there is not yet a "go to" place for a comprehensive inventory of policy actions and best practices worldwide, also serving to compare policies' effectiveness under different country circumstances.

Such gaps in evidence on policies can amplify concerns over competitiveness losses and carbon leakage, undermining trust and raising the risks of implementation slippage and free-riding. Given the urgency of addressing the climate challenge and the concerns with high and volatile energy prices, now more than ever there is a need for a focused, international and inclusive dialogue to ensure a more globally coherent approach to climate change mitigation.

In light of this, the German G7 Presidency is focussing its climate work on turning climate commitments into action, through enhancing frameworks for climate policy dialogue and co-operation. The aim is to promote an ambitious but globally more coherent and better coordinated approach to emission reductions through a broad range of policies. This paper lays out a roadmap for data and analytical work to support this aim, with a view to enhancing global dialogue and building trust on issues spanning climate change and its macroeconomic repercussions.

This paper outlines key elements to strengthen the assessment and comparison of countries' climate change mitigation policies across countries and better understand their effects:

- **Broadening and deepening the stocktaking of mitigation policies** and mapping them to the emission base that they effect, which would build on numerous initiatives already under way. It would lay the foundations for comparing a larger set of mitigation policies in more countries and sectors and at a more granular level than is currently possible, and for identifying asymmetries in policy approaches.

- **Extending and agreeing on an operational methodology for estimating the impact of these policies on emissions and on a potential metric to compare them** (e.g. by estimation of the "carbon price equivalent"). Developing and agreeing on such a methodology would strengthen countries' capacity to monitor progress towards climate change targets and improve the comparability of reporting such progress. This report provides a stylized example for such policy comparisons, applied to G20 economies and provides a roadmap for future work. Developing and agreeing on such methodologies would strengthen countries' capacity to monitor progress towards climate change targets and improve the comparability of reporting such progress. A platform whereby countries and experts can share their knowledge and experience in these areas is key to overcoming numerous methodological challenges and expediting progress.
- **Further assessing the broader economic effects of different climate policies** taking into account cross-country spillovers. Understanding these effects would help design policy approaches that minimize concerns about competitiveness, carbon leakage, and burden sharing of global mitigation efforts.

The methodological process discussed in this paper is a necessary condition for effective international cooperation in the presence of diverse national policy approaches. It assists and complements ongoing and future international policy co-operation, including in the G7/G20/IMFC, around issues relating to Carbon Border Adjustment Mechanisms and international trade in general, climate club initiatives, tracking progress under UNFCCC's Enhanced Transparency Framework, International Carbon Floor Price (as proposed by the IMF) or the Inclusive Forum on Carbon Mitigation Approaches (as proposed by the OECD).

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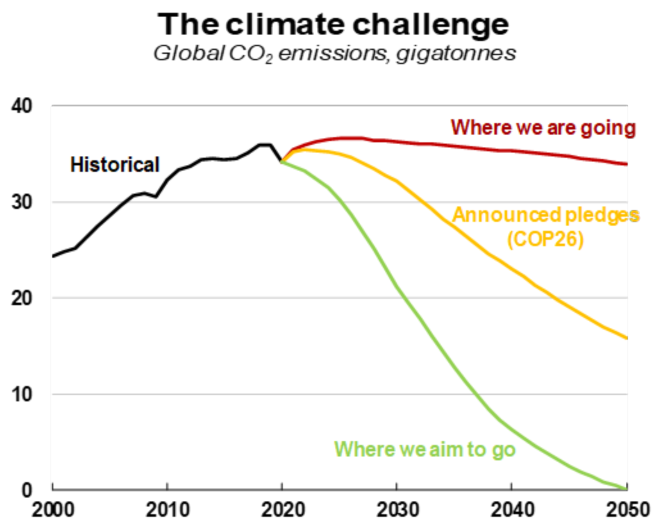
1. Introduction and motivation

In recent years, more than 130 countries, covering nearly 90% of global greenhouse gas (GHG) emissions, have set or proposed net-zero emission targets by around mid-century. But in the near term a large gap remains between the sum of country-level mitigation pledges and global climate goals. While recent Nationally Determined Contribution (NDC) pledges provide hope and momentum for international climate action, they will reduce global GHG emissions by only about half of what would be required by 2030 to be on track to meet the Paris Agreement's goal of limiting global warming to 1.5°-2°C (or to reach net zero emission by mid-century). This disparity between long-term and the nearer-term commitments in NDCs is compounded by lagging policy implementation (Figure 1).

Figure 1. The climate challenge

Global CO2 emissions, gigatonnes



Source: Authors based on IEA (2021).

The Paris Agreement embodies a bottom-up approach that does not prescribe the manner in which countries will reach their emission reduction targets, or the stringency of their targets. This is to be decided by each country, as every country has a different starting point and faces different domestic economic structures, social preferences and political circumstances. These specificities result in a variety of policy approaches (e.g., broad-based carbon pricing, feebates, emission rate standards, investment incentives, technology subsidies, etc). Carbon pricing will remain a key tool in lowering emissions, but the diverse combinations of policy instruments make it difficult to compare countries' mitigation strategies and their effects. The lack of comparable metrics can heighten concerns about free riding on mitigation, competitiveness losses and carbon leakage, and thus undermine trust, hindering more ambitious actions.

Comparing mitigation approaches can be rooted in inputs, e.g. by focusing on the effects of policies themselves, or rooted in outcomes by measuring the carbon content of individual goods. Both approaches have merits and are complementary.

A shared framework to assess policies and their effectiveness (which is the focus of this report) is key to providing forward-looking insights on emission reductions. It would allow for a structured and collaborative debate on climate policies such as the Inclusive Forum on Carbon Mitigation Approaches (IFCMA) proposed recently by the OECD and supports initiatives to scale up global mitigation action such as the Climate Club proposed by the German G7 presidency and the International Carbon Price Floor proposed by the IMF. It would also help to bring a stronger focus on tracking progress and policy implementation under the enhanced transparency framework under the UNFCCC. Measures of carbon content could inform debates on the international spill-overs of climate policies, for instance in the context of the EU's planned carbon border adjustment mechanism (CBAM). Carbon content measures are however backward looking as they reflect the impact of past policies on current emissions. Assessing and comparing effectiveness of current policies could then also be useful as an input to forward-looking carbon content measures.

The first section of the paper summarises progress on deliverables requested by the G7 Working Group on Climate Change Mitigation. This includes: (i) stocktaking mitigation policies and mapping these policies into their emission bases; (ii) the development of an operational methodology for estimating the impact of these policies on emissions, and a potential metric to compare them (i.e. the carbon price equivalent); and (iii) analyses of the broader economic effects of different mitigation policies (taking also into account cross-country spillovers). The second section discusses what additional policy instruments and modelling efforts are required to improve the assessment and comparability of countries' mitigation policy approaches. The last section details how these efforts could complement various international policy coordination workstreams (macro economy, trade, climate clubs, UNFCCC etc.).

2. What do we have to compare mitigation policies and their effects?

2.1 Stocktaking and mapping of price and non-price-based policies

The distinction between price-based instruments and non-price instruments rests on the channels through which they impact emissions. Price-based instruments (which include explicit carbon prices, such as carbon taxes, and other price-based instruments, such as fuel taxes or feed-in tariffs) change the prices of activities or assets and leave it to producers and consumers to react to the new price signals (Table 1). Non-price-based instruments (e.g., clean technology subsidies, vehicle emission rate standards, energy efficiency regulations) instead put constraints on producers and consumers to only pursue activities or invest in assets complying with regulatory requirements. They do not result in the same response as price-based instruments and tend to be less efficient from a purely economic standpoint. At the same time, they can complement price-based measures and enhance the social acceptance of mitigation strategies.

Table 1. A tipology of selected mitigation policies

	Price-based instruments		Non-price-based instruments
	Explicit carbon prices	*Other price-based instruments*	
Climate policy instruments (main policy motivation is to reduce greenhouse gas emissions)	• Carbon taxes (1) • Emissions trading schemes (2)	• Emissions-based vehicle taxes • Feed-in tariffs • Feebates • Tradable emissions performance standards	• GHG emissions intensity standards • Technology deployment subsidies • Technology mandates or bans
Non-climate policy instruments (Other principal policy motivation but highly climate-relevant)		• Fuel excise taxes (3) • Fossil fuel subsidies (4) • Electricity excise taxes (5) • Electricity subsidies (6) • Some industrial and agricultural subsidies	• Air pollution standards • Fertiliser regulations • Fuel efficiency regulation

Note: 1, 2, and 3 are systematically analysed in the OECD (2021) Effective Carbon Rates 2021. OECD (2019) Taxing Energy Use 2019 additionally accounts for 5. Recent and ongoing OECD work integrates 4 and 6 into the OECD's effective tax rates framework.
Source: OECD.

Conducting a stocktaking and comparing the impacts on emissions of price-based and non-price policies is challenging. There is a large variety of pricing and non-pricing instruments, which may interact in complex ways.

The OECD has made several contributions to document climate policies across countries. The OECD's Environmental Policy Stringency (EPS) index developed in 2013 and updated in 2022 was the first effort to gauge price and non-price-based policies.[1] The EPS covers and rates 13 policies across 40 countries over three decades from 1990 to 2020 (Figure 2). Yet, the indicator does not measure the emission coverage and includes a restricted set of key mitigation policies. The OECD's Effective Carbon Rates (ECRs) report provides a comprehensive stocktaking of emissions trading systems, carbon taxes, and fuel excise taxes as well as mapping these policies to the sectors and fuels.[2] Box 1 provides a summary of the most recent update of this dataset. The OECD Taxing Energy Use report provides additional detail on fuel and carbon taxes and estimates the energy-price signals from electricity taxes. Annex I elaborates on these and other initiatives that have taken place to document climate policy globally.

The mitigation policy comparison shown in the next Section relies on an IMF stocktaking, which includes: a compilation of carbon pricing policies at the economy wide or sectoral level; future targets at the sectoral level for emission rates or clean technologies (e.g., renewables) along with a qualitative listing of policy instruments being used to implement these targets; and fuel taxes. See various tables in Annex 2, which also elaborates on this stocktaking.

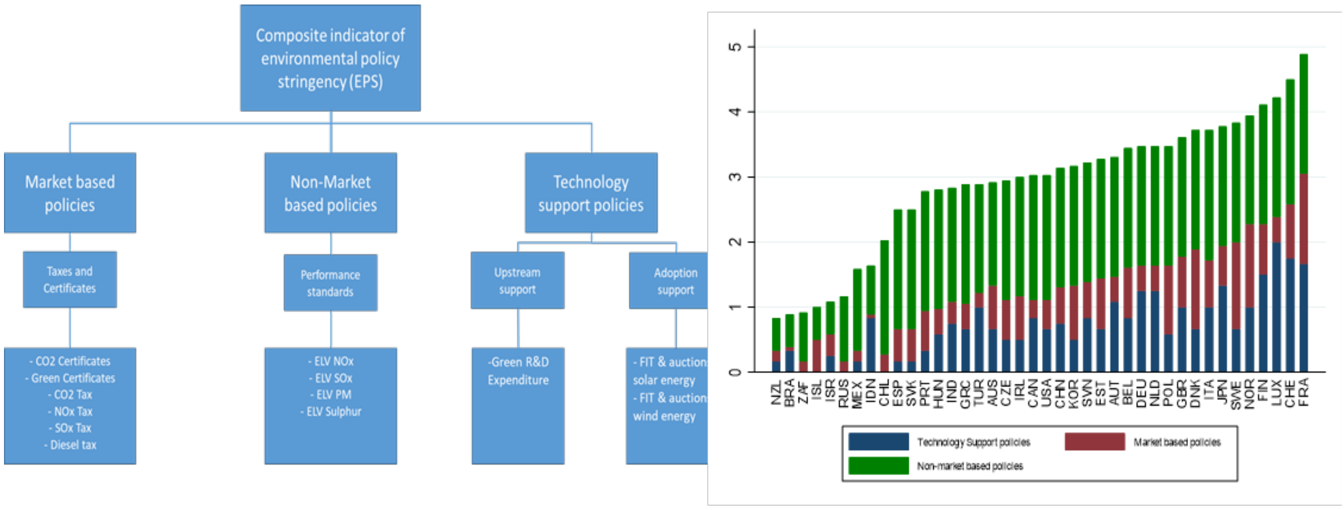
[1] Botta and Koźluk (2014), Kruse, Dechezleprêtre, Saffar and Robert (2022).

[2] https://www.oecd.org/tax/tax-policy/effective-carbon-rates-2021-0e8e24f5-en.htm.

Figure 2. OECD Environmental Policy Stringency can inform the stocktaking of climate change policy

A. The 2021 Environmental Policy Stringency Index

B. EPS sub-indicators across countries, 2020



Note: Panel A shows the aggregation structure of the updated EPS index (referred to as “EPS21”). ELV is short for Emission Limit Value. Panel B shows the contribution of the policy components to the EPS across countries for the year 2020. The blue bars show the contribution of non-market based policies to the EPS. The red bars show the contribution of market based policies. The green bars show the contribution of technology support policies. Data for Colombia, Costa Rica, Latvia and Lithuania were not available.
Source: OECD.

Box.1. Price-based instruments are becoming more widespread but average carbon prices remain low

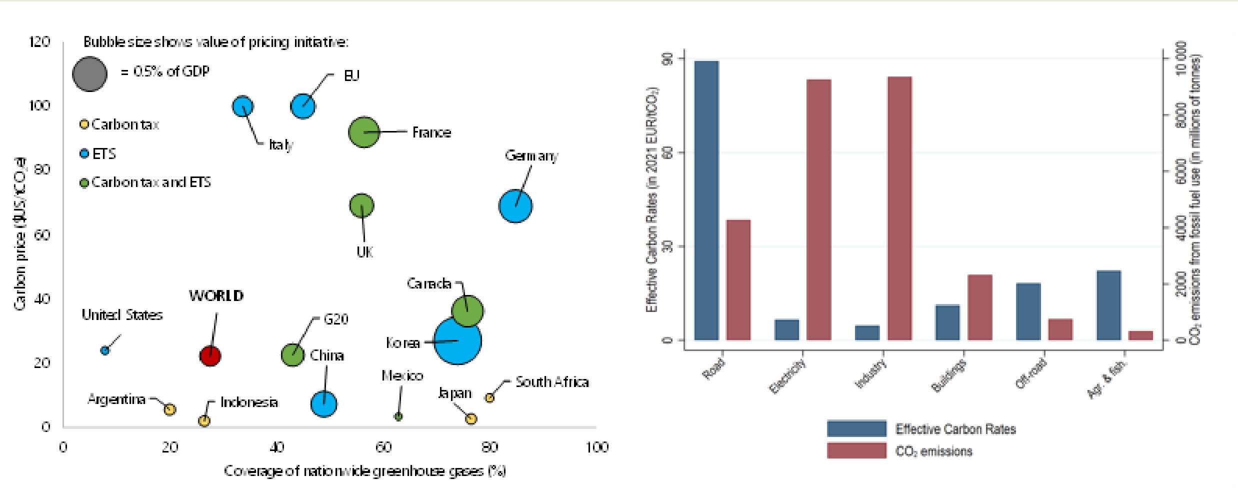
The most recent update of the OECD Effective Carbon Rates database (limited to G20 countries, except for Saudi Arabia) indicates that in 2021 49% of CO2 emissions from energy use were priced, up from 37% in 2018. This large increase in coverage took place almost entirely through emissions trading systems, including but not limited to changes in Canada, China, and Germany.

Between 2018 and 2021, explicit carbon prices resulting from carbon taxes or emissions trading systems rose markedly, driving effective carbon rates higher across most fossil fuels, especially for coal and natural gas. Currently, thirteen G20 countries have explicit carbon pricing instruments in place at the national or subnational level or participated in the EU ETS. However, coverage and rates vary strongly across countries and sectors, and explicit carbon prices remain low when averaged across all emissions and countries (Figure 3, Panel A.). On this basis the IMF estimate the latest G20 average explicit carbon price at USD 10. Further, carbon prices increasingly diverge across countries, adding to concerns about competitiveness and leakage. Countries with the highest effective carbon rates in 2018 saw prices rise further, while there was little change in countries where they were low. And considerable variation persists in effective carbon rates across sectors, with the largest emitting sectors still facing very low average effective carbon rates (Figure 3, Panel B).

Figure 3. Explicit carbon pricing schemes (Panel A) and effective carbon rates, 2021 (Panel B)

A. Coverage and level of explicit carbon prices

B. Effective carbon rates (left axis) and sectoral CO2 emissions (RHS) axis)



Panel A notes: EU ETS includes Norway, Iceland and, Liechtenstein. Prices are a weighted average between schemes. EU countries use weighted average with EU ETS. China's price is based on the opening price of USD 7.40/tCO2e. Canada's price reflects the federal backstop. Mexico's subnational schemes are not included due to lack of data. World carbon price equates to $6 averaged over all emissions.
Panel B notes: G20 includes all G20 individual countries, except Saudi Arabia. Taxes are those applicable on 1 April 2021. The ETS price is the average ETS auction or spot price for 2021. Effective carbon rates (marginal ETS permit price + carbon tax + fuel excise) are averaged across all energy-related CO2 emissions from each sector, including those not covered by any carbon pricing instrument.
Panel A Source: IMF staff calculations based on the Word Bank Carbon Pricing Dashboard and national sources.
Panel B Source: OECD (2021), “Carbon Pricing in Times of COVID-19: What Has Changed in G20 Economies”.

A systematic stocktaking and mapping of policies into their emission bases will already provide much additional orientation for policy makers, and are key steps towards estimating the emission reduction of price and non price-based instruments in a consistent way across countries and sectors. Box 2 discusses results indicating that while price-based measures are effective in reducing emissions they alone are not sufficient to meet net-zero emissions targets given current technologies and abatement costs. This underlines the importance of non-price-based, complementary policies that can accelerate the development and deployment of clean technologies and ease the substitution of low-carbon energy sources for fossil fuels.

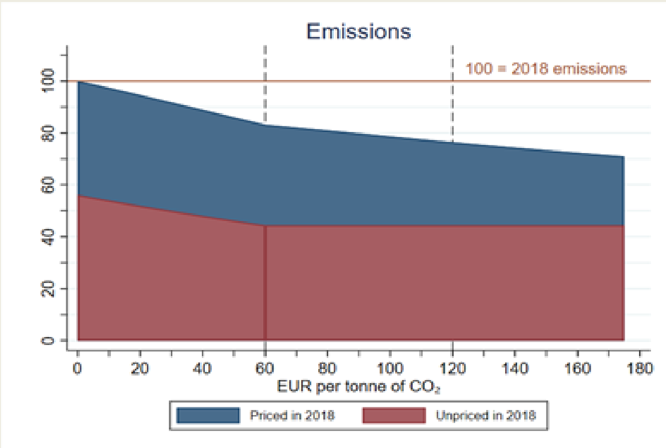
Box 2. Estimating the CO_2 emissions effects of carbon pricing

A recent OECD study estimates the long-run responsiveness of CO2 emissions and government carbon-pricing related revenues to carbon pricing within a unified empirical framework across countries, sectors and fuels. The analysis uses the OECD Effective Carbon Rates (ECR) database and covers 44 OECD and G20 countries over the 2014-18 period.

The baseline estimates imply that an increase in ECRs by EUR 10 per tonne of CO2 reduces CO2 emissions from fossil fuel use by 3.7% on average. This responsiveness varies by sector and fossil fuel, being stronger for road transport, agriculture & fisheries, coal, diesel and kerosene. At the global level, a minimum international carbon price of EUR 60 per tonne of CO2 (which is 2.4 times the 2018 average effective carbon rate) would lower global CO2 emissions from fossil fuels by about 17%. More than half of this emission reduction would result from starting to price emissions that are currently unpriced. The results underline that while price-based measures are effective in reducing emissions they alone are not sufficient to meet net-zero emissions, unless Effective Carbon Rates (ECR) reach very high levels under current technologies (Figure 3).

Figure 4. Global effects of an ECR floor on emissions

CO2 emissions from fossil fuel use

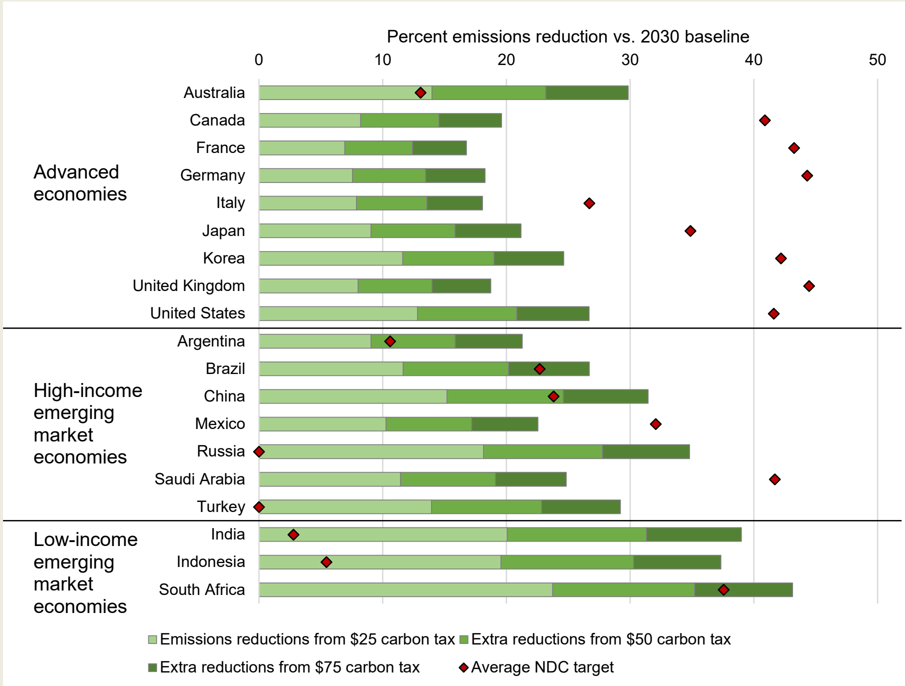


Note: Simulations of a global ECR floor by EUR 5 increments. The maximum ECR floor for emissions unpriced in 2018 is EUR 60 per tonne of CO2. Beyond EUR 60, the price floor on already priced emissions in 2018 keeps on rising until EUR 175, while that for unpriced emissions in 2018 remains at EUR 60. Semi-elasticities vary by sector. An ECR floor of 0 corresponds to 2018 policies.
Source: OECD (2022), "Estimating the CO2 emission and revenue effects of carbon pricing: new evidence from a large cross-country dataset", OECD Economics Department Working Paper, forthcoming.

Complementary IMF analysis using the Climate Policy Assessment Tool (CPAT), described in Annex 2, reinforces this finding. The IMF analysis assesses the impacts of carbon pricing on reducing future CO2 emissions below projected baseline levels that would occur in 2030 with no new, or tightening of existing, mitigation policies—any existing carbon pricing or fuel taxes are held fixed at their current levels in these projections. As indicated in Figure 4, even additional carbon pricing of USD 75 per tonne in 2030 would not be sufficient to meet mitigation pledges in NDCs for most advanced, and a couple of emerging market, economies, underscoring the need for reinforcing pricing with sectoral measures that are less efficient, but likely more acceptable, as (unlike pricing) they avoid significant inreases in energy prices.

Box 2. Estimating the CO_2 emissions effects of carbon pricing (Concluded)

Figure 5. Impacts of Carbon Pricing on CO_2 Emissions 2030, G20 Countries



Source: IMF staff using CPAT.

As discussed in the next sections, assessing and comparing the effectiveness of countries' decarbonisation strategies requires further work. This will have to cover a wider range of price and non price-based policies, taking into account their complex interactions.

2.2 A comparison of price and non-price-based policies

To facilitate international policy cooperation, a transparent methodology is required to map and compare alternative policy approaches (e.g., partial carbon pricing, renewables incentives, emission rate regulations, changes in fuel taxes). The results presented below compare policies based on their emissions reductions and economy-wide carbon price equivalent (ECPE). The ECPE refers to the economywide carbon price that would yield the same emissions reduction as the policy under consideration.

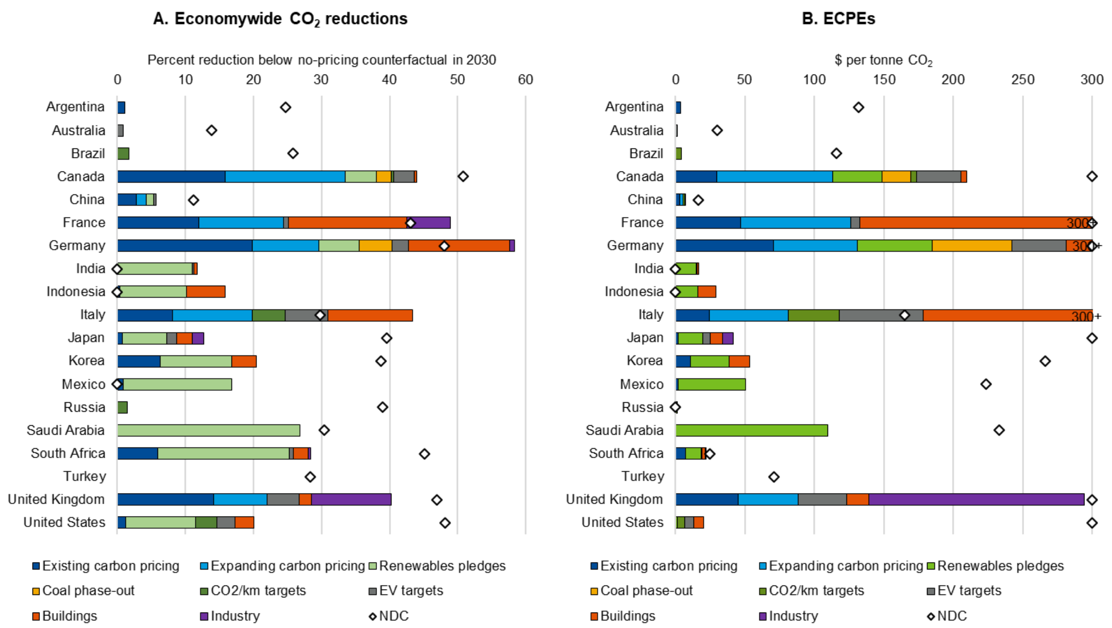
Annex 2 describes a methodology that can be used for this purpose based on the IMF-World Bank Climate Policy Assessment Tool (CPAT), applied to each G20 country, for economy wide and sectoral mitigation policy commitments to 2030. CPAT provides country-level estimates (for 200 countries) of future fuel use and emissions by major energy sectors as well as the emissions impacts of a diverse range of pricing and non-pricing mitigation approaches. The tool is parameterized to be consistent with the mid-range of the broader energy/climate modelling literature.

At the sectoral level, mitigation instruments frequently overlap (e.g., commonly used non-pricing measures in power generation include feed-in tariffs, renewable portfolio standards, net metering, and tax credits) and it can be extremely challenging to disentangle the contribution of individual measures to emissions reductions. It is, however, feasible to assess the emissions reductions and ECPEs of future sectoral targets (e.g., for renewable power generation) that overlapping measures are designed to achieve. In other cases, sectoral polices may be implemented at the same time as overarching carbon pricing—here, double counting of emissions reductions should be avoided when aggregating over policies. Annex 2 discusses the CO2 reductions and ECPEs for G20 countries of the following policies/targets in isolation:

- Explicit carbon pricing: which is currently implemented by 13 G20 countries, though with substantial variation in sectoral coverage and expected future price levels;
- Power: future renewable generation targets (which apply in all G20 countries but are not always binding) and coal phase outs (which apply in eight cases);
- Industry: CO2 intensity standards (which apply in eight countries);
- Transport: Future CO2 per kilometer standards or similar fuel economy requirements (which apply in nine countries) and sales share requirements for electric vehicles (applying in 15 cases);
- Buildings: Emissions targets for all buildings (applying in three cases) or new buildings (applying in six cases);
- Fuel taxes/subsidies: (applying in all countries) though it is not entirely clear whether currently existing taxes (whose emissions impact is already observed), as opposed to future tax increases, should count towards ECPEs for future policies.

The combined effect of the above policies and targets varies substantially across countries. Compared to a counterfactual with no carbon pricing or other new mitigation measures in 2030, CO2 reductions are around five percent or less in six countries and range from 10 to over 50 percent in the other 13 (Figure 4, panel A). Additionally, countries vary significantly in their choice of instruments and the relative contributions of sectoral targets. Renewables targets make a substantial contribution to emissions reductions in the policy mix in ten countries and explicit carbon pricing contributes substantively in eight countries[3]. ECPEs for policies combined exceed \$100 per tonne of CO2 in six cases, are between \$20 and \$50 per tonne in seven cases and are below \$20 per tonne in six cases (panel B).

Figure 6. Combined effects of current policies and sectoral targets for 2030



Source: IMF staff using CPAT.

[3] The attribution of emissions reductions to individual policies and targets is ambiguous, however, where they overlap hence the total CO2 reductions (and ECPEs) should be considered more than the relative contribution of specific policies/targets.

Countries also vary on the extent to which the various policies achieve their economy-wide mitigation pledges in NDCs. Three countries (India, Indonesia, and Mexico) more than achieve their targets since current targets are non-binding; three countries achieve (binding) NDC targets with sectoral policies and targets (France, Germany, and Italy); and three others are close (Canada, Saudi Arabia, and the UK). The other ten countries presently have sectoral policies that do not fully achieve their NDCs.

2.3 Assessment of broader economic effects of mitigation policies

Understanding the economic effects of different climate policies is key both from a domestic and international perspective. From a domestic perspective, climate policies can have different economic effects, including on economic cost, employment, energy prices, fiscal accounts, energy security, and competitiveness, even if they reduce emissions in the same amount. They can also affect other environmental policies, such as tackling biodiversity loss, in different ways. This raises important trade-offs. Understanding these trade-offs is key to designing a policy mix that is tailored to a country's economic structure and its political economy. From an international perspective, understanding the spill overs climate policies generate – through international trade and competitiveness, international fossil fuel markets, and technology developments – will support an international dialogue and coordination on climate policy.

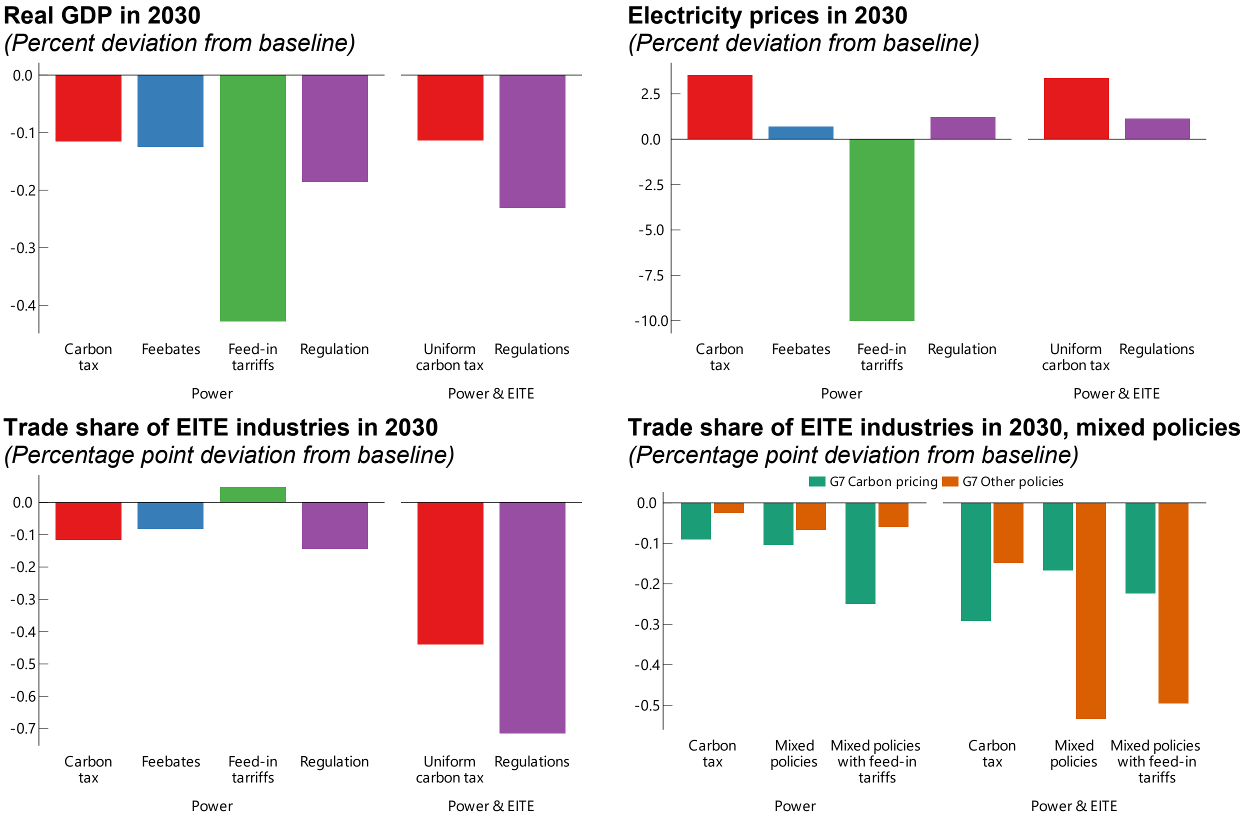
Modelling tools are useful to assess these effects. One common tool is a dynamic and global CGE model (such as the IMF-ENV and OECD ENV-Linkages models), which represents economic sectors and international trade in detail and relates emissions directly to specific economic activities. Illustrative simulations using the IMF-ENV model provide insights about the relative strengths of different policies for the main sectors with the largest amount of emissions, namely electricity generation and energy intensive and trade exposed (EITE) industries. G7 countries (and the EU), China, and India are assumed to take climate action in these scenarios. Annex 3 provides more details on the design of the simulations and country-specific results.

In the power sector where many technologies exist, most pricing and non-pricing climate policies are all effective options but vary in their impact on electricity prices and government revenues. A carbon tax for electricity generation, a direct regulation on the share of fossil fuel power, and a feebate system have similar and small economic costs, below 0.2 percent of GDP for policies equivalent to a 20-percentage point decrease of the fossil fuel share (Figure 5). One exception is the feed-in subsidies for solar and wind electricity generation, which cost more than the other options because the lower energy price causes a rebound effect in energy demand and the subsidy needs to be financed by taxes. If electricity prices are a political focus, however, feed-in subsidies—which reduce prices—as well as regulations and feebates—which only increase them very moderately—are preferable alternatives to carbon pricing, although even carbon pricing increases electricity prices by less than 10 percent. At the same time, carbon taxation allows for lowering labour income taxes (through revenue recycling), resulting in higher real income of households (the opposite effects of feed-in subsidies). These results thus highlight the importance of taking into account so-called "general equilibrium" effects.

In EITE industries where technical substitution possibilities are limited, regulation could be significantly more costly than carbon pricing. The EITE industries include many sectors with largely different technical substitution possibilities. For some of the EITE sectors, complying with a common regulation is extremely difficult and it is much easier to handle carbon pricing, which gives them the option to pay the tax and adjust their production process only a little. The carbon tax allocates emission reductions to where they are cheapest. This keeps the aggregate economic cost lower but also leads to a more even distribution of economic costs across sectors. Avoiding the larger costs of regulation through sector-specific regulation requires detailed sectoral knowledge to avoid heterogeneous implicit carbon prices (and therefore heterogeneous marginal abatement costs). The potential for policy mistakes is a lot higher with regulation than it is with carbon pricing.

From a cross-border perspective, competitiveness effects for EITE industries depend on the extent of participation of other countries in the global mitigation effort, but also on the nature of policies used and the differences in economic structures across countries. Losses in competitiveness are more substantial when countries that are large producers in EITE sectors (for instance, China, India) do not participate in global mitigation. Carbon pricing on EITE industries is better at protecting these industries than regulations that are not well-tailored to specific sub-sectors. Feed-in subsidies and feebates in the power sector help protect the market shares in EITE industries relative to non-acting countries but can also cause significant changes in market shares between acting countries, reflecting different initial conditions in the use of solar and wind technologies. Finally, the use of different policy mixes across acting countries—where some countries use carbon pricing while others implement regulation or feed-in subsidies—can further amplify competitiveness effects, but the effects vary across sectors and policies.

Figure 7.Ecomomic impact of pricing and non-pricing climate policies on G7 countries



Note: The scenario “Carbon tax” refers to a scenario, where all G7 countries, EU, China and India implement a carbon tax. The scenario “Mixed policies” refers to a scenario where DEU, FRA, ITA, Rest of EU, UK, CAN implement carbon pricing and JPN, USA, China and India implement regulation. The scenario “Mixed policies with feed-in tariffs” refers to a scenario where DEU, FRA, ITA, Rest of EU, UK, CAN implement carbon pricing and JPN, USA, China and India implement feed-in tariffs in the power sector (and regulation in EITE sectors for policy scenarios that involve both power and EITE sectors). Under regulation, countries reduce the share of fossil fuel energy in the power sector by 20 percentage points relative to baseline in 2030 (except Canada and France which have smaller reductions). Carbon taxes, feebates and feed-in tariffs are calibrated such that emission reductions are equal to the reductions under regulation. In the EITE sectors, the regulation is designed to decrease emission intensity by 20 percent relative to baseline in 2030 and the other policies are calibrated to an equivalent emission reduction.
Source. IMF-ENV model.

3. Possible avenues to enhance the comparability of climate policies

Expanding the existing work of the IMF and OECD and other international organisations requires actions in two areas: (i) broadening and deepening the stocktaking and mapping of climate policies, which would allow covering a larger set of mitigation policies in relevant countries and sectors and at more a granular level than what currently done; and (ii) extending and agreeing on methodologies for estimating expected emission reductions for policies or policy packages where it has so far not been feasible to decompose their emissions impacts. In addition, performing work in these two areas would allow further investigations of the macro-economic effects of different policy mixes, covering a rich variety of policy configurations and additional sectors.

3.1 A broader and more granular stocktaking and mapping of price and non-price-based policies

Broadening and deepening the stocktaking would result in a rich database and would serve as a basis for the estimation of expected emission reductions as well as for the calculation of carbon price equivalents. A harmonised database could also provide some orientation for international discussions on climate change mitigation and be an input to further research and analysis.

Contributing to this broader stocktaking exercise, the OECD is currently developing a Climate Actions and Policies (CAP) index as part of its international programme for action on climate (IPAC).[4] The CAP index builds on a panel dataset with data going back to at least 2010 and, where possible, to 1990. It is continually being refined and is designed to bring complementary information to the Environmental Policy Stringency index for example by allowing for: (i) measuring governments' climate action across a wide range of policy areas and instruments, including market-based and non-market-based instruments; and (ii) covering national, sectoral and international climate action. In addition to cross-sectoral and international climate policies, the CAP covers the major emitting sectors, including power generation, industry, transport, buildings, agriculture and waste. The CAP also includes some policies on GHG other than CO2, such as methane and nitrous oxide. Work is scheduled to be completed in autumn 2022.

In addition to the stocktaking, mapping policies to the emissions base would show in which sectors policy instruments apply to and how much of the emissions in that sector they cover. The OECD has already carried out a similar exercise for the Effective Carbon Rates dataset, which covers key price-based carbon policies.[5] Recent and ongoing OECD work is integrating fossil fuel subsidies and electricity subsidies into the OECD's Effective Carbon Rates, and extends mapping beyond CO2 to all GHGs.[6]

3.2. Estimating emission reductions of a wider range of pricing and non-pricing policies

Estimating the expected emission reductions attributable to a policy instrument requires detailed analysis focusing on each instrument's effectiveness. There are two approaches to estimate expected emission reductions: "top-down" and "bottom-up" approaches.

The first approach consists of general models that capture economy-wide features and that can be applied to different countries after being rightly parametrised. The results presented above rely on a "top-down" approach. But as acknowledged above, there are several and difficult challenges to developing models, consistently parameterized across countries, which can disentangle the individual impact of multiple, overlapping instruments.

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[4] https://www.oecd.org/climate-action/ipac/.

[5] https://www.oecd.org/tax/tax-policy/effective-carbon-rates-2021-0e8e24f5-en.htm.

[6] http://oe.cd/TEU-SD

The second approach attempts to capture country, sectoral and technological specificities that general models find difficult to take into consideration. This approach relies on country or industry experts' judgement to estimate emission reductions of various policy instruments - either in addition to, or as a substitute for, more formalised assessments.[7] As highlighted above, developing and implementing sector-specific regulation to limit its costs require detailed sectoral knowledge. This approach, although complex, would make the assessment of the expected emission reductions of policies and eventually the computation of their carbon price equivalents more objective as it would allow replacing emission targets for a commonly agreed emissions reduction estimate of a given policy or policy package. A challenge for this approach is to develop procedures that facilitate transparent and consistent cross-country comparisons. Annex I elaborates further on this approach and ways to address this challenge.

3.3. Enhancing and tailoring the analysis on macro-economic effects of policy mixes

The economic analysis work can be extended in two directions. First, as highlighted above, the domestic and cross-border effects of climate policies depend on the specific configuration of policies of various countries. Building on broader and deeper policy stock-taking than undertaken so far, models could help understand how the planned policy mixes of countries would affect both domestic and global macro-economic outcomes. Model-based analysis can also shed light on the likely macro-economic outcomes of international initiatives such as carbon club, carbon price floors or CBAMs.[8]

Second, efforts are ongoing to enhance the modelling toolkit, beyond CGE models, aiming at better integrating macroeconomic and climate-related variables and policies. This will allow gaining a deeper understanding of the interactions between the green transition and the near-term macroeconomic outcomes, including how they vary with monetary and fiscal policy responses.

4. Climate policy assessment and international policy dialogue

A robust, transparent and shared methodology to assess and compare climate change mitigation policies across countries could help to assuage policy makers' persistent concerns over competitiveness losses and carbon leakage, and overcome international policy coordination failures. As such it could contribute to scaling up national and international climate change mitigation endeavours by fostering international policy dialogue along the aspects analysed below.

4.1. Macroeconomic policy

Climate policy is becoming part and parcel of macroeconomic policy. Integrated assessment models and macro-economic models incorporating climate-change features suggest that different transition paths will have profound effects on macroeconomic outcomes. In particular:

- Climate policy commitments may reshape fiscal policy and rules;
- Monetary policy implementation and strategy will give greater importance to the pursuit of climate policy objectives, potentially introducing policy trade-offs;

[7] The OECD (2013) *Effective Carbon Prices* report employed this approach. https://doi.org/10.1787/9789264196964-en.

[8] For an analysis of the macroeconomic and spillover effects of carbon price floors, see https://www.imf.org/en/Publications/Departmental-Papers-Policy-Papers/Issues/2022/03/16/Economic-and-Environmental-Benefits-from-International-Cooperation-on-Climate-Policies-511562.

- Financial policy – whether banking supervision or prudential rules – is increasingly taking into account climate related risks, both physical risks of climate impacts and transition risks linked to mitigation policies.

As a result, climate change mitigation policy will become an integral part of macroeconomic policies and feature prominently in discussions among Finance Ministers and Central Bank Governors. Thorough stocktaking of key climate policies and a solid, transparent and shared methodology to compare a wide range of mitigation policies across countries would hence improve the knowledge base to inform macroeconomic policy discussions.

4.2. International trade

The effect of climate policies on trade have already been widely discussed in international forums, such as the G7, G20 and the World Trade Organization Ministerial Conferences, and the Trade and Environmental Sustainability Structured Discussions. The OECD has provided guidance on trade and environmental provisions in Regional Trade Arrangements[9], as well as the stringency of environmental policies as a driver for trade in goods and services.[10]

Instruments designed to avoid carbon leakage and to level the playing field between domestic and foreign producers are likely to become prominent issues in future climate policy discussions[11]. This is especially true for the introduction and implementation of CBAMs, which in the absence of a shared and objective framework to measure the impact of policies on emissions and then on carbon leakage could give rise to trade disputes. Indeed, while on purely economic grounds non-price-based policies do not have the same bearing on exporters as price-based policies (see Box 1 in Annex I), the non-discrimination rules applicable to GATT's primary Articles and its exception provisions might require taking them into account on legal grounds through the (implicit) price of carbon or other objective criteria.[12] Resolving tensions between economic, legal and potentially political arguments will require clear evidence on the effects of price and non-price-based policies on emissions.

4.3. UNFCCC

The Paris Agreement established, among other things, an "Enhanced Transparency Framework" (ETF). The ETF requires that parties report biennially on their progress in implementing and achieving their NDCs, but it is not designed to ensure that this reporting will be uniform in comprehensiveness, quality and detail across all Parties. Given that different Parties have varying levels of technical capacity and experience in reporting on the type of information the ETF requires, developing country Parties may use "flexibility" to report under the ETF. In addition, when considering reporting of mitigation policies and action, there is no agreed methodology across Parties for estimating the projected emissions reductions.

Third party organisations can help to improve understanding of different methodologies for estimating emissions reduction potential of different types of policies Parties have in place or plan to implement. More streamlined and comparable methodologies may also contribute to building confidence on reported data and, ultimately, mutual trust across Parties for more effective policy implementation.

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[9] https://doi.org/10.1787/5jz0v4q45g6h-en

[10] https://doi.org/10.1787/5jxrjn7xsnmq-en

[11] https://doi.org/10.1787/8008e7f4-en.

[12] https://www.cambridge.org/core/services/aopcambridgecore/content/view/B0D224B3A59E9433D10E74DE6D40A0FD/S1474745621000409a.pdf/div-class-title-a-pragmatic-approach-to-carbon-border-measures-div.pdf.

4.4. Climate Clubs

There are growing discussion of potential climate clubs and policy coordination mechanism designed to complement and reinforce the Paris Agreement and facilitate a scaling up of global mitigation action[13]. A climate club would begin with an initial group of countries agreeing to coordinate key aspects of climate policy with a view to encouraging broader membership over time.

There is ongoing debate about what elements would be included in a climate club, its design features and its mandate. One core element could involve coordination over carbon pricing or equivalently effective mitigation approaches to help overcome obstacles to scale up climate action. Other elements might include: policies to facilitate trade for participating countries and the transition of energy-intensive trade-exposed industries; mutual agreements to create markets for low-carbon products; and financing technological transfers mostly from advanced to developing countries. A shared and consensual policy assessment framework, with detailed and comparable information on the mitigation policies of the climate-club founding and prospective members, is key to the transparent and effective implementation of these elements.

[13] See https://www.bundesfinanzministerium.de/Content/EN/Pressemitteilungen/2021/20210825-german-government-wants-to-establish-an-international-climate-club.html?utm_source=pocket_mylist and Parry and others (2021).

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BETTER POLICIES FOR BETTER LIVES

Annex 1: Comparing the Effectiveness of Climate Policies

IMF / OECD report for the G7 Finance Ministers and Central Bank Governors

May 2022, Germany

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Comparing the effectiveness of climate policies

Background and introduction

Approaches countries currently use or plan to use to limit emissions differ widely. Some countries price carbon emissions explicitly – through carbon taxes or emission trading systems. Almost all countries deploy price-based instruments, such as excise taxes on fossil fuels, carbon-differentiated motor vehicle taxes, and a number of subsidies related to the carbon intensity of different products or services. Non-price-based instruments, such as energy efficiency standards and outright bans on certain products or activities, are equally ubiquitous. However, the balance between price and non-price-based instruments varies across countries, as well as the stringency of these instruments.

The distinction between price-based and non-price-based instruments is important. Price-based instruments can provide strong and explicit economic incentives to households and firms to change behaviour and production practices in the desired manner by altering the price of products, services or assets. Non-price-based instruments, in contrast, attempt to reduce emissions through legal obligations or moral suasion.

Comparing the effectiveness of price-based and non-price policy instruments raises a number of challenges, but methods exist that can provide some useful insights in these regards. This Annex suggests a process and methodology to estimate the abatement impact of the different instruments in order to assess and compare their environmental effectiveness. This Annex also suggests a method for estimating the "carbon price equivalent (CPE)" of the instruments in question. This is the level of a carbon tax that would achieve the same reduction in GHG emissions as the policy or policy package that is being studied is estimated to generate. As such, the CPE would provide a common metric to assess and compare the effectiveness of widely different policy instruments.

CPEs can be calculated at a nation-wide or a sector-wide level. Using a fuel-efficiency standard for motor vehicles as an example, the nation-wide CPE would indicate the level of an economy-wide carbon tax that would cause a similar reduction in emission to the fuel-efficiency standard. A sector-wide CPE would instead indicate the level of carbon tax on motor-vehicle fuels that would cause a similar reduction in emissions to the fuel-efficiency standard. Both these measures can help to compare the stringency of diverse policy instruments, and their relative usefulness is context specific.

This Annex builds on a previous OECD report that provided estimates of how much abatement, compared to a "no-policy" baseline, different policy instruments achieved OECD (2013). That report also estimated the costs to society of each of these policy instruments, namely the losses in so-called producer and consumer surpluses that they entailed. The report provided estimates on the social cost per tonne of CO_2-equivalent abated, referred to as each instrument's "effective carbon price". The report in turn built on an earlier attempt by the Australian Productivity Commission (2011)[1], which made similar calculations regarding policy instruments applied in the electricity generation and road transport sectors in nine countries. OECD (2013) extended the country coverage, and also provided estimates of effective carbon prices regarding the pulp & paper and cement sectors, as well as household energy use.

[1] Productivity Commission (2011) in turn drew on a report that Vivid Economics had prepared for The Climate Institute in Australia (Vivid Economics 2010).

"Effective carbon prices" and "carbon price equivalents" are different metrics to compare climate policies. The former focuses on the social costs generated by different policy instruments; the latter measures the level of a carbon price needed to achieve a given amount of abatement. The results in OECD (2013)point to large differences in effective carbon prices: within a given sector, across the countries covered; across the different sectors, within each of the countries; across the different instrument types, such as taxes, emission trading systems, fuel efficiency standards, etc., across all the countries covered.

Despite this difference, the methodology used to estimate "effective carbon prices" offers useful lessons on how to compute "carbon price equivalents", especially regarding the estimation of the emission abatement of a given policy instrument. The present Annex outlines a project for comparing a wide range of climate policies, and discusses some of the methodological choices that would need to be made.

Estimating the abatement impacts of the several policy instruments will in many cases be challenging, as available general equilibrium or partial economic models may not model them sufficiently well. For many policy instruments, estimating their emission reduction impact may need to rely on ad hoc approaches and experts' judgments with detailed sector and country-specific knowledge. The OECD (2013) followed largely this approach.

Rationale and links to other approaches

Comparing mitigation approaches can be rooted in outcomes by measuring the carbon content of individual goods, or rooted in inputs by focusing on policies. Both approaches have merits and are complementary. The first approach focusses on the carbon intensity or footprint of individual products (i.e. carbon content). Such initiatives have been undertaken by the Green House gas protocol, the ISO and are likely to become important contributions to climate disclosures in most advanced economies. This process is based on output and could become a powerful tool to compare progress in reducing emissions by providing a granular view on the carbon content of individual goods. The second approach does not rely on output but tries to estimate the effects of policies on emissions. This approach can inform more directly on the expected results of policy action as well as carbon-leakage risks by taking into account cross-country spill-overs.

Outcome-based and policy-based approaches could be combined to some extent. A policy-based approach (which is the focus of this Annex) is key to providing forward-looking insights on emission reductions. Such an approach is key to building a structured and collaborative debate on climate policies (such as the Inclusive Forum on Carbon Mitigation Approaches proposed recently by the OECD) and supporting initiatives to scale up global mitigation action (such as the Climate Club proposed by the German G7 presidency and the International Carbon Price Floor proposed by the IMF). Measures of carbon content (i.e. outcome-based approaches) could instead inform debates on the international spill-overs of climate policies, for instance, in the context of the EU's planned carbon border adjustment mechanism (CBAM). The CBAM as proposed by the European Commission only exempts imports from countries with a carbon pricing scheme, while non-price-based policies are not eligible for such exemption (see Box 1). Carbon content measures are however backward-looking as they reflect the impact of past policies on current emissions. Assessing and comparing the effectiveness of current policies could then also be useful as an input to forward-looking carbon content measures.

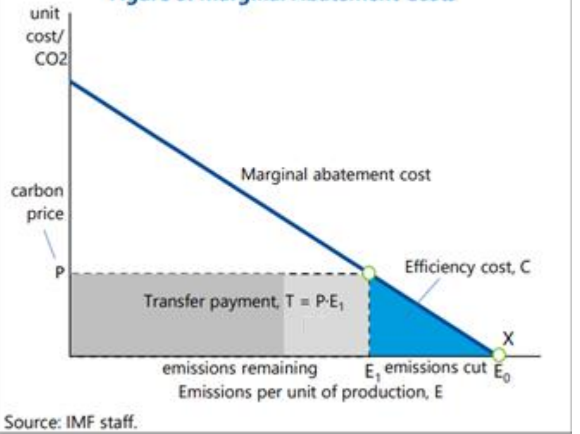
Non-price-based policies are also fundamentally different from price-based policies to the extent that they do not price firm's remaining emissions. This is one of the reasons why the Carbon Border Adjustment Mechanism (CBAM) proposed by the European Commission exempts imports from countries with a carbon pricing scheme, while non-price-based policies are not eligible for such exemption (see Box 1).

Box 1: Carbon border adjustment and non-price climate policies

Growing cross-country dispersion in carbon prices has prompted policy makers in some countries to consider and propose Carbon Border Adjustment Mechanisms (CBAMs). The main rationale for these border adjustments is to reduce the risk of carbon leakage and prevent a loss of competitiveness among domestic producers vis-à-vis producers from countries with less ambitious environmental objectives.

The CBAM as proposed by the European Commission exempts imports from countries with a carbon pricing scheme, while alternative emission reduction strategies are not eligible for such exemption. This approach aligns with economic principles. Non-price policies are fundamentally different from price-based policies in that they do not impose a tax on a firm's remaining emissions, as highlighted by Keen et al. (2021). To illustrate this point, consider a domestic and foreign firm with the same marginal abatement costs (figure 5). To cut emissions from E0 to E1, the foreign country adopts a form of regulation. This emission reduction imposes efficiency costs (C) since moving to, for instance, cleaner production technologies is more expensive. Note that this efficiency cost to the foreign firm arises only from a reduction in emissions. Now consider the domestic country imposing a carbon price P per unit of CO_2 to achieve the same emission reduction per unit of production. The domestic firm now faces the same emission reduction and efficiency costs as the foreign firm, but it must additionally pay a price on its remaining emissions per unit of output. Hence, the foreign firm enjoys a cost advantage (equivalent to the transfer payment, T), so exempting it from the BCA would not be warranted on competitiveness grounds.

Figure 5. Marginal Abatement Costs



Source: IMF staff.

However, there are other factors, both political and environmental, that would justify taking into consideration a Carbon Price Equivalent measure rather than only an actual carbon price mechanism. While CBAMs may be well justified on competitiveness grounds, considering a single policy instrument (carbon price mechanism) in operating a CBAM may be difficult to reconcile with the decentralised spirit of the Paris Agreement and the principle of "common but differentiated responsibilities and respective capabilities" (Keen et al., 2021). Furthermore, while foreign countries' regulations may not lessen the competitiveness motivation for CBAMs, they can undermine the environmental motivation as regulations limit the scale of carbon leakage. Foreign countries adopting alternative approaches to reach their emission reduction target may thus view CBAMs as unfair and disguises for "green protectionism" measures. This may lead to increased geopolitical tensions and trade retaliating measures, harming global trade and the Paris Agreement's objectives.

Key steps to estimate the environmental effectiveness of climate policies

This project aims to develop comparable metrics for assessing and comparing the effectiveness of a wide range of climate policies. This will involve three steps: 1) stocktaking and mapping of mitigation policies; 2) estimating impacts on emissions of policies; 3) computing the carbon price equivalent. This section outlines each of the three steps, their main challenges and possible solutions.

Stocktaking and mapping of mitigation policies

Deciding on which types of policy instruments to include

The first step involves choosing what types of policy instruments the project needs to cover. As mentioned above, one can distinguish between price-based instruments (instruments that alter prices and provide explicit *economic incentives* to households and firms to change behaviour and production practices in the desired manner, e.g. carbon and fuel taxes, emission trading systems and various subsidies) and non-price-based instruments (legal obligations or moral suasion, e.g. bans, emission or technology standards and information campaigns).

In its 2014 contribution to IPCC's fifth assessment report, Working Group III of IPCC provided the overview below of policy instruments countries use to mitigate climate change, cf. Table 1. A large number of these instruments are relevant candidates for inclusion in this project.

Table 1: IPCC overview of policy instruments countries use to mitigate climate change

Policy Instruments	Energy [7.12]	Transport [8.10]	Buildings [9.10]	Industry [10.11]	AFOLU [11.10]	Human Settlements and Infrastructure
Economic Instruments—Taxes (Carbon taxes may be economy-wide)	• Carbon taxes	• Fuel taxes • Congestion charges, vehicle registration fees, road tolls • Vehicle taxes	• Carbon and/or energy taxes (either sectoral or economy wide)	• Carbon tax or energy tax • Waste disposal taxes or charges	• Fertilizer or Nitrogen taxes to reduce nitrous oxide	• Sprawl taxes, Impact fees, exactions, split-rate property taxes, tax increment finance, betterment taxes, congestion charges
Economic Instruments—Tradable Allowances (May be economy-wide)	• Emissions trading (e.g., EU ETS) • Emission credits under CDM • Tradable Green Certificates	• Fuel and vehicle standards	• Tradable certificates for energy efficiency improvements (white certificates)	• Emissions trading • Emission credit under CDM • Tradable Green Certificates	• Emission credits under the Kyoto Protocol's Clean Development Mechanism (CDM) • Compliance schemes outside Kyoto protocol (national schemes) • Voluntary carbon markets	• Urban-scale Cap and Trade
Economic Instruments—Subsidies	• Fossil fuel subsidy removal • Feed-in-tariffs for renewable energy • Capital subsidies and insurance for 1st generation Carbon Dioxide Capture and Storage (CCS)	• Biofuel subsidies • Vehicle purchase subsidies • Feebates	• Subsidies or Tax exemptions for investment in efficient buildings, retrofits and products • Subsidized loans	• Subsidies (e.g., for energy audits) • Fiscal incentives (e.g., for fuel switching)	• Credit lines for low carbon agriculture, sustainable forestry.	• Special Improvement or Redevelopment Districts
Regulatory Approaches	• Efficiency or environmental performance standards • Renewable Portfolio standards for renewable energy • Equitable access to electricity grid • Legal status of long term CO_2 storage	• Fuel economy performance standards • Fuel quality standards • GHG emission performance standards • Regulatory restrictions to encourage modal shifts (road to rail) • Restriction on use of vehicles in certain areas • Environmental capacity constraints on airports • Urban planning and zoning restrictions	• Building codes and standards • Equipment and appliance standards • Mandates for energy retailers to assist customers invest in energy efficiency	• Energy efficiency standards for equipment • Energy management systems (also voluntary) • Voluntary agreements (where bound by regulation) • Labelling and public procurement regulations	• National policies to support REDD+ including monitoring, reporting and verification • Forest law to reduce deforestation • Air and water pollution control GHG precursors • Land-use planning and governance	• Mixed use zoning • Development restrictions • Affordable housing mandates • Site access controls • Transfer development rights • Design codes • Building codes • Street codes • Design standards
Information Programmes		• Fuel labelling • Vehicle efficiency labelling	• Energy audits • Labelling programmes • Energy advice programmes	• Energy audits • Benchmarking • Brokerage for industrial cooperation	• Certification schemes for sustainable forest practices • Information policies to support REDD+ including monitoring, reporting and verification	
Government Provision of Public Goods or Services	• Research and development • Infrastructure expansion (district heating/cooling or common carrier)	• Investment in transit and human powered transport • Investment in alternative fuel infrastructure • Low emission vehicle procurement	• Public procurement of efficient buildings and appliances	• Training and education • Brokerage for industrial cooperation	• Protection of national, state, and local forests. • Investment in improvement and diffusion of innovative technologies in agriculture and forestry	• Provision of utility infrastructure such as electricity distribution, district heating/cooling and wastewater connections, etc. • Park improvements • Trail improvements • Urban rail
Voluntary Actions			• Labelling programmes for efficient buildings • Product eco-labelling	• Voluntary agreements on energy targets or adoption of energy management systems, or resource efficiency	• Promotion of sustainability by developing standards and educational campaigns	

A stocktaking of current climate policies can build on several existing databases and publications. These include, but are not limited to:

- The Climate Change Performance Index (CCPI)[2] (Burck et al., 2020) focusses for example on climate mitigation output indicators, covering four topics: Climate Policy, Energy Use, Renewable Energy and GHG Emissions evaluating, amongst other things, the progress towards countries' NDCs.
- The IEA's Policies and Measures Database[3] provides access to information on past, existing or planned government policies and measures to reduce greenhouse gas emissions, improve energy efficiency and support the development and deployment of renewables and other clean energy technologies. This policy database gathers data from the IEA/IRENA Renewable Energy Policies and Measures Database, the IEA Energy Efficiency Database, the Addressing Climate Change database, and the Building Energy Efficiency Policies (BEEP) database since 1999, along with information on carbon capture and methane abatement policies. As it stands it is composed of more than 6000 individual policies.
- The European Energy Agency has assembled a similar database of policies and measures (PaM) that are implemented, adopted or planned by European countries to reduce greenhouse gas (GHG) emissions. These PaMs have been reported by European countries under the Governance of the Energy Union and Climate Action Regulation and are collected via the Reportnet platform. Where available, each policy is linked to quantitative information on the GHG emissions savings achieved by PaMs (or groups of PaMs), both ex-post (retrospectively) and ex-ante (anticipated savings).
- The NewClimate Institute, with support from PBL Netherlands Environmental Assessment Agency and Wageningen University and Research, gathers information on climate mitigation policies and benchmarks these against a policy matrix, representing a comprehensive policy package to mitigate the effects of climate change. Planned policies are excluded from the database, with an exception for energy and emission targets announced as Intended under Nationally Determined Contributions (INDCs) for the post-2020 period. Policy coverage varies across countries but is comprehensive for G20 economies.
- Climate Change Laws of the World covers national-level climate change legislation and policies globally. The database covers climate and climate-related laws, as well as laws and policies promoting low carbon transitions, covering climate litigation cases from over 40 countries. These cases raise issues of law or fact regarding the science of climate change and/or climate change mitigation and adaptation policies or efforts before an administrative, judicial or other investigatory body.

In principle, the project should focus on all instruments that intentionally or unintentionally affect GHG emissions. However, almost any policy measure will have some impact, either positive or negative, on GHG emissions. So, such as approach may produce an exceedingly large list of policy instruments.

To limit the list of instruments to a manageable size, a first delimitation could be to only include policy instruments that are presumed to have a relatively large impact on GHG emissions in the country,

[2] https://ccpi.org/wp-content/uploads/CCPI-2022-Results_neu.pdf.

[3] https://www.iea.org/policies.

whether this is intentional or not. Policy instruments introduced with an explicit intention to reduce GHG emissions may have only a modest – if any – impact on GHG emissions, for instance due to interactions with other policy measures (which will be discussed further below). Despite this, the project should probably cover most policy instruments that have been introduced with the explicit intention of limiting GHG emissions, as these policies are central ingredients of countries' decarbonisation strategies. Assessing and comparing the effectiveness of these strategies is one of the main goals of this project.

However, as shown in both OECD (2013) and Productivity Commission (2011), some of the policy instruments that have the largest impact on a country's GHG emissions were not introduced with the explicit goal of reducing emissions. Taxes on motor vehicle fuels are a prominent example. These mainly were introduced many years ago primarily for fiscal reasons, or as a road pricing system. Another example concerns standards for the insulation of buildings. More recently, many countries have made such standards stricter, in view of limiting emissions.

- Price-based instruments -- Taxes

To be more specific, the project should, among others, cover all price-based instruments with a clear impact on GHG emissions. This includes any taxes on fossil-fuel-based energy products, such as taxes on motor vehicle fuels, heating fuels, coal and natural gas, whatever the original motive behind their introduction. The project should also cover carbon-differentiated motor vehicle taxes and any climate-related trading systems, such as GHG emission trading systems, tradable green certificate systems (e.g. tradable certificates that document that electricity has been generated by renewable sources), tradable renewable energy content systems, road pricing and congestion charging systems.

- Price-based instruments -- Subsidies

A large number of governments provide different types of subsidies to limit GHG emissions. They include but are not limited to direct tax preferences to stimulate the purchase of various low-carbon products or services (e.g. purchases of energy-efficient household appliances, installation of solar panels on roof tops, promotion of public transport), feed-in tariffs for renewable energy generators (solar photovoltaics, wind turbines, hydro-electric power generation, etc.) and public support for research and development (R&D) activities.

Public R&D support measures often involve subsidies, but their impacts on emissions are difficult to quantify as the outcome of R&D activities is highly uncertain. Another potentially important group of subsidies include support measures to promote afforestation and to prevent deforestation. Such measures can help reducing GHG concentrations in the atmosphere, but their impacts are challenging to quantify as they realise over the long term. Issues related to the durability of some of these measures are an additional complication as forests that are planted or protected today could be cut or burned down in the future.

- Non-price instruments -- Bans

Countries also apply a large range of non-price policy instruments in order to limit GHG emissions. Examples are bans on certain products or activities deemed to cause large emissions, such as bans on the opening of new coal mines, bans on the sales of incandescent light bulbs, bans on the sales of motor vehicles with internal combustion engines, bans on the sales of fossil fuel-based domestic heating systems, etc. Such bans can certainly help reducing a country's GHG emissions, but the magnitude of the reductions will depend on the emission-intensity of the goods or services that effectively replace them.

- Non-price instruments -- Standards

A wide variety of standards are also in use with the aim to limit GHG emissions, including outright bans to certain products and activities. These include emission standards for power plants, energy-efficiency standards for individual products (e.g. refrigerators, deep freezers and other electrical appliances or for new buildings) or for an average of the products that a given producer places on the market, such as the CAFE standards for motor vehicles in the United States or the motor vehicle CO_2 emission standards applied by the European Union. Other examples are standards for the content of biofuels in motor vehicle fuels, or for renewables contents in the electricity that power generators place on the market.

- Non-price instruments – Information measures

Various forms of information-related policy instruments are also being used in many countries. This could be public information campaigns that try to encourage “climate-friendly” behaviour. Compulsory labelling systems that provide information on the climate impacts of a range of products (including motor vehicles, electrical appliances, food products, etc) are also a type of information-related policy instrument.

- Non-price instruments – Voluntary measures

Some countries rely also on voluntary policy instruments to limit GHG emissions. These could, for example, be negotiated agreements between public authorities and individual firms or a group of firms, where the latter commit to reducing emissions by a certain amount. Another example of voluntary policy instruments is the establishment of criteria for labelling systems that allow compliant firms to put a certain label on their products, such as the EnergyStar system in the United States.

While such policy instruments can reduce GHG emissions, it is difficult to quantify their effects, as one would need to envisage what firms would have done in their absence. For example, OECD (2003) found that whereas the targets set for most voluntary approaches seemed to be met, these targets seldom were much different from what would have happened in any case. An additional challenge to estimate the impact of voluntary approaches on emissions is that they differ greatly in scope, time horizon and in other dimensions across countries.

In some country public procurement rules require the public sector to purchase only products with a certain voluntary label. In this case, one could try to estimate the emission impacts of these rules, based on some stylised, simplifying assumptions – such as an assumption that the labelled products cause 5% lower emissions than non-labelled products.

- Other non-price instruments

Another instrument category used in some countries concerns area planning regulations o, such as minimum housing density in a given area opened up for development, or good access to public transport for new housing areas. The impact of such regulations might be important, but they will materialise over a very long time period and therefore can be difficult to quantify.

Some countries have recently introduced new speed limits on different types of roads with an aim to reduce GHG emissions. While these limits clearly can have an impact on emissions, it can be difficult to quantify their effects as it is not clear what the baseline (i.e. the "normal" speed limit) they need to be compared with. For new speed limits, the old speed limits could be used.

- Instruments with unintended impacts

Though no policy instruments are introduced with an explicit objective of increasing GHG emissions, some can unintentionally have this effect. This is the case for instance of various types of subsidies for fossil fuel use or generation, whose main aim is to provide relief for the energy poor; to protect employment in fossil-fuel-related activities; to enhance energy security. The OECD companion to the inventory of support measures for fossil fuels (OECD (2021)) covers more than 1300 government budgetary transfers and tax expenditures providing preferential treatment for the production and consumption of fossil fuels. Some of these measures – such as income support for former coal miners – may not have a large impact on emissions, but others, such as tax exemptions for fuels used in shipping, are likely to increase GHG emissions.

There are also examples of policies that unintentionally may have contributed to reduce GHG emissions. National parks were established to protect nature and provide recreation opportunities and not to reduce such emissions. Also, many countries have for many years been promoting cycling – mainly for health reasons, to reduce congestion and local air pollution.

Decide on which emission categories to cover.

Should the project only address the impacts of different policy instruments on CO_2 emissions, or should also possible impacts on other types of GHG emissions (methane, N_2O, SF_6, …) be included? Focussing only on impacts on CO_2 emissions would clearly be easier, and for most policy instruments, this would also capture the bulk of total GHG emission impacts. Hence, the project could, in a first phase, focus on CO_2 emissions only.

However, some countries apply policy instruments that explicitly aim to limit non-CO_2 GHGs, for example, methane emissions in the agriculture sector or from gas pipelines, SF_6 emissions in selected industry sectors, etc. Hence, in a second phase, the project could also cover the impacts of policies that directly aim to reduce such non-CO_2 emissions.

Decide on which jurisdictions to cover.

In a number of countries, policy instruments aiming to limit GHG emissions are being applied at national and sub-national levels, such as the States in the United States, States and Territories in Australia, Provinces in Canada, Länder in Germany, etc. In some cases, these policies have similar aims and overlap.

On the one side, only focussing on nation-wide policy instruments may give a very partial picture of climate policies in a country. On the other side, including in the stocktaking all relevant policy instruments of many sub-national governments (i.e. the 50 US States) could be very time consuming.

A practical solution could involve covering all relevant nation-wide policy instruments, as well as instruments applied by a selection "reasonably representative" of sub-national governments.

The treatment of policy instruments applied at the European Union (EU) level is a similar issue. This includes, among others, the Union's emission trading system for GHG emissions (EU ETS), and the EU-wide average CO_2 emission limits for new passenger vehicles in member countries. These instruments play an important role in the abatement efforts of the member states but allocating to individual countries the overall emission reductions that these instruments are estimated to generate is difficult. Hence, one feasible option would involve considering the policy instruments applied by the EU as separate from national policy instruments and including them in country-level analysis. A similar approach could be applied in federal countries, such as the United States, Australia and Germany.

Estimating the abatement impacts of different policy instruments

Establishing a baseline against which to compare future GHG emissions

Establishing a baseline is a necessary step in estimating the abatement impact of policies. The baseline helps to answer this question: what would the GHG emissions be if this policy instrument was not in place? This is a hypothetical question and as such, it is impossible to provide an exact answer to it even in the best of circumstances because of multiple sources of uncertainties. For instance, nobody can say with certainty what the price of crude five years from now will be. Political events, which are difficult or impossible to predict, also have larga e effect on the economy. For instance, following the Russian invasion of Ukraine, many countries have stated the intention to radically change their energy policies, putting much greater emphasis than before on energy security and promoting domestic and renewable energy resources.

Relying not on one on multiple baselines would help to explicitly recognise these uncertainties and take them into account in assessing the impact of policies on GHG emissions. These baselines could be based on varying assumptions concerning macroeconomic variables, such as price developments of fossil fuels, and structural factors, such as the functioning of energy markets and the extent of fossil fuel import restrictions. The robustness of these assumptions and of the impact-assessment of policies on emissions will diminish with the length of time the project will cover. The longer the time, the larger the set of factors, such as technological developments, likely to violate the baseline assumptions to estimate the abatement impact of emissions

Once a set of possible future scenarios has been established, the project will estimate the impact of the policy instruments on GHG emissions against each baseline. There are two approaches to estimating expected emission reductions: "top-down" and "bottom-up" approaches.

The first approach consists of general models that capture economy-wide features, and that can be applied to different countries after being rightly parametrised. However, there are several and difficult challenges to developing models, consistently parameterized across countries, which can disentangle the individual impact of multiple, overlapping instruments.

The second approach attempts to capture country, sectoral and technological specificities that general models find difficult to take into consideration. This approach relies on country or industry experts' judgement to estimate emission reductions of various policy instruments - either in addition to, or as a substitute for, more formalised assessments.[4] This would provide an objective assessment of the expected emission reductions of policies and eventually the computation of their carbon price equivalents as it would allow for a commonly agreed emissions reduction estimate of a given policy

[4] The OECD (2013) *Effective Carbon Prices* report employed this approach. https://doi.org/10.1787/9789264196964-en.

or policy package. A challenge for this approach is to develop procedures that facilitate transparent and consistent cross-country comparisons.

Macroeconomic models underlying the top-down approach often focus on price-based policy instruments, as these instruments tend to be important in addition to being easier to implement in models. For policy instruments modelled explicitly in a global or national macroeconomic model, one can "simply" run the model with and without the instrument in question being applied (for each of the baselines taken into consideration). One would then get an estimate of how much abatement each of these instruments contributes to compared with each baseline. Complications to be considered include: interactions among different instruments; price elasticity estimates and other assumptions that might be no longer relevant given changing circumstances and large out-of-sample changes in policy variables, which may have non-linear effects not captured by the model.

Estimating the impact on emissions of non-price instruments is more challenging as general equilibrium models cannot easily accommodate them. One example is tenders for power purchasing agreements, which may occur at infrequent and varying time intervals, with y varying price outcomes. It can also be difficult to include several price-based instruments, such as carbon-differentiated motor vehicle taxes, in macroeconomic models.

This may therefore require resorting to partial equilibrium or bottom-up ad hoc approaches. A disadvantage is that such approaches will often not reflect second-round and rebound effects, for example, when higher energy prices trigger shifts in consumption, which could cause increased consumption of non-energy products – which also could have positive or negative impacts on GHG emissions.

Some models of national or international energy markets are partial equilibrium models and can perform similar "with and without" analyses as suggested for the macroeconomic models above. For instance, in the context of a case study of Denmark for the OECD (2013) report, the consultant (Copenhagen Economics) used a simulation model incorporating the link between prices and taxes on energy with the final use of energy demand. In every sector, the consumer was assumed to be able to substitute between the relevant energy types, while it was not possible to substitute between sectors, and between the consumption of energy and the consumption of other goods and services.

Consultants preparing a case study of Canada (Bataille and Melton of Navius Research Inc.) used an integrated, energy-economy equilibrium model (CIMS) that simulated the interaction of energy supply-demand and the macroeconomic performance of key sectors of the economy, including trade effects. Unlike most computable general equilibrium models, however, that version of CIMS did not balance government budgets and the markets for employment and investment. Also, its representation of the economy's inputs and outputs was skewed toward energy energy-intensive industries, and key energy end-uses in the residential, commercial, institutional and transportation sectors.

The project can also build on more ad hoc judgements of different experts to assess the impacts on GHG emissions of policies – either in addition to, or as a substitute for, more formalised assessments. These experts will need to have in-depth knowledge of the respective countries that they cover, in relation to i.e. the operation of their energy markets, the different policy instruments they apply, their economic structure, typical behaviour of different market actors, etc. Such expert judgements also played an important role in the preparation of OECD (2013):

- For example, given the dominance of the oil-shale in electricity production in Estonia, the consultants (Silja Kralik and Eva Kraav) that prepared the case study of that country for OECD

(2013) assumed that the electricity source that was replaced by new renewable generation or lower emission technologies was oil-shale – which cause very high GHG emissions. The authors of the Chilean case study (Menecon), assumed that electricity generation based on non-conventional renewable energy sources induced by the policies in place in that country displaced a mix of fossil-fuel generation having an emissions intensity equal to the average emissions intensity of fossil-fuel generation in Chile.

- The authors of the French case study (Jouvet et al. of Paris-Dauphine University) assumed that the cement sector in the country buys its electricity at non-regulated prices where CO2 cost pass-through can occur. Vivid Economics, which prepared case studies of policies applied in the pulp & paper and cement sectors in a number of countries, in many cases had to make their own assumptions regarding the electricity prices applied in these sectors, as this information was often not publicly available.

Expert judgments may result in estimates that are difficult to compare as they may rely on different assumptions and approaches. International Organisations (IOs) involved in the project would then need to harmonise to the largest extent possible the assumptions and approaches of country experts.

In addition to partial equilibrium models and ad-hoc approaches, reliable price elasticity estimates of emissions can also be useful in estimating the impact of policies on emissions. For instance, the Australian Productivity Commission (2011) report used price elasticity estimates in most of the case studies it covered. For the electricity demand in pulp and paper and the cement sectors, the Productivity Commission used a price elasticity range between -0.2 and -0.7; for the fuel demand in the transport sector, it used a range of -0.25 to -0.75 for long-term policies. Most of the case studies prepared for OECD (2013) used a range between -0.25 to -0.75; however, the Spanish and the Brazilian case studies used country-specific and fuel-specific estimates.

For other relevant policy instruments, it might be possible to carry out new econometric analyses (e.g. differences-in-differences analyses) to assess their impacts on emissions. The behavioural changes policies might engender are a difficulty shared by all the approaches outlined above. A stricter energy-efficiency standard for motor vehicles will lower the cost of using the vehicles, and could hence trigger more driving – i.e. a rebound effect. A stricter energy efficiency standard for dwellings might cause people to increase the indoor temperature, or to keep windows open for longer periods than what is needed to properly ventilate the flats. It is vital to try to take such behavioural changes into account when estimating the impact on emissions of a given policy instrument. The consultants preparing case studies for OECD (2013) made several ad hoc attempts to take possible behavioural adjustments into account.

Decide on the treatment of overlapping policy instruments

In many cases, a country applies several policy instruments with the aim of limiting emissions from the same sources. In this case policies overlap, complicating the assessment and comparison of their effectiveness. For example, if electricity generation in a country is covered by a binding and fixed cap on CO_2 emissions (which was the case, for instance, in the EU ETS prior to certain modifications introduced in 2017, which included mechanisms that effectively could reduce the total cap on emissions), a ban on the use of incandescent light bulbs, or a stricter energy efficiency standard for electrical appliances, would not cause any additional emission abatement overall. Instead, such overlapping policy instruments would only shift CO_2 emissions from one source covered by the "cap" to another one.

The EU-wide and US-wide standards on average motor vehicle CO_2 emissions are other examples of instruments that can have important interactions with other policy instruments, such as subsidies applied to promote the sales of zero-emission vehicles. As long as the upper limits of these emission standards are binding, subsidies for zero-emission vehicles will make it easier for car producers to comply with them, which would allow them to sell more high-emission vehicles.

There can also be overlaps between one or more policy instruments applied (only) within a given jurisdiction. One example would be if a country applied a tax on some potentially high-emission products, in combination with a labelling system and an information campaign highlighting the relevance of the labels and the emissions that these products could cause. In this example, the overlapping instruments could be underpinning each other, with the existence of the tax and the information campaign increasing people's awareness of the labels in question – and the labels making it easier for people to avoid paying the tax by choosing to buy low-emission product varieties. OECD (2007) provides further discussion of different types of interactions between policy instruments.

One possibility is to take into account such policy overlaps based on a case-to-case assessment but following a common general methodology to make them comparable. In the previous example, it could for instance be appropriate to allocate a relatively large share of the overall emission reduction to the tax (depending on its magnitude), as empirical evidence suggest that taxes are more effective in reducing emissions than labelling systems and information campaigns.

However, it would perhaps be best not to consider overlaps between instruments applied by jurisdictions at different levels (e.g. States and Federal authorities in the United States, or individual member states and the EU). This would, for example, mean that individual member states would be "awarded" the within-country impacts on CO_2 emissions from motor vehicles stemming from any subsidies for zero-emission vehicles that they provide, even if these subsidies will have little or no impact on EU-wide emissions from motor vehicles. Despite the overall environmental inefficacity of the "additional" policy instruments, such an approach would perhaps be the best way to illustrate the efforts each country is willing to make in order to reduce GHG emissions.

Decide on the which sectors to be included

An important issue is what sectors of the economy the project should cover. Ideally, it would be to cover all economic activity– but that may turn out very complicated, time consuming and costly.

OECD (2013) focused on electricity generation, road transport, pulp & paper, cement and the household sectors. These sectors were selected also because they are reasonably comparable across countries.

Other relevant sectors that the project could cover include iron & steel, aluminium, petroleum refining and (perhaps more difficult) agriculture. Production techniques in some other sectors (e.g. chemicals and transport equipment) can vary greatly across countries, so it can be difficult to compare findings.

In the end, the scope of the sectors covered depends on the resources available. One option could be to include the same five sectors that were covered in OECD (2013), plus two or three additional sectors, in order to have a more complete picture of climate related policies. These two or three additional sectors could for instance cover Iron & steel and aluminium production, including a sector (aluminium) where non-CO_2 GHGs can be of large importance.

Decide on the time dimensions of the analysis

The time dimensions of the analysis regard the time when a given instrument was first introduced and the time period over which the abatement impact of the instrument is estimated.

Regarding the first issue, one option could be to only include policy measures introduced after the agreement on the Kyoto Protocol in 1997, or after the Paris Agreement in 2015, as this would put the focus on what countries have done to comply with these agreements. However, the “starting point” would differ across the countries covered – some countries had already taken many measures affecting GHG emissions prior to these agreements, while others had not done much to limit their emissions.

In addition, such a limitation would exclude some of the most important policy measures affecting GHG emissions; in particular taxes on motor vehicle fuels and, in some countries, on other fossil fuels. As mentioned above, in many cases, such taxes were introduced long before policymakers started to worry much about the concentrations of GHGs in the atmosphere.

Hence, it can seem best to include all relevant policy instruments, regardless of when they first were introduced – even if it can be somewhat difficult to establish the “counterfactual” to a tax on petrol or diesel that was, for instance, introduced many decades ago.

Difficulties in establishing a counterfactual could in this case be overcome by basing the analysis on price elasticity estimates which generally are already available for energy products – even if these estimates are most reliable when marginal changes in the prices or taxes are analysed.

Another decision related to the time dimension is whether the analysis should try to make a backwards-looking “snapshot” of the impacts of the relevant policy instruments applied in a given year, or whether the project should aim to make a forward-looking estimate of the impact of current policy instruments up to a given year in the future, for example 2030.

OECD (2013) and Productivity Commission (2011) both provided backward-looking snapshots of the abatement impacts of the policy instruments in the most recent year for which emission data was available. However, given the urgency to accelerate emission reductions and monitor progress in this direction, this project needs to be forward looking. In addition many countries have committed to “build back better” in response to the pandemic, and have put in place a number of new policy instruments aiming to reduce GHG emissions. The impacts of these instruments will only to a small extent show up in currently available emission data as the effects will materialise over many years. One possibility would be to do both; i.e. to make a backward-looking snapshot of the impacts of the policy instruments that each country had in place in 2019 (or the latest year for which emission data are available), and to make estimates of the impacts of all relevant policy instruments that countries have put in place by 2022, up until 2025 or 2030 – compared to the set of baselines.

Derive the carbon price equivalent of policies

The abatement impact of a policy instrument is a key input to estimate the carbon price equivalent (CPE). This is the carbon price that would be needed to trigger the same amount of emission reductions of a given policy. Such estimates could be made considering the economy-wide carbon prices, or sector-wide carbon prices (carbon prices applied only to the sector in question).

If the policy instrument that is being analysed is applied only in one sector of the economy (say an energy-efficiency requirement regarding electricity generation or road transport), one can estimate: **a)** the economy-wide carbon price that would have caused the same amount of abatement; **b)** the carbon price applied only in this sector that would cause the same emission abatement amount – or one can present both estimates.

In the economy-wide case, if the policy instrument is applied to a relatively small sector of the economy, the “carbon price equivalent” could be low, even if the policy regarding that sector is highly ambitious and effective. In case of sector-wide case, the estimated “equivalent carbon price” would be higher, possibly giving the impression that the policy is very ambitious and effective – even if only a small part of the economy is being affected and the overall emission abatement is small.

Hence, in addition to the nation-wide and sector-wide "equivalent carbon prices", the project could present information on how much emission reduction each policy instrument contributes to in each of the base-line scenarios.

Decide on the treatment of possible co-benefits

Many of the policy instruments to reduce emissions generate other benefits than limiting GHG emissions. For example, public support for the insulation of low-quality housing and stricter standards for energy-efficiency of energy appliances can reduce energy consumption and strengthen energy security. Support measures for electric vehicles can lower air pollution. Speed limits on roads can reduce the number of traffic accidents.

Neither OECD (2013) nor Productivity Commission (2011) took such co-benefits into account. However, both reports also made it clear that it could be "unfair" to judge the environmental effectiveness and economic efficiency of the policy instruments in question only according to their impact on emissions.

This project focusses on the impact of policies on GHG emissions and not on assessing their overall impact on social welfare. This does not require taking into consideration policies' co-benefits. However, disregarding such benefits will certainly make some instruments seem more costly to society – than if they had been taken into account. For this reason, important co-benefits could be listed separately to give readers a good idea of major aspects of the policy instruments.

Interpretation of the findings of the project

It is important to be aware that no single number can provide a complete and "fair" comparison of all the policy instruments across all the countries covered. Instead of presenting *one* figure for the amount of abatement that a given policy instrument causes, it would be better to present a *range*, based for example on different price elasticity assumptions, etc.

All the estimates of abatement impacts and related costs will be rather uncertain, given the difficulties in determining what would have happened in the absence of policy instruments and uncertainties regarding future economic and geopolitical developments. As suggested above using a selection of baseline scenarios based on different assumptions sand performing sensitivity analysis could help to address this problem by producing a number of estimates.

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Annex 2: Emissions Impacts and Economywide Carbon Price Equivalents (ECPEs) of Prospective Mitigation Policies

To facilitate monitoring of internationally coordinated climate mitigation regimes, a transparent methodology is required for mapping alternative policy approaches (e.g., partial pricing, regulations, changing fuel taxes) into their emissions and/or ECPEs, while accounting for potential overlaps (e.g., where the power sector is subject to both carbon pricing and renewables policies).

This Annex illustrates how a modelling framework can be used for this purpose. The methodology is based on the Climate Policy Assessment Tool (CPAT), which is routinely used for individual- and cross-country assessments of mitigation policy.[1] The Annex first describes CPAT and then discusses, for each G20 country, the emissions impacts and ECPEs of explicit carbon pricing schemes, sectoral approaches, and fuel taxes. Given the focus on 2030 among commitments in Nationally Determined Contributions (NDCs) and sectoral targets, the focus is a snapshot in that year. Where countries use a variety of overlapping measures whose emissions impact is difficult to disentangle, the focus is on sectoral emissions or clean energy targets rather than individual instruments.

Climate Policy Assessment Tool (CPAT)

(i) Model description

CPAT is a climate mitigation policy modelling platform developed jointly by the IMF and World Bank staff. Covering over 200 countries, CPAT provides projections of fuel use and CO_2 emissions for the four major energy sectors—power, industry, transport, and buildings. The tool starts with recently observed use of fossil fuels and other fuels by sector and then projects fuel use forward in a business as usual (BAU) case[2] using assumptions on:

- GDP projections;
- the income elasticity of demand and the price responsiveness of fuel use across sectors;
- the rate of technological change that affects energy efficiency and the productivity of different energy sources; and
- future international energy prices.

The impact of carbon pricing on fuel use and emissions depends on: (i) the proportionate impact on future fuel prices; and (ii) the price responsiveness of fuel use in different sectors. Proportionate price

[1] See for example, Black and others (2021a, b), IMF (2022), Parry and others (2021b). CPAT evolved from earlier modelling used, for example, in IMF (2019a and b).

[2] That is, with no new or tightening of existing, mitigation policies.

increases depend on BAU prices, carbon emissions factors for fuels, and the pass through of carbon charges into fuel user prices which, for the most part, is taken to be 100 percent.[3]

In the power (and district heating) sector, results are averaged over two models. One is a simplified model of fuel generation choices, parametrized to match the fuel price responsiveness of more complicated energy supply and integrated assessment models. The other is a technology-explicit, hybrid economic-engineering model where forward-looking agents choose dispatch and investment decisions to minimize levelized costs (e.g., capital, operational, and fuel costs). In the latter case, carbon prices reduce dispatch from fossil fuel plants and shift investment towards now-cheaper (in levelized terms) renewable generation. Switching between sources for dispatch and investment are gradual given constraints on the rate renewables can be scaled up, lags in altering investment decisions, and the distribution of costs within generation sources.

The industrial sector is disaggregated into eight industries (e.g., iron and steel, machinery, cement). In each industry, carbon pricing reduces the emissions intensity of production (e.g., through adoption of cleaner or more energy efficient technologies) and reduces production levels as carbon charges are reflected in higher consumer prices. In the transport sector, fuel consumption from gasoline and diesel vehicles declines in response to higher prices as individuals switch to more fuel-efficient vehicles and reduce vehicle miles travelled. And in the buildings sector, fuel and electricity demand are decomposed into responses reflecting changes in energy and CO_2 intensity (e.g., insulation upgrades, shifting from fossil to electric heating, adoption of energy-efficient appliances) and behavioral changes (e.g., economizing on use of lighting, heating).

To analyze policies affecting only new investment in the transport and building sectors, CPAT is supplemented with two dynamic models of capital turnover. In the light-duty vehicle sector, the dynamic model distinguishes internal combustion engine vehicles (ICEVs) and electric vehicles (EVs) in the vehicle stock in any future period, as determined by the previous history of purchases of these vehicle types and vehicle fleet turnover rates (6.7 percent a year based on an assumed 15-year life). In the building sector, commercial and residential buildings are distinguished with 1.8 and 1.2 percent of these stocks replaced annually (based on assumed building lives of 55 and 85 years respectively). The CO_2 and electricity intensity of new buildings is initially assumed to be 30 percent of that of the existing building stock, consistent with observed rates of energy efficiency improvement.

CPAT is populated using energy consumption data by country and sector compiled from the International Energy Agency (IEA) and other sources (the latest data is for 2019). GDP projections are from the latest IMF forecasts. Data on energy taxes, subsidies, and prices by energy product and country is compiled from publicly available and IMF and World Bank sources, with inputs from

[3] That is, fuel supply curves are perfectly elastic, which can be a reasonable approximation when fuel prices are determined on world markets or, in the longer term, there are large reserves. In countries with state-owned enterprises or regulated fuel pricing, pass through rates for fossil fuels are estimated based on historical relationships.

proprietary and third-party sources.[4] International prices for coal, oil, and natural gas are projected forward using an average of IEA (which are rising) and IMF (which are flat) price projections as of mid-2021. Fuel and electricity price responsiveness is parameterized to be broadly consistent with empirical evidence and results from energy models (fuel and electricity price elasticities over the longer term are generally between -0.5 and -0.8). Carbon emissions factors by fuel product are from IIASA (2021), and emissions in 2019 are calibrated to match those implied by inventories countries reported to the United Nations Framework Convention on Climate Change.

(ii) Caveats

One caveat is that fuel price responses become very uncertain for large policy changes that might ultimately drive non-linear adoption of technologies, like carbon capture and storage and direct air capture. In addition, fuel price responsiveness is approximately similar across countries—in practice, price responsiveness may significantly differ across countries with the structure of the energy system and regulations on energy efficiency and emission rates. CPAT implicitly accounts for general equilibrium effects such as the (modest) feedback effect on energy demand from policy-induced changes in GDP but does not explicitly account for international feedback effects (e.g., changes in trade patterns) and changes in international fuel prices that might result from simultaneous climate or energy price reform in large countries. The model is parameterized, however, such that emissions projections and the price responsiveness of fuel use and CO_2 emissions is broadly consistent with that from far more detailed energy and computable general equilibrium models that, to varying degrees, account for these sorts of factors.

(iii) Calculating CO_2 reductions and ECPEs for alternative mitigation approaches

The economywide CO_2 reductions of alternative mitigation approaches are obtained by subtracting economywide emissions in 2030 under the policy or target from economywide BAU CO_2 emissions in 2030. The ECPE of the other policy is then obtained by modelling in CPAT the equivalent carbon price at economywide level required to achieve the equivalent CO_2 reduction.

Renewables targets in CPAT are modelled by a renewable generation subsidy funded by a tax on electricity consumption (this promotes shifting towards renewables while approximately neutralizing any impact on overall electricity production). Similarly, coal phaseouts are modelled by a tax on coal use with impacts on electricity demand approximately neutralized through using revenues used to subsidize electricity consumption.

Policies to reduce the (direct) CO_2 intensity of industrial production are modelled by a charge on the carbon content of fuel inputs with revenues returned in output-based subsidies.

[4] See Parry and others (2021c) for details.

The supplementary dynamic model of vehicle turnover is used to assess CO_2/km standards and EV targets for new vehicles, in the former case through a 'shadow' price set to achieve the target. Similarly, the supplementary building model is used to calculate (direct and indirect) reductions in CO_2 emissions from emissions targets for new and existing buildings emissions.

Lastly, the ECPE of countries' pre-existing fuel tax/subsidy systems is computed by first setting the tax/subsidy on all fossil fuels across different sectors gradually to zero by 2030 (which in most cases increases economywide emissions). An economywide carbon price is then imposed to equal the emissions reductions sufficient to achieve the original BAU emissions with pre-existing fuel taxes/subsidies kept fixed at 2021 levels.

Existing Explicit Carbon Pricing in G20 Countries

Explicit carbon pricing. Economywide carbon pricing—carbon taxes or emissions trading systems (ETSs)—promote the full range of behavioral responses for reducing energy use and shifting to cleaner energy sources across the economy. This includes fuel switching from coal and gas to renewables in the power sector, switching to more efficient gasoline/diesel and electric vehicles as well as reductions in vehicular km travelled in road transport, and improvements in energy efficiency and CO_2 intensity in the industrial and buildings sectors.

Thirteen G20 countries (plus the EU) have carbon pricing instruments (Table A2.1). This includes a mix of ETSs, carbon taxes, or both, while covered sectors and fuels vary. Canada requires provinces and states to implement a minimum carbon price through a carbon tax or ETS for fuels used in power, transport, and buildings. Japan and South Africa have implemented carbon taxes midstream on fuel supply, while Korea has implemented an ETS downstream for large emitters in the power and industry sectors and midstream for suppliers of heating fuels. ETSs at the EU level and in the UK apply to emissions from power generation and industry. France and Germany also apply pricing systems (a tax and ETS respectively) midstream to fuels used in the building and transport sectors.

Table A2.1. Explicit Carbon Pricing Policies, G20 Countries

	Instrument/coverage (April 2022, 2030 prices, US $/ton)[a]
Canada	Carbon tax/ETS for power, industry, transport, buildings (36, 140)[b]
China	ETS for electricity to be expanded to industry (7, 7)[c]
France	EU ETS for power/industry (100, 140), domestic tax for buildings/transport (87, 87)
Germany	EU ETS for power/industry (100, 140), domestic ETS for buildings/transport (34, 60)
Italy	EU ETS for power/industry(100, 140)
Japan	Carbon tax for all emissions (3, 3)
Korea	ETS for power/industry/buildings (15, 15)
S. Africa	Carbon tax for all emissions (9, 9)
UK	ETS for power/industry (69, 130)

Source: Black and others (2022).
Notes. [a]Where prices, or caps in ETSs, are not specified in legislation for 2030 they are based on 2021 prices or, as in Germany, the last available year where a price is specified. For the EU ETS, the 2030 price is an estimate based on CPAT. [b]For some provinces and territories industry is covered by a tradable emission rate standard rather than carbon pricing. [c]China's ETS takes the form of a tradable emission rate standard.

However, only three of the eight countries (plus the EU) have prices above $45 per tonne on covered emissions: France, Germany, and the UK. In April 2022, the EU ETS's permit prices were $100 per tonne, while prices in the French and German schemes were $87 and $34 per ton, implying average carbon prices of $92 and $69, respectively.[5] In the UK, ETS prices were $100 per ton of CO_2. Canada's federal system has a price of $36 though this is expected to rise to $136 by 2030. The remaining the five countries with carbon pricing instruments covering less than half of national emissions had national prices of $3, $3, $7, $8, $9, and $100, in Japan, Mexico, China, USA, and Italy respectively. Prices are expected to rise in the EU, UK, and German ETS and Canadian system, but future price trajectories are not available for the other schemes.

Additionally, three other G20 countries have partial carbon pricing (or pricing-like schemes) that cover a subset of sectors or jurisdictions (Table A2.1). China has introduced a mechanism for power, though it is not yet equivalent to an ETS[6] and initial prices are low ($7 per tonne). Indonesia recently introduced a carbon tax, but the price and coverage remains low ($2 and 27 percent). The US has three regional ETSs, but these cover a small portion of US emissions (8 percent).

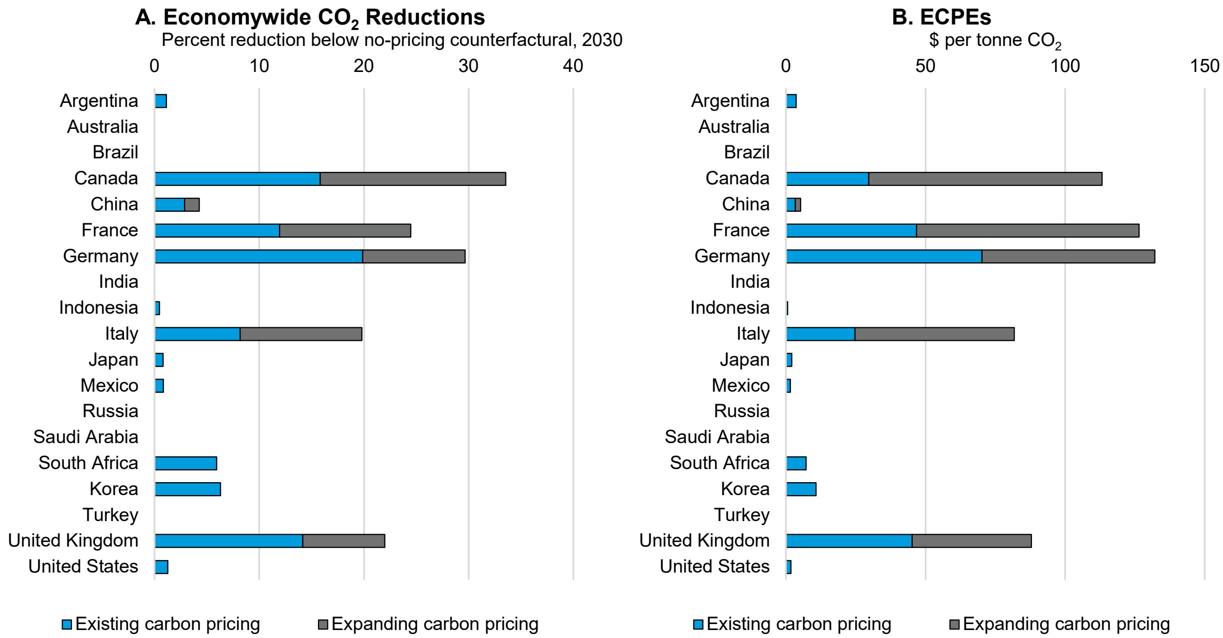
At the economywide level, these explicit carbon pricing schemes—under the BAU assumption of prices frozen at current levels—imply 2030 emissions would be between 1 percent (Japan) and 20 percent (Germany) lower than in the absence of this pricing. Accounting for expected increases in emissions prices to 2030 implies further reductions of 8-13 percent in France, Germany, Italy, and the UK and 18

[5] Prices are weighted average prices of covered emissions, and hence are the average price facing emitters.

[6] Specifically, coal and natural gas generators must meet separate emission rate standards.

percent in Canada. On this basis ECPEs exceed $80 per ton in five cases (Canada, France, Germany, Italy, UK) but are around $10 or less in six other countries with pricing policies. See Figure A2.1.

Figure A2.1. Mapping of Explicit Carbon Pricing



Source: IMF Staff using CPAT.

Other Policies in G20 Countries

Power. All G20 countries have targets for the future share of renewables in power generation and corresponding policies intended to make headway on these targets (see Table A2.2). Multiple and overlapping instruments, which either explicitly or implicitly subsidize renewables relative to other generation technologies, are commonly used including feed-in tariffs, renewable portfolio standards, net metering (allowing households to sell renewable energy to the grid), and investment or production tax credits for renewables. Country-specific policy instruments are not modelled here, given the impracticality of decomposing their individual impacts—instead, countries are assumed to achieve their renewable generation shares for 2030.[7] Eight G20 countries have also pledged to phase out coal-fired power generation including, in five cases, a complete ban on or before 2030. In modeling these combinations, the CO_2 reduction from the combined policies is compared with that from the renewables target alone to infer the additional emissions reduction from the coal phaseout—this

[7] Or linearly interpolated shares for countries with target dates beyond 2030.

avoids double counting emissions reductions but, given the ambiguity in attributing CO_2 reductions to the individual targets, the focus should be on the combined effect.

Table A2.2. Sector-Specific Targets and Policies for Power Generation, G20 Countries

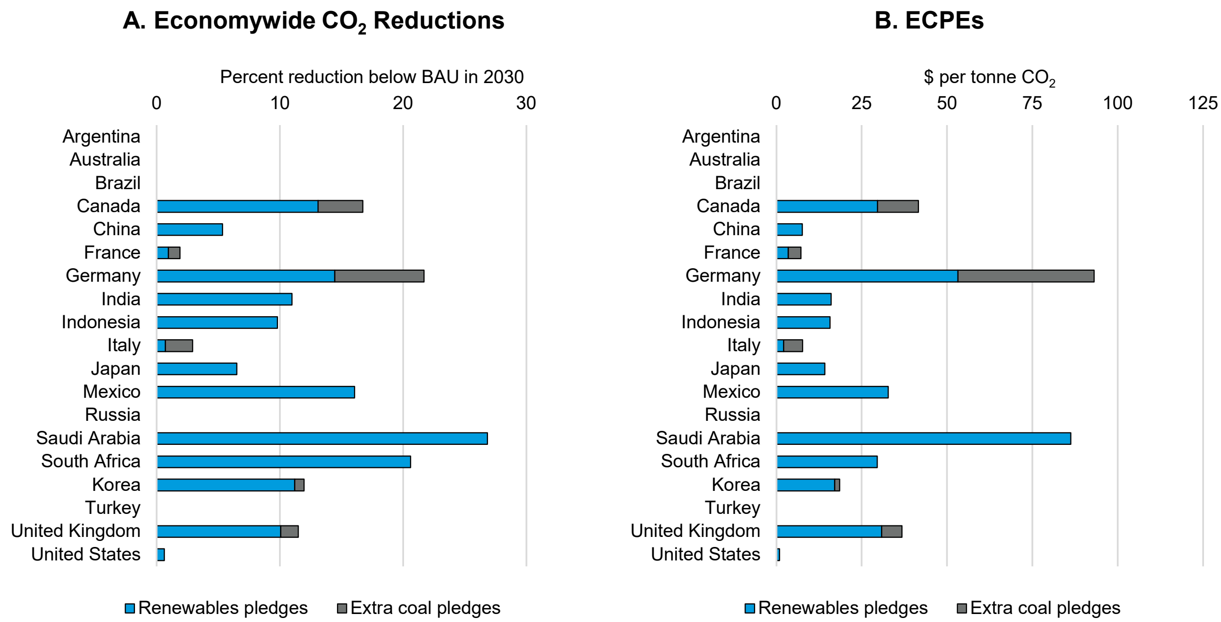
	Renewables							Coal	
	Generation shares, %		Regulatory and fiscal policies					Generation shares, %	
	2021	Future target (year)	Feed in tariff	Renewable portfolio standard	Tradable renewable energy credits	Net-metering	Investment or production tax credits	2021	Future target (year)
Argentina	27	20 (2025)[a]	●	●		●	●	1	
Australia	20	23.5 (2020)	○	●	●	○		51	
Brazil	83	n/a				●	●	5	
Canada	68	90 (2030)	○	○	●	○	●	4	0 (2030)
China	28	80 (2060)[b]	●	●			●	56	
France	22	40 (2030)[c]	●		●		●	1	0 (2022)
Germany	41	80(2030)	●		●		●	17	0 (2030)
India	22	50(2030)	○	●	●	○	●	64	
Indonesia	17	48 (2030)	●	●			●	51	30 (2025)[f]
Italy	41	55 (2030)	●			●	●	5	0 (2025)
Japan	21	36-38 (2030)	●		●			36	26 (2030)
Korea	5	30 (2030)		●	●	●	●	30	0 (2050)
Mexico	18	35 (2024)				●	●	5	
Russia	18	20 (2020)	●					9	
S. Arabia	0	50(2030)				●		0	
S. Africa	6	41(2030)		●				87	
Turkey	44	60(2030)[d]	●			●		19	
UK	39	100 (2035)	○	●	●			2	0 (2024)
US	19	28(2030)[d]	○	○	○	○	●,○	12	

Source: Black and others (2022).

Notes: [a]Argentina's target exculdes large hydro. [b] China also targets a generation share of 39% by 2025. [c] EU wide target. [d] Inferred from numeric targets. ●= national. ○=subnational.

At the economywide level, achieving stated renewables and coal phaseout targets for power generation would reduce CO_2 emissions by between 1 percent (US) and 27 percent (Saudi Arabia) below 2030 BAU levels, and (where targets bind) on average by 9 percent across countries (see Figure A2.2). The ECPEs of renewables targets vary between $1 per ton (US) to $86 per ton (Saudi Arabia) and average $24 per ton. The additional effects on the ECPE of coal phaseouts on top of renewables targets are mostly quite modest, at $13 per ton or less, except in the case of Germany, where the ECPE increases from $53 to $93.

Figure A2.2. Mapping of Power Generation Targets



Source: IMF Staff using CPAT.

Industry. Beyond carbon pricing (and fuel taxes), there is little in the way of concrete policies for the industrial sector in G20 countries. Eight countries have targets for reducing CO_2 or energy intensity of industry (see Table A2.3) though in four cases these targets overlap with explicit carbon pricing. Implementing industry emissions targets would reduce economywide CO_2 emissions most significantly in the UK and Germany (about 10 and 5 percent below BAU levels in 2030 respectively with ECPEs of about $100 and $50 per tonne) and more moderately in other cases (2 percent or less in Canada and Japan with implied ECPES of $10-20 per tonne).

Table A2.3. Sector-Specific Emissions Targets for the Industrial Sector, G20 Countries

	Target
Australia	Reduce the energy intensity of industry 30 percent between 2015 and 2030.
China	Peak aluminium and steel CO_2 emissions by 2025, and reduce them 40 and 30 percent, respectively from that peak by 2040.
France	Reduce (all GHG) emissions from industry 37 percent by 2030 relative to 2019.
Germany	Reduce CO2 emissions 49-51 percent below 1990 levels by 2030
Japan	Reduce industrial energy consumption 1 percent a year.
S. Africa	Reduce energy consumption of manufacturing 16 percent below 2015 levels by 2030.
Turkey	Reduce energy intensity by at least 10 percent in each sub-sector by 2023 (2011 baseline)
UK	Reduce CO2 emisisons 67 percent below 2018 levels by 2035.

Source: Black and others (2022).

Transportation. Aside from fuel taxes (see below), common emissions abatement approaches for light-duty vehicles are standards for the average CO_2 per km of producers' overall sales fleets, or (similarly) for average fleet fuel economy. One or other of these policies applies nationally in nine G20 countries, and at the EU level, and have been gradually tightened over the last two decades. Standards in 2020 varied from the equivalent of around 100 grams CO_2 per km in EU countries and Korea to 140 grams CO_2 per km in South Africa and are scheduled to continue tightening (Table A2.4). Feebates—applying fees to the purchase of emissions-intensive vehicles and subsidies for relatively clean vehicles—promote similar behavioral responses as CO_2/km standards.

Table A2.4. Vehicle Emission Rate Targets, Electric Vehicle Targets, and Fiscal Incentives in Vehicle Registration Fees, G20 Countries

	CO2/km		% EVs in vehicle sales		
	2020	Target (year)	2021	Target (year)	Additional incentives in registration fees (in US$)
Argentina					
Australia			1	30 (2030)	EV luxury car tax threshold at $56,800 compared with ICE threshold of $49,370.
Brazil	125	119 (2022)	<1		
Canada	123	100 (2026)	4	100 (2035)	Feebate: $4,000 subsidy for EVs, taxes on ICEVs rising to $3,200.
China	116	72 (2030)	6	100 (2035)	Feebate: $4,000 subsidy for EVs, taxes on ICEVs risng to 40% of base prices. 10% sales tax exemption for EVs.
France	100	61 (2030)	11	100 (2030)[a]	Feebate: $7,000 subsidy for Evs, taxes on ICEs rising to $12,000.
Germany	100	61 (2030)	14	100 (2030)[a]	Feebate: $7,000 subsidy for Evs, taxes on ICEVs rising to $5,000.
India	114	112 (2022)	<1	30 (2030)[b]	Subsidy up to $137/kWh for EVs <$20,455, general sales tax reduced 28% to 5%.
Indonesia			<1	numeric (2025)c	EV luxury tax exemption.
Italy	100	61 (2030)	4	100 (2030)[a]	Feebate: $4,600 subsidy for Evs, taxes on ICEs rising to $3,000.
Japan	106	92 (2030)	<1	100(2035)	Feebate: $7,000 subsidy for Evs, rising environmental preformance tax on ICEVs.
Korea	98	84 (2030)	3	numeric (2025)[d]	EV subsidy up to $17,000; excise tax reduction up to $2,700; acquisition tax reduction up to $1,200.
Mexico	114	85 (2025)	<1	n/a[e]	
Russia				production (2030)[f]	5% purchase price subsidy on Russian-made EV up to maximum of $8,570.
S. Arabia				30 (2030)	
S. Africa	138	n/a	<1		
Turkey				numeric (2030)[g]	Special consumption tax reduced from 45%-160% to 10%-60% for ZEVs.
UK	100	61 (2030)	11	100 (2030)	Feebate: $2,000 EV subsidy, taxes on ICEs rising to $3,870.
US	123	100 (2026)	2	50 (2030)	$7,500 producer subsidy for EVs (for first 20,000 vehicles sold).

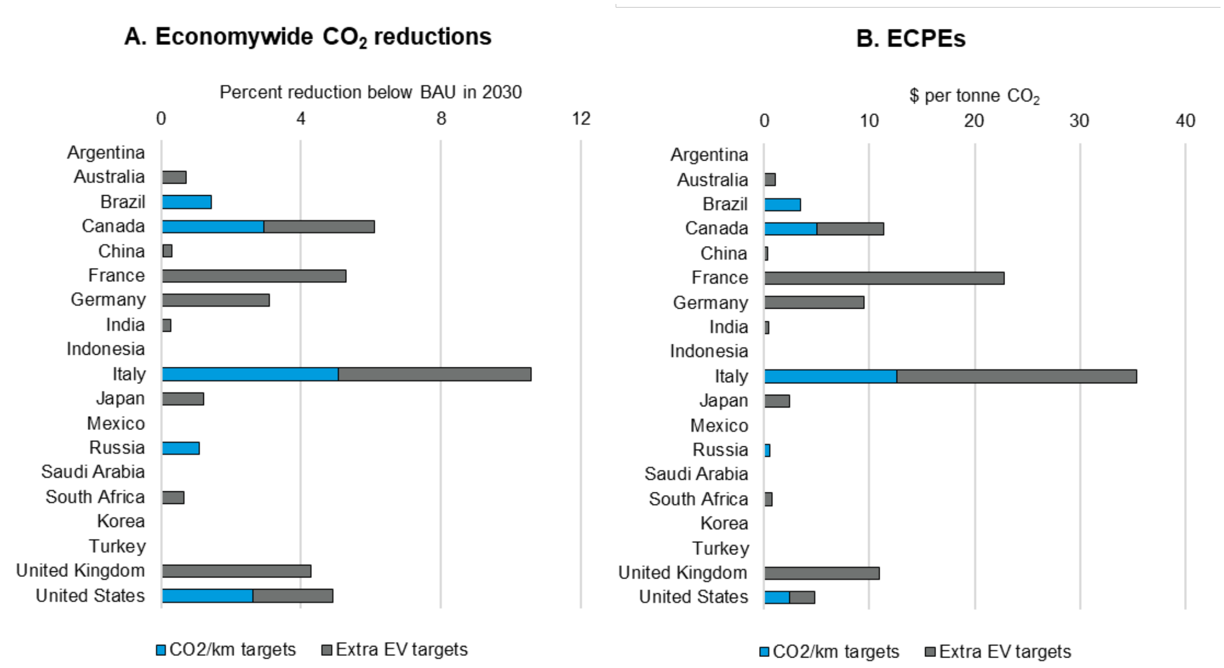
Source: Black and others (2022).

Notes: [a]EU wide target. [b]Target is for private cars. Target for commercial vehicles=70%, buses=40%, two and three-wheeler sales=80%. [c]Target of 2 million EVs in the passenger vehicle stock by 2025. [d]Target of 1.13 million EVs in the passenger vehicle stock by 2025. [e]No federal target but Jalisco, Mexico committed to 100(2030). [f]Annual EV production target of 220,000 units by 2030. [g]Target of 1 million EVs in the vehicle stock by 2030.

Nine G20 countries include some form of feebates into initial vehicle purchase tax systems (Table A2.4), with electric vehicle (EV) subsidies varying between $2,000 (UK) and $7,500 (US) and fees for high emitters rising to between $3,000 (Italy) and $12,000 (France). Again, given the overlapping nature of non-pricing transport policies, it is difficult to separate the individual impacts of regulations and feebates on emission rates—instead it is more practical to look at the emissions impacts from countries achieving their specified reductions in future CO_2/km. Targets for phasing in EVs or phasing out internal combustion engine vehicles (ICEVs) also apply in 15 G20 countries—indeed 10 countries have pledged to fully phase out ICEVs in new vehicle sales by 2030 or 2035.[8]

Achieving both CO_2/km and EV share targets combined would reduce economywide CO_2 emissions below 2030 BAU levels by 6 percent or less in all but one case (Italy). These reductions are much smaller than those from the power sector, due to generally smaller proportionate reductions in sectoral emissions, the smaller share of light-duty vehicles in economywide BAU emissions, and that policies only affect new investment (whereas power sector policies affect both dispatch and investment). ECPEs of transportation targets are around $10 per ton or less aside from two cases (France, Italy). See Figure A2.3.

Figure A2.3. Mapping of Vehicle Sector Targets



[8] In computing the emissions effects, offsetting indirect emissions from the additional electricity used by EVs are not accounted for in this analysis but are generally modest.

Source: IMF Staff using CPAT.

Buildings. France, Germany, and Italy have targets for reducing energy use from the building stock, by 25-44 percent between 2020 and 2030, while six other G20 countries have zero emissions targets for new buildings by 2030[9] (in five cases) or later. Again, countries typically use multiple overlapping instruments (Table A2.5) including building codes, retrofitting incentives (e.g., for insulation), building certification programs, clean fuel requirements (e.g., phasing out fossil fuel heating systems in new buildings), performance standards and labelling schemes for household appliances.

Table A2.5. Sector-Specific Targets and Policies for Buildings, G20 Countries

	Targets	Policies					
	Target	Building Energy Codes for all Building Types	Retrofitting Incentives	Building Certification	Clean fuel requirements	Performance standards for household appliances	Appliance Labelling Scheme
Argentina				●[v]		●	●
Australia		●		●[m,v]		●	●
Brazil				●[v]		●	●
Canada	All new buildings net zero emissions by 2030.	●	●	●[v]		●	●
China	Green buildings to account for 50% of new urban buildings.	●	●	●[m,v]		●	●
France	Reduce building sector emissions 44% below 2020 emisisons by 2030; EU legislation requires all new buildings to be nearly zero energy.	●	●	●[m,v]	●	●	●
Germany	Reduce building sector emissions 43% below 2020 emisisons by 2030; EU legislation requires all new buildings to be nearly zero energy.	●	●	●[m,v]	●	●	●
India	Reduce energy use for new commercial buildings 50% by 2030.			●[v]		●	●
Indonesia	Reduce energy intensity ≥ 1% per year till 2025.*			●[v]		●	●
Italy	Reduce building sector emissions 25% below 2020 emisisons by 2030; EU legislation requires all new buildings to be nearly zero energy.	●	●	●[m,v]	●	●	●
Japan	All new houses net zero emissions by 2030.	●		●[m,v]		●	●
Korea	All new buildings net zero emissions by 2030.	●	●	●[v]		●	●
Mexico	Reduce energy consumption for all buildings 3.7% a year 2031-2050.	●	●	●[v]		●	●*
Russia		●	●	●[m,v]			●
S. Arabia		●	●	●[v]		●	●
S. Africa	All new buildings net zero emissions by 2030.	●	●	●[m,v]		●	●
Turkey		●	●	●[v]		●	●
UK	Reduce CO2 emisisons for all new buildings 75-80% by 2030.	●	●	●[m,v]	●	●	●
US	All new buildings net zero emissions by 2030.	●		●[m,v]		●	●

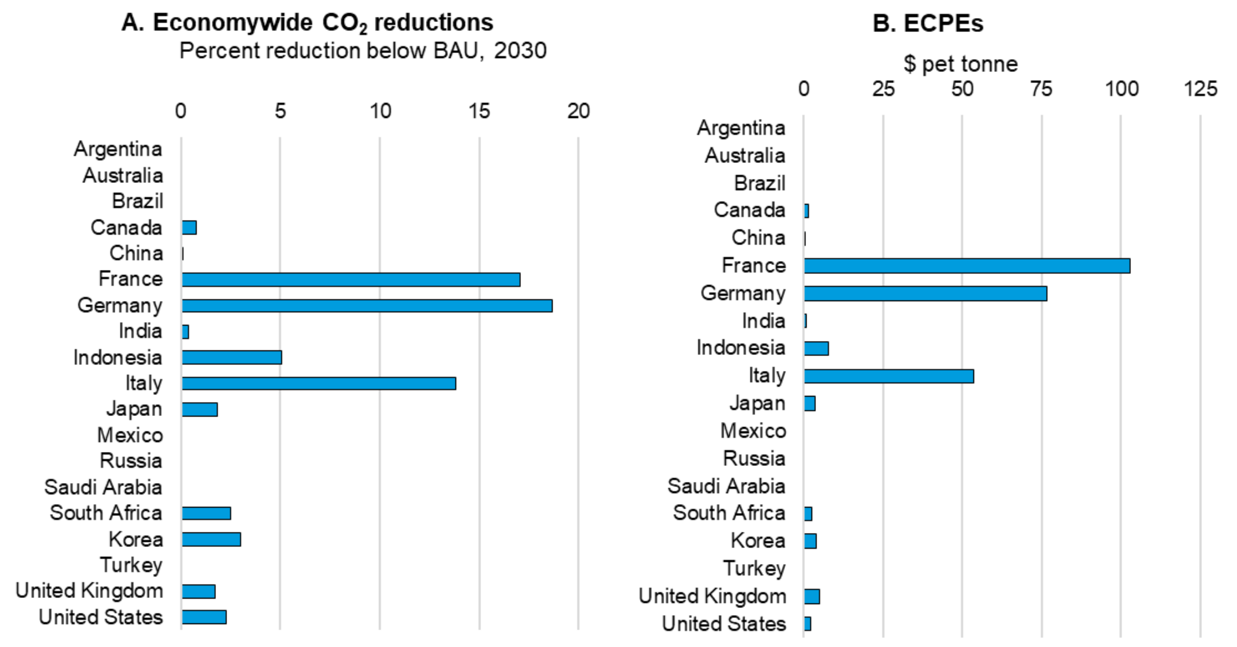
Sources: Black and others (2022).

Notes: ●= national policy.●[v]=widely voluntary. ●[m,v]= Partially mandatory, widely voluntary.

[9] That is, any net electricity use by buildings (after buying/selling to the grid) needs to be provided by renewable sources like solar panels.

At the economywide level, CO_2 emissions reductions from energy targets for buildings (Figure A2.4) for France, Germany and Italy are 14-19 percent below BAU levels, but they are 3 percent or less in the other cases where standards apply only to new buildings (given that less than 2 percent of the building stock is replaced each year and new buildings are already far more energy efficient than existing buildings). In the former cases ECPEs are $54-103 per tonne, while in the latter they are below $8 per tonne.

Figure A2.4. Mapping of Building Sector Targets



Source: IMF Staff using CPAT.

Fuel taxes. Fuel taxes and subsidies have been implemented historically for many reasons, usually unrelated to climate mitigation—for example, to raise revenue or address (albeit bluntly) local externalities like air pollution and traffic congestion. Tax rates (expressed in terms of their emissions-weighted charges per ton of CO_2) and subsidies vary considerably across fuels, sectors, and countries (see Table A2.6). For example, coal remains relatively untaxed across all countries and sectors, while gasoline and diesel account for much larger taxes relative to other fuels.

Scenarios for increasing individual fuel taxes are not considered because countries have not made specific commitments to significantly increase them over the next decade. Rather, the focus is on the ECPE implied by each country's set of fuel taxes or subsidies, which gives a sense of how a proportionate scaling up or down of these tax/subsidy schemes might enhance, or offset, the effect of an explicit carbon pricing scheme. Whether existing fuel taxes should be included in an assessment of countries' current ECPEs is not entirely clear. On the one hand, as noted these taxes have generally been imposed for non-climate-related reasons, taxes are not levied in proportion to carbon content, the impact of these taxes is already implicit in currently observed emissions, and if taxes remain unchanged, they will not contribute towards cutting emissions from current levels to levels consistent with future mitigation targets. On the other hand, fuel taxes are transparent and raise fuel prices, so they do act to reduce emissions compared to a scenario without them. These arguments apply conversely to subsidies.

Table A2.6. Excise Taxes by Fuel and Sector in 2020, G20 Countries

(expressed in charges per ton CO_2)[a]

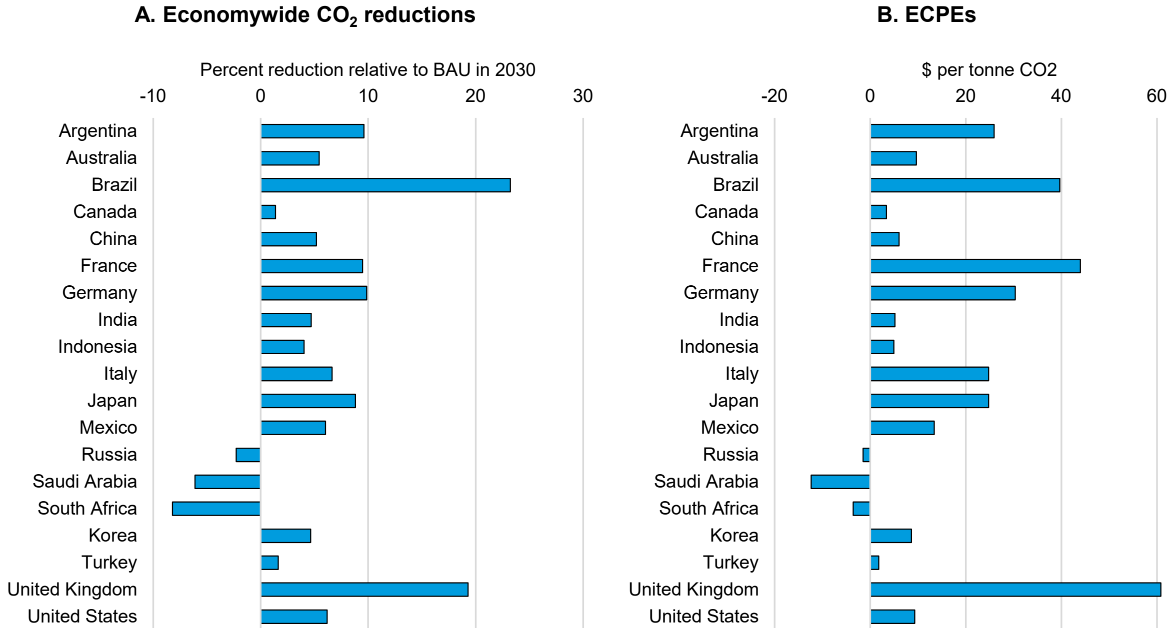
	power			industry			transportation[b]		buildings[c]	
	coal	natural gas	oil	coal	natural gas	oil	gasoline	diesel	natural gas	oil
Argentina	0	-31	19	5	0	33	105	45	-41	1
Australia	0	0	79	6	24	96	157	99	-54	68
Brazil	5	106	20	42	106	23	149	42	203	65
Canada	5	-34	14	5	-45	90	157	83	-9	97
China	3	70	6	4	70	35	168	65	-24	49
France	-7	113	79	29	111	192	377	262	93	208
Germany	14	-22	31	-3	-18	167	364	218	-60	213
India	4	-99	101	4	-99	50	232	130	0	-2
Indonesia	0	33	-7	0	11	-10	38	-11	-65	-93
Italy	-11	-51	7	16	-3	191	396	278	-120	201
Japan	0	-25	21	3	80	98	270	148	218	178
Korea	0	39	12	24	78	92	296	175	-43	108
Mexico	0	-16	8	1	0	44	112	103	-71	18
Russia	0	-34	2	0	-33	2	49	5	-158	-25
S. Arabia	0	-68	-13	0	-68	-26	-46	-159	0	-88
S. Africa	0	79	90	0	79	107	204	101	0	75
Turkey	0	20	0	5	14	43	219	74	-133	111
UK	20	-35	53	37	73	176	341	285	-103	93
US	0	0	10	0	0	39	71	46	-19	33
simple average	**2**	**2**	**28**	**9**	**20**	**76**	**193**	**105**	**-20**	**69**

Source: Black and others (2022).

Notes: [a]Tax rates include fuel excises and subsidies (VAT is excluded). [b]For light-duty vehicles. [c]For fuels used in residential buildings.

However, for reference, Figure A2.5 shows estimates of economy-wide CO_2 reductions implied by existing fuel taxes compared with a baseline of removing those fuel taxes by 2030 along with corresponding ECPEs. In most cases, fuel tax systems reduce economywide CO_2 emissions by around 5-20 percent or, where there are subsidies, moderately increase them by 1-6 percent. ECPEs are mostly in the range of $5-40 per ton, aside from countries like France where road fuels (subject to significant excise) are a large share of economywide emissions, and cases where are subsidized (e.g., Russia, Saudi Arabia, and South Africa) implying negative ECPEs.

Figure A2.5. Mapping of Fuel Taxes/Subsidies



Source: IMF Staff using CPAT.

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Annex 3: Climate policy options: A comparison of economic performance

Prepared by IMF staff[1]

May 9, 2022

[1] Jean Chateau, Florence Jaumotte, and Gregor Schwerhoff, with research support from Jaden Kim.

1. Introduction

While economists overwhelmingly recommend carbon pricing as the most efficient form of climate policy, other types of climate policy have great importance in practice. The idea of carbon pricing is to directly internalize the externality of carbon emissions. By using a price signal, market forces are employed to identify the most efficient measures to reduce emissions. Since carbon pricing is efficient and can be scaled up in a straightforward manner, economists recommend it as the best option (High-Level Commission on Carbon Prices 2017). In practice, however, a great variety of climate policies exist that can be used by themselves or in combination with carbon pricing (Nascimento et al. 2022).[2] One advantage of these other policies is that they do not appear as a new tax and their costs to economic agents are less visible than those of carbon pricing, making them easier to implement politically (Furceri, Ganslmeier, and Ostry 2021). Another rationale for these policies is that they can address bottlenecks or market imperfections that would limit the efficiency of carbon pricing. An example are subsidies for insulating buildings to overcome misaligned incentives in the sector. Another example are R&D subsidies to accelerate the development of low-carbon technologies in sectors where no low-cost clean alternatives exist yet. Finally, considering policy objectives beyond environmental and aggregate economic performance, such as distributional equity and minimizing the risk of an inefficient level of abatement in the presence of uncertainty, can also justify the use of a country-specific policy mix (Goulder and Parry 2008).

Understanding the economic effects of different climate policies is key both from a domestic and international perspective. From a domestic perspective, climate policies that generate a same emissions reduction can have different economic effects, such as on economic cost, employment, energy prices, fiscal accounts, energy security, and competitiveness. This raises important trade-offs. Understanding these trade-offs is key from a political perspective to design a policy mix that is optimal and tailored to a country's economic structure and political economy. From an international perspective, climate policies generate multiple spillovers, most prominently through trade and competitiveness, fossil fuel markets, and technology developments. These spillovers will depend on the extent of participation of other countries in the global mitigation effort, but also on the nature of policies used and the differences in economic structures across countries. Uneven climate policies across countries cause governments to be concerned about changes in economic competitiveness and loss of economic activity to countries with less ambitious policies and can hold back countries' efforts to mitigate. Understanding these spillovers is important to support an international dialogue and international coordination on climate policy.

This paper compares and quantifies the broad economic effects of different climate policies in major emitting sectors and countries. The analysis focuses on climate mitigation in the G7 countries (plus Europe) as well as China and India. It compares policy options for two major emitting sectors, namely the power sector and energy-intensive and trade-exposed (EITE) industries. In the power sector, it compares the effects of four alternative policies, namely a carbon tax on electricity generation, a direct regulation

[2] The descriptive literature on the comparison of climate policy instruments has established that a mix of policy instruments is necessary to achieve desirable outcomes across a set of relevant indicators. (Bennear and Stavins 2007) identify two reasons for using multiple policy instruments: multiple market failures and political constraints. (Vogt-Schilb and Hallegatte 2017) provide a systematic comparison for seven policy options across nine outcome variables based on a literature review. They conclude that a carbon price combined with sectoral policies which aim at long-term decarbonization (such as renewable energy targets), would perform well across the set of outcome variables.

on the fossil fuel share, a feed-in subsidy for solar and wind power generation, and a feebate system. In the EITE industries, it compares carbon pricing and regulation on the carbon emission intensity of the industry. The simulations are done across a range of outcome variables, including real GDP, investment, employment, household consumption, electricity prices, electricity supply, government revenues and spending, gross output and market shares of EITE industries, carbon leakage rates, and import bills of fossil fuels (as a measure of energy security). The model used in this paper is the IMF-ENV model, a dynamic and global computable general equilibrium (CGE) model, which endogenously determines a range of relevant policy outcomes and features a detailed representation of sectors and world trade.

2. The IMF-ENV model and scenario design

This section introduces the modeling setup. It first gives a brief description of the model used. It then describes the scenarios and adds some theoretical considerations on the effects to be expected in these scenarios.

2.1 The model

The model IMF-ENV allows to analyze the economic effects of climate policy options in a CGE perspective. IMF-ENV is a global, dynamic, and sectoral CGE model, see (Chateau, Jaumotte, and Schwerhoff 2022) for a brief description, especially Box 1. It is built on the ENVISAGE model (van der Mensbrugghe 2019) and the OECD ENV-Linkages Model (Chateau, Dellink, and Lanzi 2014). The model allows simulating impacts of climate mitigation policies on emissions, macroeconomic variables, sectoral outcomes, and trade. The model is based on a neo-classical framework, dealing only with real values and with almost perfect markets for commodities and production factors. One important feature of the model is that it has vintage capital. This captures the fact that while 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 long-term elasticities, which makes the adjustment of capital more realistic. The model also has a detailed sectoral and trade representation, making it well suited to study the effects of climate policy on trade and fossil fuel markets. Finally, the model relates directly emissions to economic activities. The model does not have heterogenous households, so that distributional effects within countries cannot be analyzed. Further, it does not have endogenous technology, so that technology spillovers cannot be modeled directly.

2.2 Scenario design

Two sets of scenarios are designed, scenarios for decarbonization of the power sector and scenarios for a deeper decarbonization of both power sectors and Energy Intensive and Trade Exposed (EITE) industries. We illustrate the results by assuming that only nine countries (the G7 countries as well as China and India) and the EU are acting. These countries are chosen as major emitters with different economic structures. We next present these scenarios but Box 1 also provides further detail on the implementation of the scenarios in the model.

Scenarios on decarbonization of the power system

Scenarios are designed to compare four policy options of equivalent stringency. The four policies are calibrated to achieve the same environmental outcome, namely the same cumulative decrease in CO2 emissions from fossil fuel combustion in power generation. These four scenarios are:

- Regulation on a clean energy standard: a regulation mandates a reduction in the share of fossil-based power by 20 percentage points relative to the baseline by 2030. Exceptions are France and Canada, which already have a very high share of low-carbon energy and hence are assumed to reduce the fossil fuel share by respectively 7 and 10 percentage points only.

- Carbon tax for power sector: a gradually increasing carbon tax for electricity generation is implemented, with the level of the tax calibrated to achieve the same path of CO2 emission reductions as in the regulation scenario.

- Feed-in-tariff for solar and wind power generation: the producers of wind and solar receive a subsidy in USD per unit of electricity, such that they sell electricity above their unit cost of production. The subsidy rate is assumed to be the same for solar and wind power. It is adjusted in each period in such a way that the resulting cumulative CO2 emissions for the power sector are the same as in the regulation policy.

- Feebates: a system of fees and rebates across electricity generation types is implemented. The system implies that electricity generation which emits more (less) than a given target of CO2 emissions per kwh will pay (receive) a fee (a rebate). The price of emission per KW/hr is adjusted in each period to guarantee same emissions reductions as under the regulation policy. The feebate system is balanced across electricity producers so that it is neutral on public finance.

To make this comparison fair in terms of fiscal resources used, all policies are designed to be budget neutral through changes in wage income tax rates (or VAT in a sensitivity analysis). This means that the feed-in subsidy is financed by raising wage income taxes, while revenue from carbon taxes is used to reduce wage income taxes.

Scenarios on decarbonization of Energy Intensive and Trade Exposed (EITE) industries

Climate policy in the EITE sectors is implemented as two types of carbon taxes and a regulation. Four EITE sectors are considered here to implement these targets: “Iron and Steel”, “Chemicals”, “Non-metallic minerals” and “Pulp and paper”.

The three “power and EITE sectors scenarios” are:

- Regulation for power and EITE sectors: CO_2 emission reductions are controlled i) by a regulation on the share of fossil fuels in the power sector (identical to the power regulation scenario discussed previously), and ii) by a regulation on the “direct” (scope 1) CO_2 emission intensity for each individual EITE sector. The mandatory regulations for the energy intensive industries assume linear reductions, starting in 2022, of each EITE sectoral emission intensity (“direct” CO_2 emissions per unit of gross output). The emission intensity is designed to decline by 20 percent below the baseline level by 2030.

- Uniform carbon tax on power and EITE sectors: the power sector and EITE industries all face the same carbon tax, as in an Emission Trading Scheme with permit auctioning. The level of the CO_2 tax is adjusted each year such that the joint annual total CO_2 emissions of power and EITE sectors are identical to the corresponding emissions in the “Regulation for power and EITE sectors” scenario.

- Segmented carbon markets: the scenario assumes two distinct carbon markets, one for the EITE sectors and one for the power sectors. The sectors thus have different carbon taxes, each of them is adjusted such that the emissions of the corresponding group of acting sectors are the same as in the “Regulation for power and EITE sectors” scenario.

Again, all these scenarios are budget neutral: the wage income tax rates are adjusted so that the policies are revenue neutral for the government. It should be mentioned that "non-ferrous metals" production is generally considered an energy intensive activity as well, but energy demand by this sector is mostly electricity, and not fossil fuels. For this reason, the regulation is not applied to this sector since its "direct" carbon intensity is low. But since it is still electricity intensive and therefore very sensitive to policies implemented in the paper, this sector is included as part of EITE sectors in the corresponding charts.

2.3 Theoretical considerations on economic cost

Both regulation and carbon pricing impose a permanent cost on the sector to which they are applied. When a sector (or firm) is subject to carbon pricing, it substitutes away from emissions to other factors of production until further substitution is as expensive as the carbon price. Similarly, regulation forces the sector to substitute inputs and thus operate at a more expensive input mix than the unregulated sector would. While the ongoing cost due to the carbon price are more visible, both types of climate policy are similar in the sense of imposing an ongoing cost on the sector.

Several factors influence the relative economic cost of carbon pricing and regulation. *On the one hand*, carbon pricing incentivizes the use of all margins of adjustment, and hence delivers a given emission reduction at the least cost. This is especially visible when the carbon price is applied to multiple sectors with different substitution possibilities. Carbon pricing will allocate emissions reductions to sectors with the greatest substitution possibilities, reducing the overall aggregate cost. Regulation will be costlier than carbon pricing (to achieve a given emission reduction objective) the more it implies heterogenous implicit carbon prices (and therefore heterogenous marginal abatement costs) across different emission sources. Designing smart regulation that avoids too stringent quantitative constraints on emission sources that are hard to cut and therefore entail high marginal abatement costs requires detailed sector-specific knowledge and entails potential for policy mistakes. *On the other hand*, carbon pricing imposes an additional cost, because the tax needs to be paid on remaining emissions. This means the sector has two types of additional cost compared to before the introduction of the carbon price: a slightly more expensive mix of production factors and the carbon price paid on remaining emissions. *Finally*, revenues from carbon pricing can be recycled into other cost reductions (e.g., lower wage tax) for the abating and other sectors, partly offsetting the cost from carbon taxation. The net effect will depend on the sectoral coverage of the carbon tax, the emission intensity of production and ease of substitution to alternative low-carbon technologies in the various sectors covered, and the use of carbon tax revenues.

Feebates share features with both regulation and carbon taxes. Like carbon taxes, feebates affect electricity generation from fossil fuels according to the carbon content. At the same time, just like the regulation, the sector as a whole does not have additional external payments under feebates, because fees and rebates net out. However, the internal pricing signals cause the sector to reoptimize production factors. Again, the resulting mix of production factors is more expensive than the production factors in the unregulated situation would be.

For feed-in subsidies, the rebound effect is an important influence on the overall cost. Feed-in subsidies impose a cost on the economy, if not on the targeted sector, because they need to be financed by increased taxes. Compared with the other policies which aim directly at reducing fossil fuel emissions, they operate by making renewable energy cheaper. The rebound effect occurs when savings on energy cost cause an increase in energy consumption. If the government subsidizes the production of renewable energy, the supply of energy with a low cost to consumers increases. This reduces the equilibrium energy price and thus increases demand. As a result, the additional renewable energy does not replace fossil fuel energy fully, but only partially (Kalkuhl, Edenhofer, and Lessmann 2013). Due to this mechanism, displacing fossil fuels with subsidies to renewable energy requires a large subsidy, which causes a large cost to the government. Further, the feed-in subsidy does not differentiate incentives for different fossil fuels and hence does not use the option to switch from coal to gas to reduce emissions. Lacking this adjustment option is a further cause for the higher total cost of feed-in subsidies.

Additional factors influence the cost of climate policy but are not represented in the model. When technology is endogenous, the cost of a given input mix changes over time. The input factors which are employed most receive most R&D. A change in the input mix would thus redirect R&D and reduce cost over time. Another cost factor is the administrative and monitoring cost of the policies. However, IMF-ENV has neither endogenous technological change nor administrative cost. The cost of climate policies in the results below thus reflect only the cost differences due to changes in the mix of production factors, taxes and subsidies and their recycling or financing.

2.4 Political economy

The political feasibility of climate policy requires comparing policy options across more variables than just aggregate GDP effects. The aggregate economic effect is a major focus of climate policy, because when economic losses are minimized, redistribution should allow the government to achieve an optimal allocation of resources within the economy. However, political economy effects require additional considerations. One consideration is that energy prices are very visible and can elicit a broad mobilization against policy reforms which cause these increases. Energy prices are thus an important additional consideration because policies which minimize economic losses cause higher energy prices. Another consideration is that energy intensive and trade exposed (EITE) industries are aware that climate policy can put them at a disadvantage with international competitors. This is not a major consideration for the economy as a whole (Chateau, Jaumotte, and Schwerhoff 2022), but EITE industries are politically influential. Given these two considerations, we compare the effects of the policy options for energy prices and market shares of the EITE sectors in addition to aggregate GDP.

Section 3 presents the results of scenarios on the decarbonization of power systems, and Section 4 those on the joint decarbonization of power systems and EITE industries. Section 5 elaborates further on the international spillovers, discussing carbon leakage rates, considerations on energy security, and competitiveness effects under different coalition size and policy mixes.

3. Decarbonization of power systems under alternative policies

We compare scenario outcomes for all politically relevant indicators available in the model. Since the policy measures are implemented in the electricity sector, we begin the scenario comparison with the electricity mix, electricity prices and total electricity supply in Section 3.1. Given that the direct effect of the policies has different fiscal impacts, we next discuss fiscal effects in Section 3.2. In a third step, we evaluate the aggregate macroeconomic effects in terms of GDP, investment, household income and employment in Section 3.3. In Section 3.4 we conclude with the effects on competitiveness, which have a considerable relevance for the political economy of climate policy.

Carbon pricing, regulation and feebates achieve similar macroeconomic outcomes, but feed-in subsidies have the advantage of reducing energy prices. The comparison in climate policy outcomes in this paper is in line with standard results on climate policy in that carbon pricing generates in most cases the least aggregate economic cost (High-Level Commission on Carbon Prices 2017). The effects of carbon pricing on GDP, household income and employment are better than for all other climate policies. The reason is that carbon pricing leaves the most flexibility to the economy to implement emission reductions. The regulation and feebates, however, perform almost as well and are thus attractive alternatives if they are more feasible politically. Feed-in subsidies have a higher aggregate cost because they require an increase in the overall level of taxation and thus more distortions. If electricity prices are a political focus, all three alternatives might be better than carbon pricing, although even carbon pricing increases electricity prices by less than 10 percent.

3.1 Policy instruments

Differences in power systems and economic structures imply very different magnitude of policy tools, even with a similar environmental target. Table 1 shows that while the policies in all countries achieve similar economy-wide emission reductions across countries (second column), the level at which they need to be implemented varies. A regulation that requires a 20-percentage point decline in the share of fossil fuels in all countries translates into carbon prices (third column) that vary from 13 USD in China to 67 USD in the UK. Differences in the level of carbon taxes reflect differences in opportunities for cheap abatement (higher in countries starting with a high fossil fuel share) and differences in the stringency of the targets (conditioned on the initial level of the renewable share). For feed-in tariffs, only the data for solar energy is shown, the numbers for wind energy are similar. The subsidies for wind and solar are in the range of 22 to 45 percent of the production cost, with highest values for France and Canada which have already very high levels of low-carbon technology. Feebates add a fee on fossil-based power, proportional to their carbon content, and subsidizes non-carbon electricity (for sake of simplicity only the values for coal and solar are shown in the last two columns). The rebates paid to solar energy are all below 10 percent of production cost, showing how competitive solar energy already is. The level of the fee on coal is inversely proportional to the share of coal power in electricity mix: with a large share of coal, a low fee is sufficient to generate sufficient revenue for financing low-carbon electric generation.

Table 1: Power scenarios: Policy stringency in 2030

Policy in 2030	Economy-wide CO_2 emission reduction[#]	Additional carbon tax	Feed-in tariffs for wind and solar	Rebates for Solar power (in feebate)	Fees for Coal power (in feebate)
Unit	Percent deviation from Bau	2018 USD/t of CO_2	percent of unit production cost	percent of unit production cost	percent of unit production cost
Canada	-5.5	39	-45	-4.2	44
China	-12	13	-28	-8.8	15
France	-6.5	43	-36	-1.6	26
Germany	-13.6	45	-31	-6.3	25
India	-14.5	15	-22	-6.3	7
Italy	-7.6	63	-33	-4.2	32
Japan	-11.2	38	-22	-4.1	12
UK	-10	67	-26	-0.9	21

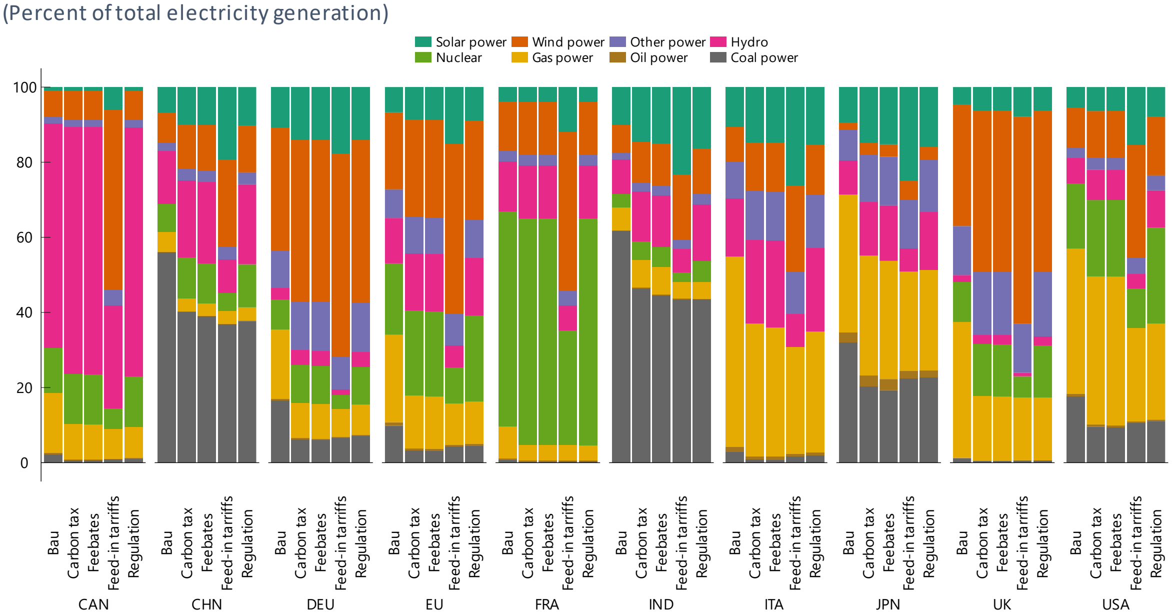
USA	-10	17	-30	-3.3	18

Source: IMF-ENV model.
Note: The carbon tax reported here is the additional price of CO_2 relative to baseline needed to generate the same emissions for the power sector as under the "regulation" scenario. Feed-in tariffs also present subsidy rates as difference from baseline level. # The Economy wide CO_2 emissions reductions are for the scenario "regulation".

3.2 The electricity sector

While emission reductions in the power sector are the same across policies by scenario design, the energy mix changes in different ways. The regulation to reduce the share of fossil fuels by 20 percentage points (except for France and Canada) is directly visible in Figure 1. In the other three policy scenarios, the options to adjust the electricity mix are used differently. The carbon tax, for example, generally causes a lower reduction in the fossil fuel share. The reason is that the emissions reductions are achieved not only through a shift from fossil fuels to low-carbon energy, but also by fuel switching, in particular from coal to gas. The feed-in subsidy is designed to support only wind and solar energy. As a result, the emission reductions are achieved by boosting these two sources—even though they may not be the most cost-effective for all countries. This contrasts with the regulation which limits the use of fossil fuels, but allows all low-carbon options, including hydropower and nuclear power, to expand. Feebates generate an energy mix which is very similar to that of the carbon tax. This is not surprising, because feebates change the relative price among the energy sources depending on their carbon intensity, as does carbon pricing.

Figure 1: Power scenarios: Changes in Power mix in 2030
(Percent of total electricity generation)

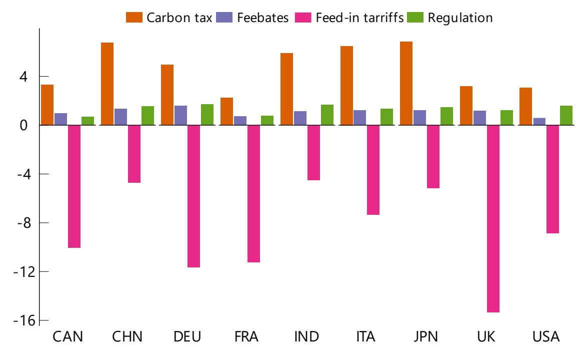


Source: IMF-ENV model.

The construction of additional natural gas capacity is not consistent with net zero emission targets. As mentioned above, a carbon tax incentivizes fuel switching, that is, moving to fuels with a lower emission intensity. An important example for this is the United States, which can reduce the use of coal by expanding the use of natural gas, to which it has access through fracking technology. However, it is important to note that the analysis here focuses on the year 2030. The United States government has committed to reaching net zero emissions by 2050 (US Department of State 2021). Building additional capacity for generating electricity with natural gas would not be consistent with the net zero goal, because this kind of infrastructure is typically used for 40 years or more. If the US were to use carbon pricing as its main climate policy strategy, it would implement a steadily increasing price path until 2050, which would make a large-scale switch to gas unattractive. An expansion of gas capacity would also be inconsistent with President Biden's goals to create a carbon pollution-free power sector by 2035.[3] An accelerated exit from fossil fuels might cause stranded assets (Mercure et al. 2018), but expanding capacity in natural gas risks causing more stranded assets later. A precise understanding of stranded assets requires a detailed analysis of the age distribution of the fleet of electricity generation capacity, which is beyond the scope of a CGE model.

Carbon prices increase the electricity prices the most, while other policies have more muted effects or even decrease prices substantially in the case of feed-in tariffs. Carbon prices increase the electricity prices the most, despite making use of all the possible margins of adjustment, see Figure 2. These margins include a switch to all kinds of less carbon intensive energy sources (as we have seen above). The comparably high effect on prices results because the carbon tax keeps taxing emissions that have not been abated. France excluded, price increases are between 3 and 8 percent, with lower values in the US and UK and higher values in China, India, and Japan where the power sector is more fossil fuel intensive. Regulation and feebates also tend to increase the electricity price, but by much smaller amounts. Regulations put a restriction on the electricity market, which increases the cost of electricity production. Under feebates, the impact of the fee on fossil fuels is broadly offset by the subsidy on low-carbon energy, but not fully so. The remaining price increase is due to a forced switch to electricity sources with higher cost. Feed-in subsidies, by contrast, provide additional resources to the sector. As a result, prices fall by 5 to 15 percent depending on the country. In the interpretation of the higher prices, we also need to take into account that the policies affect household income differently through the financing of the policies, as discussed below. In the carbon tax scenario households benefit from a tax reduction while under feed-in subsidies households have less income due to higher taxes.

Figure 2: Power scenarios: The effect of policies on electricity prices in 2030
(Percent changes with respect to baseline)

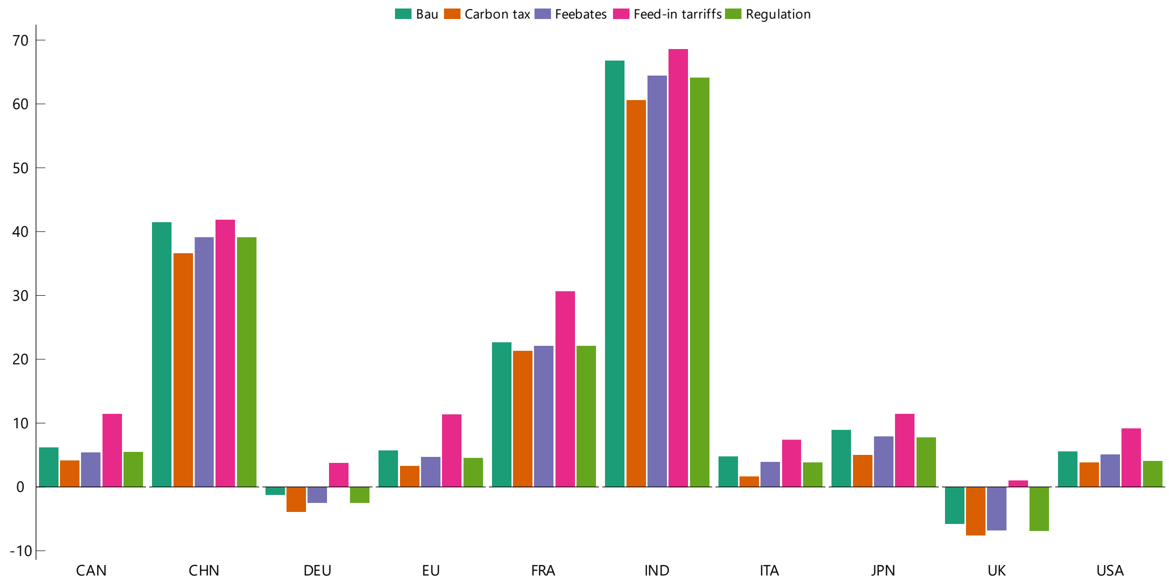


Source: IMF-ENV model.

Policies which increase electricity prices decrease electricity supply and vice versa. Figure 3 shows electricity generation in deviation from the 2021 level. The fast-growing countries India and China have the highest growth in electricity generation. Feed-in subsidies increase electricity generation compared to the baseline (BAU) scenarios throughout. All other scenarios incentivize a moderate increase in energy efficiency. The carbon tax, which increases the electricity price the most, also has the lowest supply. However, changes are quite close to BAU in all cases. The policy scenarios chosen here are designed only for the electricity sector. In the case of economy-wide climate policy, end-uses like transportation would electrify. Electrification would cause an increase in electricity generation for all policy options.

[3] https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/

Figure 3: Power scenarios: The effect of policies on the electricity supply in 2030
(Percent deviation from 2021)



Source: IMF-ENV model.

3.3 Fiscal implications

While the introduction of carbon taxes allows the reduction of other distortionary taxes, the financing of feed-in subsidies requires an increase in other taxes. To ensure a fair comparison, the model implements all policies as budget neutral in the sense that (real) government expenditures are the same in all scenarios. Carbon taxes, for example, generate government revenue, see Table 2. That revenue can be used, if the budget is kept balanced, to reduce other taxes, for example labor income taxes and VAT.[4] Table 2 also shows that feed-in subsidies generate a cost between 0.3 and 0.8 percent of GDP depending on the country. This needs to be financed by increasing other taxes (see last column). However, even policies which do not affect tax rates might still change tax bases. If that happens, the model adjusts tax rates in such a way that the policy is again revenue neutral. As a result, even regulation and feebates cause changes in the composition of government revenue. The change in other taxes is reflected in net household income. This means that the higher electricity prices caused by carbon taxes are compensated by higher net earnings for households and vice versa for feed-in subsidies.

[4] For China, it appears that despite extra revenues from the carbon tax, it is not possible to reduce the labor tax. This is because the carbon tax implies GDP losses that reduce tax bases and therefore to keep the budget balanced, the government needs to increase tax rates.

Table 2: Tax changes for carbon tax and feed-in subsidy scenario

	Carbon Tax Scenario		Feed in subsidy Scenario	
	Carbon tax revenue in percent of GDP	Change in Labor Tax rate (percentage point)	Feed-in subsidy expenditures in percent of GDP	Change in Labor Tax rate (percentage point)
Canada	0.02	0	0.7	1.4
China	0.09	1.7	0.4	3.3
France	0.01	0.1	0.4	1.7
Germany	0.02	0	0.3	1.5
India	0.4	-0.3	0.8	2.6
Italy	0.1	-0.2	0.3	1.1
Japan	0.19	-0.4	0.3	1.3
UK	0.02	0	0.4	1.7
USA	0.05	0	0.4	0.8

Source: IMF-ENV model.

The effect of climate policy on government revenue depends on the country's emission intensity and its ability to substitute between energy sources. India and Japan require particularly high carbon taxes (compared to GDP) to achieve the required emission reductions, because they cannot easily substitute away from coal. When the electricity sector has a high emission intensity, it needs to continue paying relatively high carbon taxes, even though it has achieved the targeted emission reductions. The more flexible electricity systems of Germany and the UK require taxes of only 0.02 percent of GDP. Among the countries with a low share of carbon taxes to GDP, Germany can switch relatively easily to renewables and the US to gas.

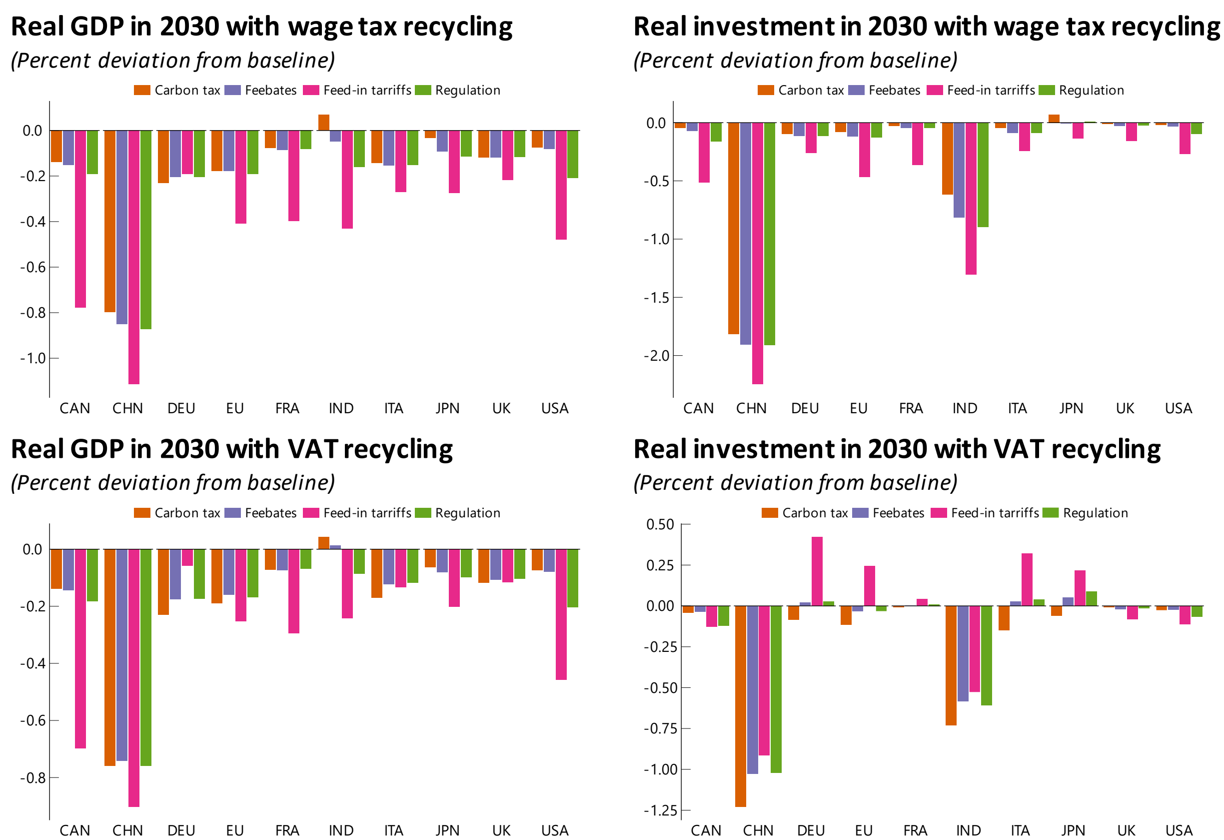
3.4 Macroeconomic implications

Economic costs are similar and small for the different policies, except for feed-in subsidies which are more costly. Figure 4 shows the effect of the different policies on GDP and investment when tax reductions (to recycle carbon tax revenues) or increases (to finance feed-in tariffs) are applied to wage taxes (first row), compared to a recycling through changes in VAT (second row). In almost all cases, a feed-in subsidy causes higher GDP losses than the other policy options.[5] This is for two reasons. First, the policy is less efficient at reducing emissions because it does not directly target the carbon content of fossil fuels and it creates a rebound effect in electricity consumption as it reduces the price faced by consumers. The subsidies must be financed by an increase in income taxes which increases the overall tax level, unlike the other policy options. Second, the cost is also higher because the policy is focused on solar and wind, which may not always be the most cost-effective sources of low-carbon energy and hence distorts the optimal mix of low-carbon energy sources. The other policy options (carbon tax, regulation, and feebates) have overall similar and smaller economic costs.

[5] It should be noted that Germany is an exception where feed-in tariffs perform well. But this result is not robust when a more significant decarbonization of the power sector is considered, reducing the fossil fuel share by 30 instead of 20 percentage points (see sensitivity analysis in sub-section 3.6 below).

Another striking result is that across countries, the cost of decarbonization is much higher for China than the other countries, no matter the policy considered. As shown later, Chinese and Indian EITE industries are much more affected by adjustment of the power system since the share of electricity costs in total costs of these industries are much higher than for G7 economies. Moreover, given the importance of EITE industries in the total Chinese economy (in terms of valued added share as percentage of GDP), China records the largest cost, even if the unit abatement cost in the Chinese power system is lower than in G7 countries.

Figure 4: Power scenarios: Impacts on GDP and investment for two types of revenue recycling

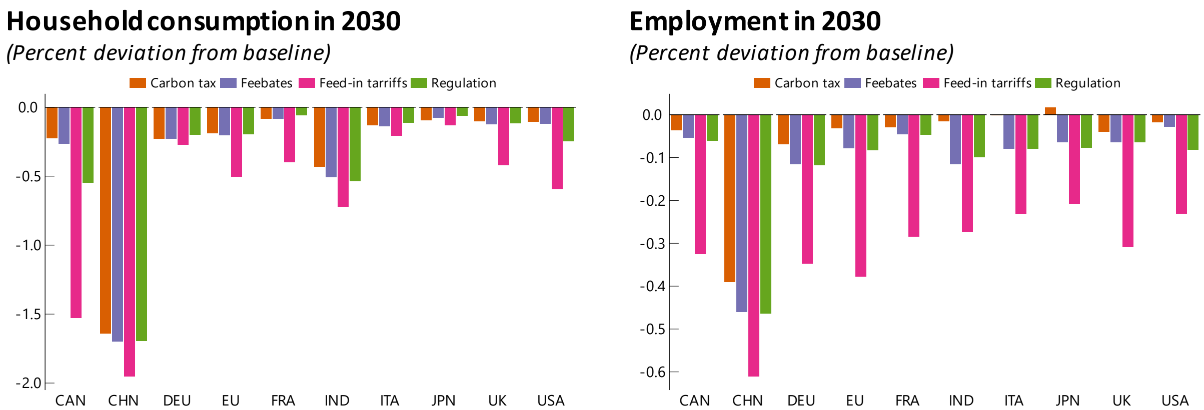


Source: IMF-ENV Model.

Implementing tax reductions through VAT instead of wage taxes causes a shift from consumption to investment in IMF-ENV. Under standard assumptions, a change in VAT has equivalent effects to a change in wage taxes, except that wage taxes can be designed to affect the degree of redistribution (Atkinson and Stiglitz 1976). As IMF-ENV has only a representative household, the two types of tax changes should thus not make a difference, because they affect the amount of consumption that can be purchased with a given amount of work in the same way. Nevertheless, investment behavior changes noticeably when tax adjustment is done via VAT instead of labor taxes, see Figure 4. With large VAT increases, like in the feed-in subsidy scenario, households observe the current increase in the price of consumption (relative to the price of the investment good) and therefore increase savings relative to consumption. This reflects the myopic expectations of agents in the IMF-ENV model. In a model with perfect foresight, households would also anticipate the future increases of prices for consumption goods compared to current prices and would therefore probably increase less current savings than they do in this model.

Carbon taxes are the policy option which is best suited for employment. All policy options have only a small effect on employment, see Figure 5. Carbon pricing has the lowest employment cost of all. In Japan, carbon pricing would even increase employment. The reason is that the carbon tax revenue is used to reduce labor income taxes, which reduces the gross cost of labor and hence provides an incentive to create employment. Feed-in tariffs have somewhat higher employment costs as they are financed by a larger increase in wage taxes (see last column of Table 2), which reduces the real income of households.

Figure 5: Power scenarios: Household consumption and employment



Source: IMF-ENV Model.

3.5 Competitiveness effects

The effect of climate policy on gross output in the Energy Intensive and Trade Exposed (EITE) sectors depends on the direction of energy prices and relative competitiveness changes. As we have seen above, climate policies cause a mix of higher and lower cost to firms, due to the revenue neutral design of the policies. For EITE industries, however, the energy prices are decisive (third panel of Figure 6). The impact on competitiveness, and output, of these industries will depend on relative price changes across countries.

Climate policies mostly reduce market shares of EITE industries for countries implementing climate policies in the power sector, but the effects are small. The scenarios assume that only the countries shown implement climate policy and all other countries don't. As a result, the acting countries tend to lose a small share in global trade of EITE goods, see the second panel of Figure 6. However, losses are limited to 0.3 percentage points given electricity is but one component of production costs. Losses in market shares are typically a bit larger under the carbon tax that increases electricity price the most, except for the US that gains market share due to greater use of low-cost gas with the carbon tax and France which implements smaller policies. Feed-in subsidies reduce electricity costs and producer prices in EITE industries in most countries. Therefore, acting countries as a whole are losing less market shares under this scenario. But due to the differentiation in price changes, some acting countries gain market share in EITE sectors and increase output consequently, while others lose market share and reduce output.

Across countries, China is experiencing the largest market share losses for EITE sectors for all policy options, because energy intensity for those sectors is higher than in high-income countries.

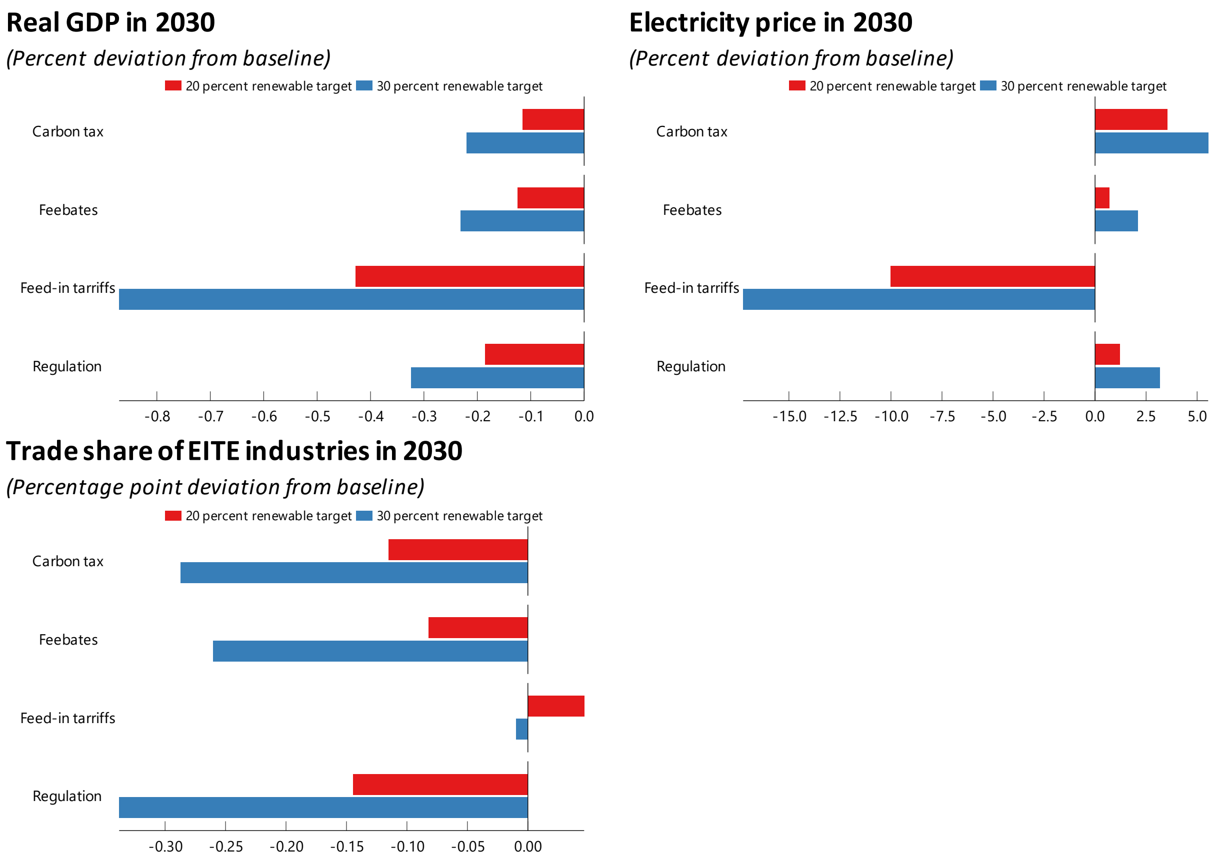
Figure 6: Power scenarios: Impact on EITE sectors

Source: IMF-ENV Model.

3.6 Ambition level

The ranking of policy options may depend on the ambition level. The ranking of climate policies regarding economic impact depends on many factors. One of these factors is the ambition level of the policy. Figure 7 compares the effect of the four policy options on three outcome variables for two different ambition levels. A decrease in the fossil fuel share by 20 percentage point has been implemented above. We compare these results to a 30 percentage-point decline in the fossil fuel share. Naturally, the higher ambition levels cause slightly higher losses in GDP and trade shares (although still well below 1 percent from baseline), as well as more extreme changes in the electricity price. While for the 20 percent target, carbon pricing causes a somewhat larger loss in trade shares than regulation, it is the other way around for the 30 percent target. This reversal in the ranking shows that the ranking at one ambition level cannot necessarily be transferred to other ambition levels. At higher ambition levels, the larger flexibility of the carbon tax proves to be a more important advantage.

Figure 7: Power scenarios: The role of policy ambition level for the ranking of policies for G7 countries



Source: IMF-ENV Model.

4. Decarbonization of industrial and power sectors with alternative policies

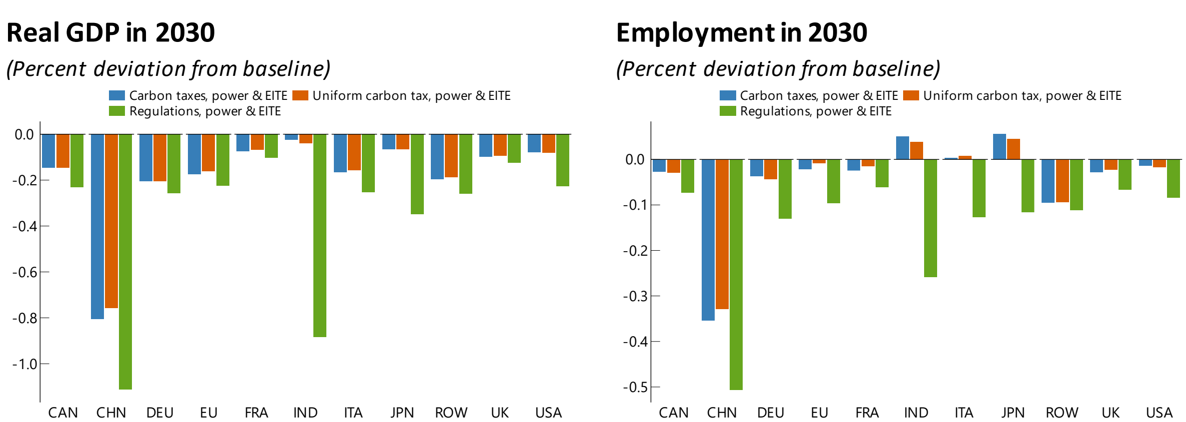
This section discusses scenarios where both power and EITE sectors face climate policy. It compares regulations to control power and EITE emissions and two types of carbon price systems as alternative policies to achieve the same emissions reductions. Under the regulation scenario, the emission intensity in four EITE sectors ("Iron and Steel", "Chemicals", "Non-metallic minerals" and "Pulp and paper") is mandated to decline by 20 percent below the baseline level by 2030.

The scenario comparison in the energy intensive industries is quite different from the electricity sector, mostly because the EITE industries are more difficult to regulate. There are many ways to produce electricity, but the product, electricity, is highly homogenous. In the EITE sectors, however, many different products are produced, both across subsectors and within. The ability for technical substitution varies strongly between sectors. Broad regulation requiring a same reduction in emission intensity for all EITE sectors affects the different sectors so differently, that meaningful emission reductions might cause strong disruptions in some of them. Avoiding this through sector-specific regulation requires detailed sectoral knowledge. This difference makes it relevant to analyze both types of sectors.

4.1 Macroeconomic implications

Regulation generally causes higher economic cost than carbon pricing in the EITE sectors. As shown in Figure 8, regulation causes higher GDP losses than a carbon tax in the EITE sectors in all countries. The reason is that for some of the EITE sectors, complying with regulation is extremely difficult. For these sectors, it is much easier to handle carbon pricing, because it gives them the option to simply pay the tax and adjust their production process only a little. With a carbon tax, emissions reductions are then larger in the EITE sectors where it is cheaper to abate, in particular in non-metallic minerals that embody a large part of CO_2 process emissions (left panel of Figure 9). In addition to reducing the aggregate economic cost, the use of a carbon tax—as opposed to regulation constraints—also leads to a more even distribution of economic costs across sectors (right panel of Figure 9). Linking carbon markets (*i.e.* uniform CO_2 tax) or not (*i.e.* two distinct CO_2 taxes) is of secondary importance.

Figure 8: Power and EITE sectors scenarios: Macroeconomic impacts



Source: IMF-ENV Model.

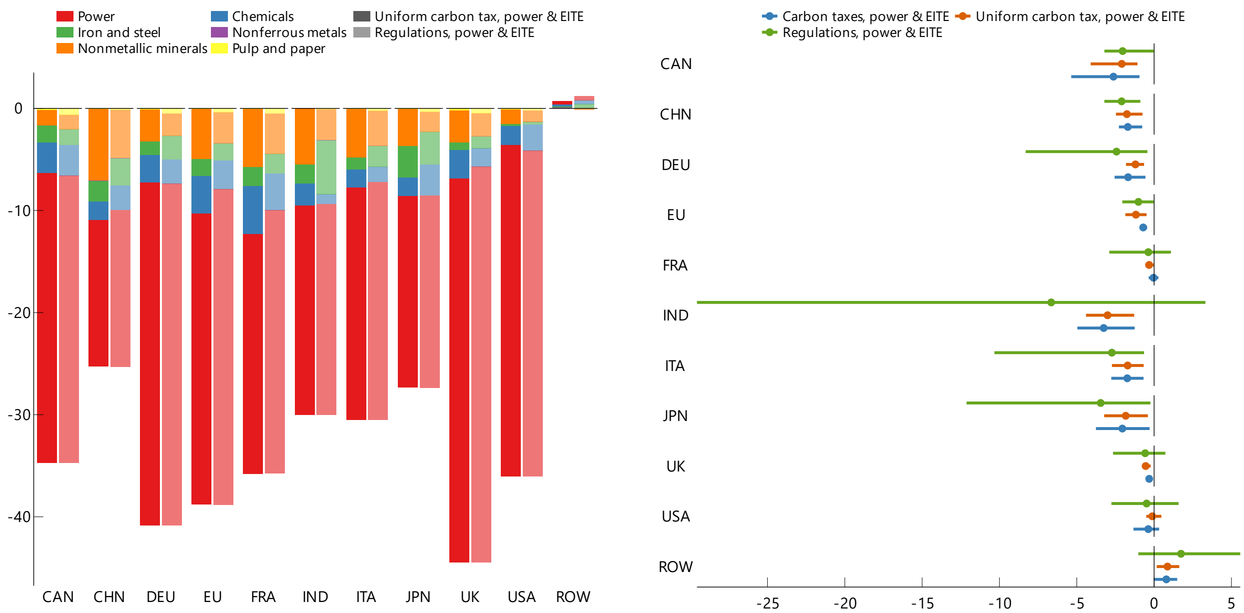
Figure 9: Power and EITE sectors scenarios: Sectoral results

Changes in power and EITE# *sectoral CO_2 emissions in 2030*

(Contribution to deviation of emissions from baseline)

Gross output of EITE industries

(Range of deviation from baseline across five industries)



Source: IMF-ENV Model.

Note: # Sectoral emissions for EITE reported here are only direct CO_2 emissions, indirect emission associated to electricity are reported in "Power". Sectoral CO_2 includes emissions from fossil fuel combustion, as well as process and non-energy related CO2 emissions.

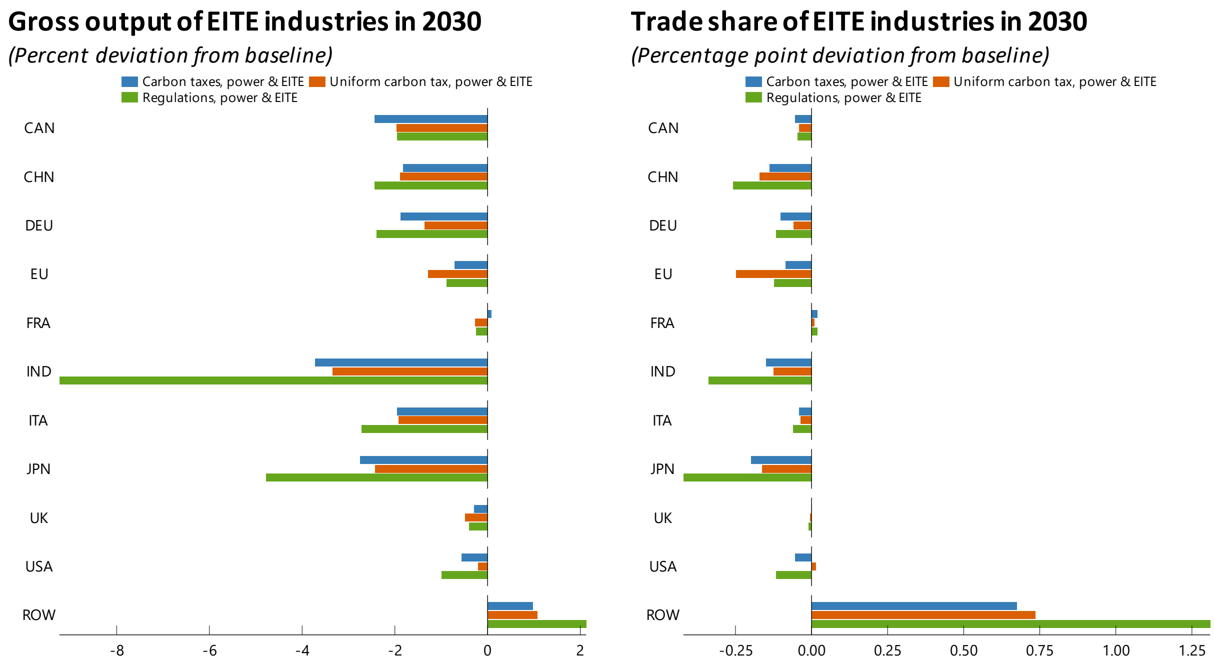
Across countries, China has the highest GDP losses, while India and Japan are the most sensitive to the switch from carbon taxation to regulation. Figure 8 shows that China has the highest GDP losses from decarbonization across all policy types. While the EITE sectors in China do not experience higher losses (in percentage changes) than the EITE sectors in other countries as shown below, the key difference is that these sectors account for much larger share of the economy in China (around 15%) than in other countries (5% on average for G7). The carbon tax generates very moderate GDP losses for all other countries. However, a switch to regulation would significantly increase the cost for India and Japan. Both countries have low-cost abatement options but, in both countries, there are individual sectors which cannot adjust to regulation well. This is the iron and steel sector in India and chemicals in Japan.

4.2 Competitiveness effects

The EITE sectors suffer larger losses in competitiveness when climate policy applies directly to them. Figure 10 shows the effect of climate policy on gross output and trade shares in the EITE sectors. Compared to the losses caused by climate policy in the electricity sector (Figure 6), losses in the EITE sectors are considerably larger. Note that the scale in Figure 10 is different from the scale in Figure 6. One reason is that Figure 10 shows the effect of climate policy in two sectors (electricity and EITE), while Figure

6 shows the effect of policy in only one sector (electricity). However, the most important difference is that the EITE sectors are, by definition, trade exposed. Changes in trade shares are driven strongly by the assumption that only the countries under consideration here implement climate policy. As a result, when climate policy is implemented both in the electricity and EITE sectors, the rest of the world (ROW) gains substantial market shares for EITE sectors at the expense of the acting countries.

Figure 10: Electricity and EITE sectors scenarios: Gross output and trade shares of EITE industries



Source: IMF-ENV Model.

Regulation is more damaging to competitiveness than carbon pricing, especially in Japan and India. Figure 6 shows that in several countries gross output losses in the EITE sectors are higher under carbon pricing than under regulation (note, however, that this does not apply to economywide GDP). When climate policy is applied to the EITE sectors directly, losses are considerably higher under regulation for the group of acting countries as a whole and for most countries (Figure 10). The negative impacts of regulation in the EITE sectors are particularly large for Japan and India. Each of these countries has a sector where regulation as designed here is prohibitively expensive. The carbon tax performs better because the burden of emission reduction is smoothed across sub-sectors, while regulation imposes very different costs to each EITE sub-sector. The cost smoothing channel is thus stronger than the effect of taxing the unabated emissions which caused the carbon tax to have higher cost in Figure 6.

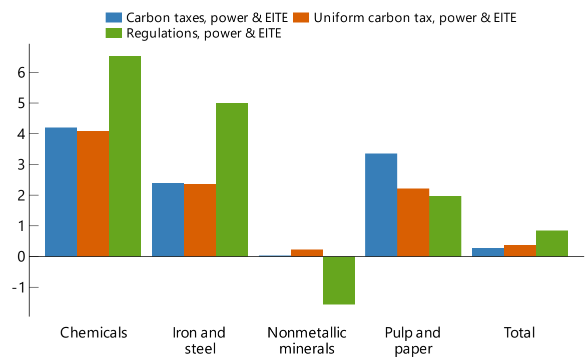
5. International Spillovers

In the last section, we analyze the interaction of climate policies between countries. Climate policy in one country affects economic outcomes in other countries through various channels. We discuss carbon leakage, energy security and the effect of diverse climate policies across countries.

5.1 Carbon Leakages

In total, carbon leakage is close to zero, mostly because the group of countries implementing climate policy includes the major global economies. Carbon leakage has the potential of undermining the purpose of climate policy. Whereas a loss in competitiveness affects the economic cost of climate policy, leakage might undermine the environmental effect of climate policy. It is therefore important for countries to understand the possible extent of leakage before implementing ambitious climate policy. Recent research shows that strategic behavior of firms could keep leakage to zero (Baccianti and Schenker 2022). Even without representing the strategic behavior of firms, the IMF-ENV simulations find nearly zero leakage for the total economy, see Figure 11. The reason for the low leakage rates is mainly that the scenarios assume that countries representing two thirds of global CO2 emissions implement climate policy jointly. There are thus not many countries to which emissions could leak, meaning that the competitiveness channel of carbon leakage remains limited. In addition, the second channel for carbon leakage, through the international fossil fuel market, is not very strong either, because the scenarios discussed here do not directly involve large changes in oil demand, as the emissions from transportation and housing sectors are not targeted.

Figure 11: Power and EITE scenarios: Leakage rates in 2030 (percent of emission reduction in acting countries)



Source: IMF-ENV Model.
Note: 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.

In the EITE sectors, leakage is at up to 7 percent in "Chemicals" and lower in all other sectors. The main reason for these low leakage rates is, as before, that the main producers of EITE goods are assumed to implement climate policy jointly. The effect of the choice of climate policy on sectoral leakage depends on the specific sub-sector. A common carbon tax identifies the cheapest abatement options across sectors, which might be concentrated in some sectors. Regulation, by contrast forces all sectors to reduce emission intensity by the same amount, which may impose higher costs and hence more leakage on sub-sectors with limited technical substitution possibilities.

5.2 Energy Security

Both regulation and carbon taxes increase energy security by decreasing fossil fuel imports, with more gains in terms of value under regulation. Climate policy affects the demand for the different energy sources. Each type of climate policy does so in a different way. Carbon taxes, for example discourage the use of coal more than the use of other fossil fuels, because coal has a higher carbon intensity per unit of energy. Regulation as implemented here, does not distinguish between the types of fossil fuels, and thus does not put an extra penalty on coal. The change in domestic demand directly affects imports since fossil fuel resources are unevenly distributed across countries. A reduction in fossil fuel imports translates into a higher level of energy security since low-carbon energy is mostly produced domestically. Figure 12 shows that imports of fossil fuels decline in all acting countries relative to the baseline. The declines in the volume of imports (in terms of oil equivalent) is similar in the two scenarios in all countries except for Italy and

India, see the right panel. However, the value of imports declines more under regulation because oil and gas are more expensive than coal for the same energy content, and the reduction in fossil fuel consumption is more tilted toward oil and gas under regulation than under carbon pricing.

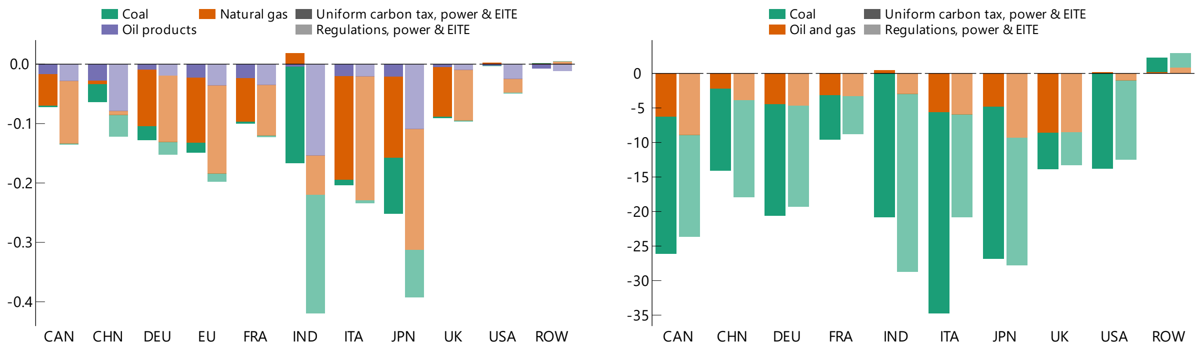
Figure 12: Power and EITE sector scenarios: Fossil fuel imports

Changes in import bills in 2030

(Constant USD, Difference from baseline as percent of GDP)

Changes in import volumes in 2030

(Mtoe, percent deviation from baseline)



Source: IMF-ENV Model.

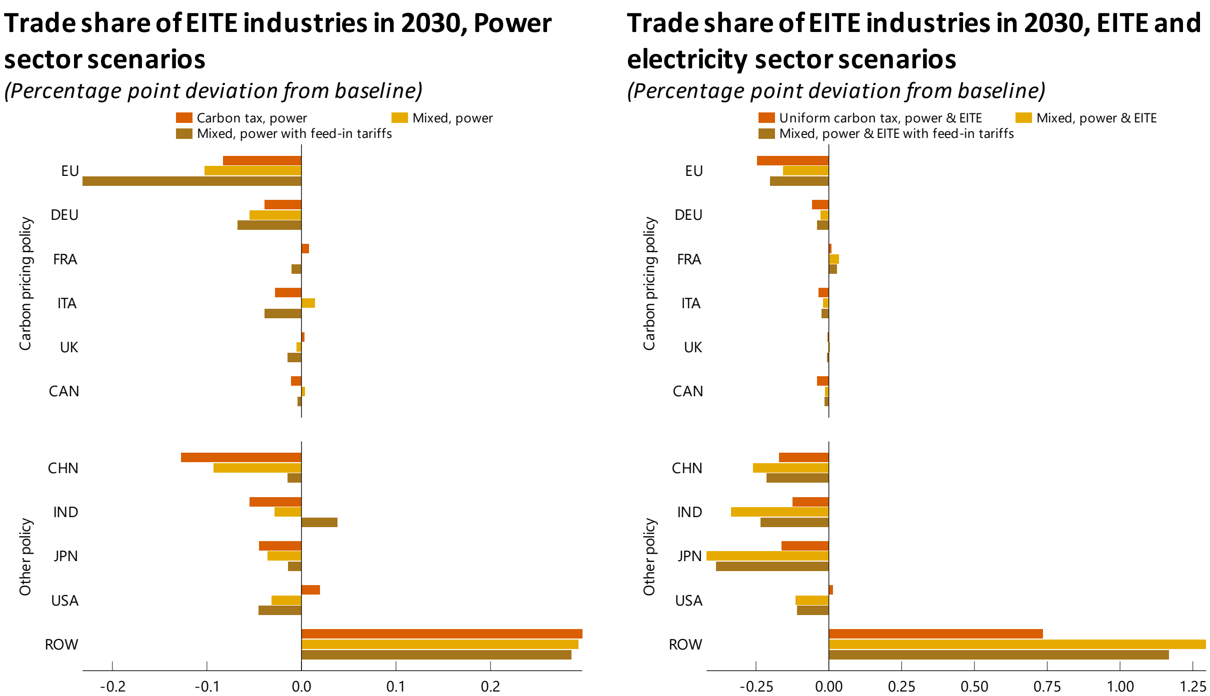
5.3 Diverse climate policies across countries

When acting countries adopt different climate policies, the resulting economic impacts differ from the cases where all countries implement the same policy type. To study the effect of different policy options in different countries we implement two "mixed policies" scenarios. The first one has EU countries, the UK and Canada implement carbon taxes, while the US, Japan, India, and China implement regulation. The second one assumes EU countries, the UK and Canada implement carbon taxes, while the US, Japan, India, and China implement feed-in tariffs in the power sector and regulation in EITE sectors. As before, the ambition level of the policy is similar across all countries. Figure 13 shows a comparison of the three scenarios, a carbon tax for all countries, and the two mixed scenarios.

For climate policy applied to the power sector only, most countries implementing a carbon tax face slightly higher losses in market shares of EITE industries. In the first mixed scenario, most of the countries implementing the carbon tax (except Canada) lose a little bit in terms of trade shares when other countries implement a regulation rather than a carbon tax, as shown in the left panel of Figure 13. As explained before, this is because the carbon tax keeps taxing emissions that have not been abated while regulation does not. However, of the countries switching to regulation, the US is much worse off with regulation than with a carbon tax because the carbon tax allowed them the flexibility to substitute coal with natural gas while the regulation imposes a given reduction in the fossil fuel share. It also causes the US to import more electricity from Canada. The increase in exports allows Canada to benefit from the US' switch from a carbon tax to regulation.[6] In the second mixed scenario, where other countries implement feed-in tariffs, the losses of trade shares for countries implementing the carbon tax are larger.

For climate policy applied to both power and EITE sectors, countries implementing a carbon tax are now slightly better off. Consider a switch from the uniform carbon price to the first mixed policies scenario in the right panel of Figure 13. The countries staying with carbon pricing increase slightly their trade shares while countries switching to regulation have lower trade shares, especially India and Japan. The reason for this development is that regulation is more expensive for EITE sectors, as discussed above, and in the scenario covering both types of sectors, this effect prevails. When these countries implement feed-in tariffs in the power sector while continuing to implement regulation in EITE sectors, it helps offset some of the negative effects of regulation in EITE sectors, but they are still worse off than under carbon pricing.

Figure 13: Mixed policy scenarios: Effect of policies on competitiveness of EITE sectors



Source: IMF-ENV Model.

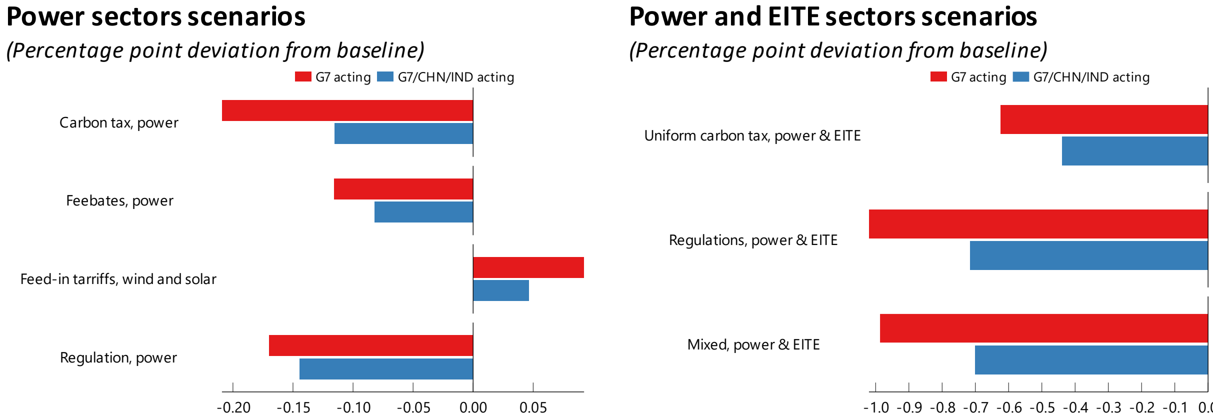
Note: On the left panel countries that implement carbon tax scenarios are ordered in the top of the charts, while other countries implement for power sectors either feed-in subsidies (brown bar) or regulation (yellow bar). In the right chart when EITE industries are also regulated countries on top implement carbon tax for both EITE and Power while countries at the bottom implement feed-in subsidies for power and regulation for EITE sectors.

Losses in competitiveness decrease in the size of the coalition. Figure 14 shows the effect of the coalition size on competitiveness losses. The figure compares competitiveness losses only for G7 countries but varies the size of the coalition implementing climate policy. The blue bars show results when only the G7

[6] These changes in EITE market shares however do not correlate closely with changes in aggregate GDP, reflecting effects through other sectors.

implement climate policy and the red bars show the results when India and China implement climate policy as well. The left panel focuses on the case where climate policy is implemented the electricity sector only, the right panel shows results for the case when climate policy is implemented in both the EITE and the electricity sectors. The losses vary by scenario, but they are always smaller when the larger coalition acts. The reason is that in the larger coalition, the additional countries do not free-ride on the efforts of the G7 countries by taking over some of their market share.

Figure 14: Losses in market share of G7 countries and the influence of coalition size



Source: IMF-ENV Model.

Note: The blue bars correspond to core scenarios where all G7, India and China are acting. The red bars show alternative scenarios where only G7 countries are acting.

Box 1. Power Sector and Power Policies in the IMF-ENV model

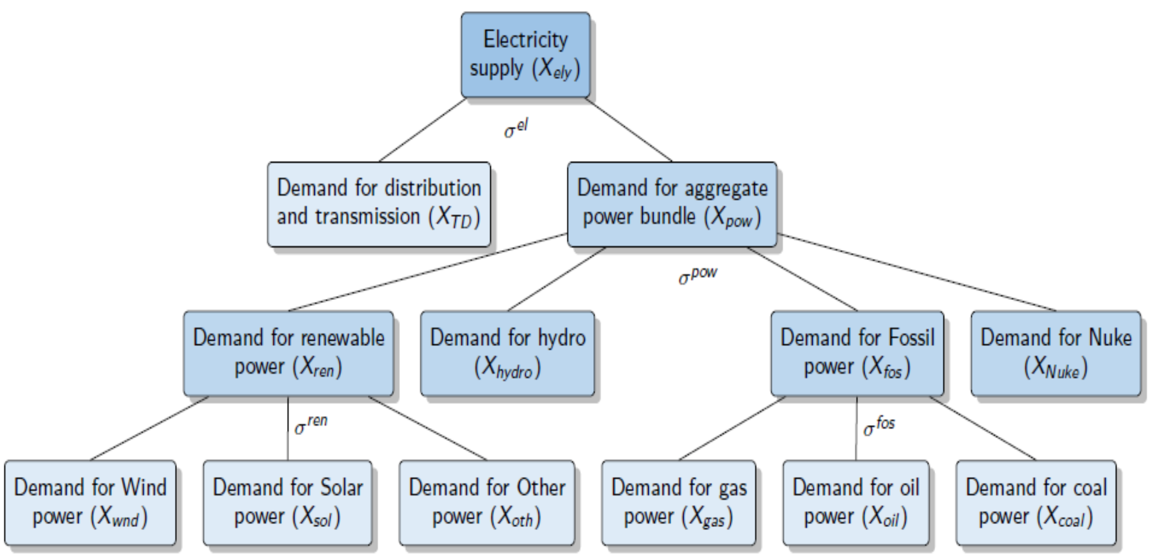
Representation of the power sector

The standard representation of electricity supply in each region r in the IMF-ENV model assumes that a representative electricity provider chooses an optimal mix of electricity generation across electricity generation technologies *a* = {solar, hydro, nuclear, wind, other renewables, oil power, gas power, coal power}:

$$Max\, X_{ely} \,.P_{ely} - X_{TD} \,.P_{TD} - \sum\nolimits_{a} X(a).p(a)$$
$$X_{ely} < F\big(X_{TD}\, ;\;\; X_{pow}(X(a_1), \ldots, X(a_n)\,)\big)$$

where the supply of electricity X_{ely} is a combination of X_{TD}, the demand for electricity transmission and distribution services, and the demand for power X_{pow}. Electricity generation $Xpow$ is a combination of electricity generation from various primary energy sources $X(a)$. $p(a)$ is the production cost by type of electricity generation technology, in USD per kilowatt hour.

The production function $F(.)$ is a nested CES function of electricity generated by the various primary energy sources *a.*



This box provides more detail on the design of the policy scenarios for the electricity sector discussed above.

Regulation on a Clean Energy Standard

The regulation scenario requires that a minimum share of electricity must be generated from low-carbon sources (all energy sources except fossil fuels). It is modeled as an additional constraint to the optimization described above, which imposes a minimum share of non-fossil power generation (Φ) in total electricity generation. The share Φ is growing from the starting year of the policy (here 2022) until it reaches a given target in 2030:

$$Max\, X_{ely}\,.P_{ely} - X_{TD}\,.P_{TD} - \sum_a X(a).p(a)$$
$$X_{ely} < F(X_{TD}, X(a_1), \ldots, X(a_n))$$
$$\Phi.X_{pow} < [X(solar) + X(wind) + X(hydro) + X(nuclear) + X(other)]$$

Feed-in tariff policy

Under this policy, the producers of wind and solar receive a subsidy in USD per unit of electricity, such that they sell electricity above their unit cost of production. The representative electricity provider pays only $\mathrm{p(a)} * (1 - \mathrm{subs})$ for solar and wind. The subsidy rate is assumed to be the same for solar and wind power. It is adjusted in each period in such a way that the paths of CO2 emissions from the power sector are the same as in the regulation policy.

Carbon Tax

In the carbon tax scenario, each electricity producer pays a tax in USD for each unit of CO2 emissions from fossil fuel combustion. This tax is therefore paid only if fossil fuels are burned and therefore is not paid by producers of renewable and nuclear energy. Since the carbon content of coal, oil and gas differs, the extra cost of the tax for one unit of electricity will differ by fuel.

Feebates

The system of fees and rebates in the power sector implies that electricity generation which emits more than a given target of CO2 emissions per kwh will pay a fee and vice versa. In other words, the system can be summed up as follows: the price of electricity is adjusted to

$$p(a) + \tilde{p}\left(\frac{CO2(a)}{X(a)} - \frac{\overline{CO2}}{\overline{X}}\right).$$

where $\frac{\overline{CO2}}{\overline{X}} = \frac{\sum_a CO2(a)}{\sum_a X(a)}$ is the target of CO2 per Kwh and $\tilde{p}$ is the carbon price in USD. In the policy simulation, this price is adjusted in each period (and for each country) in such a way that the path of CO2 emissions from the power sector is the same as under the regulation constraint. The feebate is balanced so that it is neutral on public finances.

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