INTERNATIONAL MONETARY FUND

Climate Policy Options: A Comparison of Economic Performance

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WP/22/242

2022
DEC

WORKING PAPER

 WP/22/242

IMF Working Paper
Research Department

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Authorized for distribution by Antonio Spilimbergo
December 2022

ABSTRACT: We use a global computable general equilibrium model to compare the economic performance of alternative climate policies along multiple dimensions, including macroeconomic outcomes, energy prices, and trade competitiveness. Carbon pricing which keeps the aggregate cost lower and preserves better the overall competitiveness than across-the-board regulation is the first-best policy, especially in energy intensive and trade exposed industries. Regulations and feebates are good alternatives in the power sector, where technological substitution is possible. Feed-in subsidies, if used alone, are not cost effective.

RECOMMENDED CITATION: Jean Chateau, Florence Jaumotte, and Gregor Schwerhoff. 2022 “Climate Policy Options: A Comparison of Economic Performance”. IMF Working Paper 2022/242

JEL Classification Numbers:	C68, F42, H23, Q54, Q58
Keywords:	Climate policy; policy coordination; carbon leakage; carbon tax; regulation.
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WORKING PAPERS

Climate Policy Options: A Comparison of Economic Performance

Prepared by Jean Chateau, Florence Jaumotte, and Gregor Schwerhoff[1]

[1] Jaden Kim provided outstanding research support for this paper. We thank Antonio Spilimbergo, Romain Duval and Ian Parry for very useful comments and suggestions. Alimata Kini Kabore provided editorial assistance.

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1. Introduction

While economists overwhelmingly recommend carbon pricing as the most cost-effective form of climate policy, other types of climate policies 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 effective measures to reduce emissions. Since carbon pricing is cost-effective 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). 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; Blanchard and Tirole 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.

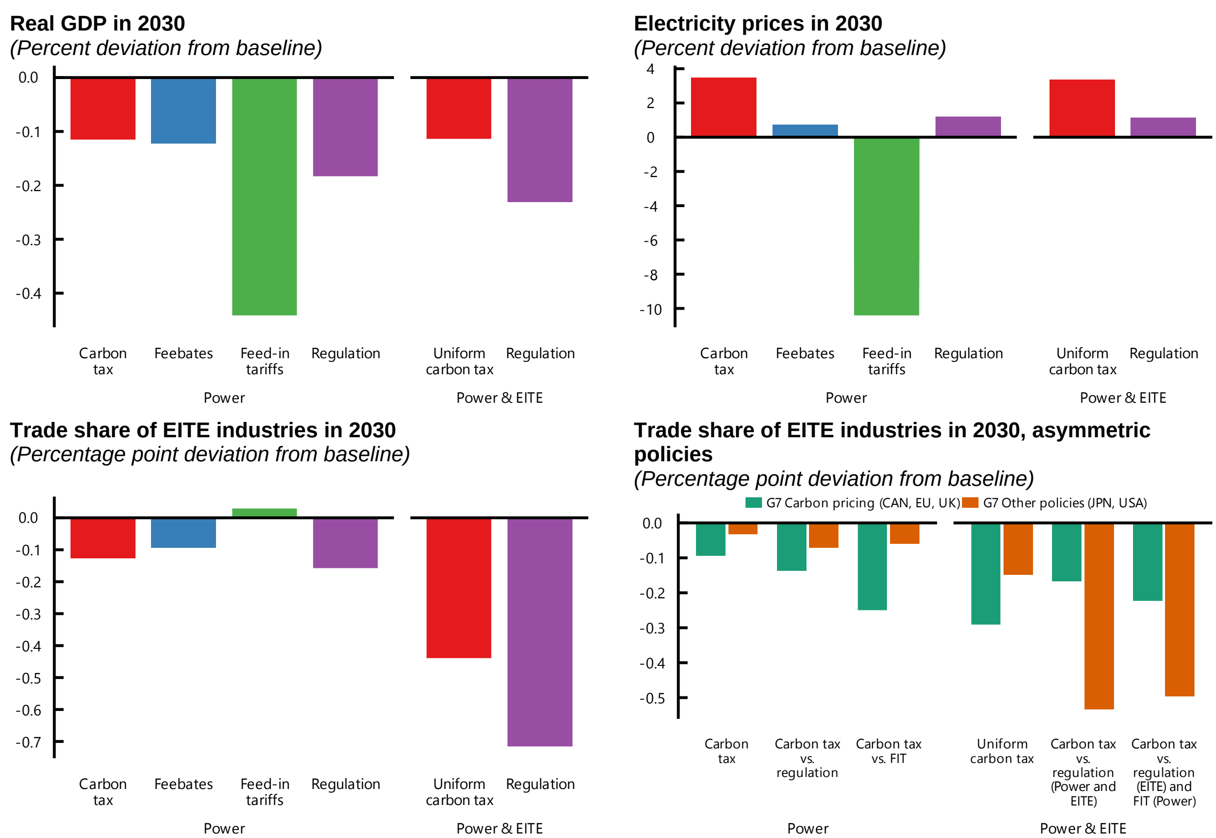
Given the diversity of policy approaches, making climate policy comparable can greatly facilitate international cooperation. Climate policy works best when countries cooperate and act jointly, because joint action reduces concerns for carbon leakage and competitiveness.[2] The IMF, for example, suggests an International Carbon Price Floor, which requires all countries to act on climate change, but differentiates ambition by development level (Parry, Black, and Roaf 2021; Chateau, Jaumotte, and Schwerhoff 2022). Ambition is typically measured in carbon prices. However, other climate policies reduce emissions as well, so it is important to be able to translate them into equivalent carbon prices. We provide such a conversion of climate policies into a carbon price equivalent (see also Black et al. 2022) but, more importantly, we compare the performance of equivalent climate policies across several important economic indicators. The comparison across additional indicators can help guide policymakers in choosing the policies that have the most favorable economic effects for a given ambition level and that limit negative cross-border spillovers.

This paper uses a global computable general equilibrium model to compare 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 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. An overview of the main results is provided in ***Figure 1*** and discussed below.

[2] The EU is considering a Carbon Border Adjustment Mechanism to avoid carbon leakage as the economic bloc moves ahead with ambitious mitigation policies.

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. 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 (panel 1 of ***Figure 1***). 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 (panel 2 of ***Figure 1***). At the same time, carbon taxation allows for lowering labor 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 considering so-called “general equilibrium” effects.

Figure 1: Economic impact on G7 countries



Source: IMF-ENV model.
Note: In panel 4, the first three sets of bars refer to the “Power sector scenarios.” They compare a scenario where all countries implement a carbon tax vs. scenarios where CAN, EU, and the UK implement a carbon tax but JPN, USA (and China and India) instead implement either (i) a regulation or (ii) feed-in tariffs. The three sets of bars on the right refer to the “Power and EITE sector scenarios.” Similarly, they compare a scenario where all countries implement a carbon tax vs. scenarios where CAN, EU, and the UK implement a carbon tax but the other countries implement either (i) a regulation in both power and EITE sectors or (ii) feed-in tariffs in the power sector and a regulation in the EITE sectors. FIT=Feed-in tariffs, also referred to as feed-in subsidies in the text.

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 a common carbon price, 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 and generates revenue that can be used to reduce distortionary taxes (such as labor taxes). This keeps the aggregate economic cost lower but also leads to a more even distribution of economic costs across sectors (panel 1 of ***Figure 1***). 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.

The different climate policies are not neutral from a competitiveness angle, but the use of carbon pricing does not necessarily put a country at a disadvantage. While carbon taxes impose a surcharge on remaining (unabated) emissions, they typically also reduce the abatement cost by allocating emissions reductions where they are cheapest and producing revenue that can be used to reduce other costs (e.g., labor costs). Overall, the choice between using carbon pricing or regulation to reduce emissions in the power sector has little impact for the competitiveness of EITE industries. And in EITE industries, using carbon pricing to reduce emissions is much more effective at preserving overall competitiveness than hard-to-tailor regulations. Feed-in subsidies and feebates in the power sector can help protect the market shares of EITE industries relative to non-acting countries by keeping electricity prices lower. But they can also cause significant changes in market shares between acting countries, reflecting different initial conditions in the use of solar and wind technologies (panel 3 of ***Figure 1***). Finally, simulations of different policy mixes across acting countries—where some countries use carbon pricing while others implement regulation and/or feed-in subsidies—tend to confirm that carbon pricing covering multiple sectors would be a better way to protect overall competitiveness than regulations (panel 4 of ***Figure 1***).

Those countries which are implementing climate policies are projected to achieve considerable emission reductions at very moderate economic cost. In an analysis of climate policies which have already been legislated by countries for the power and EITE sectors, we find that the plans of Canada, the EU, the UK, and the US can be expected to reduce emissions by 10 to 30 percent below baseline by 2030. These substantial reductions come at a cost of no more than 0.6 percent of baseline GDP in 2030. While some of the acting countries experience higher energy cost, energy expenditure tends to increase by less due to energy efficiency gains. Trade share losses for EITE industries are generally moderate, of no more than 0.2 percent, except for the EU, where they are at about 0.6 percent.

A first strand of the literature discusses qualitatively the pros and cons of various climate policies and why policy approaches may need to go beyond carbon pricing. For example, (Bennear and Stavins 2007) identify multiple market failures and political constraints as two reasons for using multiple policy instruments. Considering a range of outcome variables, including distributional equity and minimizing the risk of an inefficient level of abatement in the presence of uncertainty, (Goulder and Parry 2008) add that policy objectives beyond environmental and aggregate economic performance justify the use of a country-specific policy mix. (Vogt-Schilb and Hallegatte 2017) provide a qualitative comparison of 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. (IMF 2019) also provides a descriptive comparison of climate policy options, see for example Table 1.2.

A second strand of the literature uses modeling approaches to compare the performance of a subset of policies. (Kalkuhl, Edenhofer, and Lessmann 2013) compare the welfare effects of different climate policy options with a numerical general-equilibrium model. They find that subsidies for renewable energies are not very effective, because they add renewable energy, but do not discourage fossil fuel use. As a result, total energy supply increases, and emissions do not decrease. A feebate, where fossil fuels are taxed to finance a subsidy on renewable energy, is a better substitute for a carbon price. (Bertram et al. 2015) use an Integrated Assessment Model to analyze politically more feasible alternatives to carbon pricing. They find that support for low-carbon energy technologies and a moratorium on new coal-fired power plants can be used to limit energy prices, which are often a focus of households when climate policy is introduced, at limited efficiency cost.

This paper contributes to the literature by providing a more systematic and quantified comparison of the economic effects of different climate policies for a given emission reduction. It quantifies the trade-offs they imply between different policy objectives, such as domestic macroeconomic outcomes, energy prices, and competitiveness—the latter two are important for political economy reasons. Among policy options, it puts a special focus on the role of regulations in the power and EITE industries—a prominent and popular alternative to carbon pricing. It highlights how the ranking of policies is a function of technological substitution possibilities and heterogeneity of abatement costs across sectors. Finally, it examines in depth the cross-border competitiveness effects of different policies, and of the use of asymmetric policies across countries, a topic of concern especially for countries moving unilaterally with carbon pricing.

The remainder of this paper is organized as follows. In Section 2, we introduce the model IMF-ENV, the design of the scenarios, and some theoretical considerations about the economic cost and political economy of climate policies. In Section 3, we analyze the effect of various policy designs in the electricity sector. This is extended to an analysis of both the electricity and EITE sectors in Section 4. Section 5 provides a deeper analysis of the policies on international spillovers discussing carbon leakage rates, considerations on energy security, and competitiveness effects under different coalition size and policy mixes. Section 6 concludes.

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. Therefore, 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 directly relates 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.[3]

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. Note that this scenario provides a carbon price equivalent for 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

[3] We do not analyze distributional effects, but typically such distributional effects have limited impact on macroeconomic outcomes. Regarding technology, the model does not have endogenous "new technologies" such as carbon capture and storage or hydrogen, but the model takes into account endogenous change in the production process of existing technologies. Moreover, such new technologies are unlikely to become profitable enough to be implemented on a massive scale in only eight years (the study focuses on 2022-2030). Therefore, we do not expect these limitations of the model to affect the results significantly.

(receive) a fee (a rebate). The price of emission per kWh 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:

<u>Regulation for power and EITE sectors:</u> 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.

<u>Uniform carbon tax on power and EITE sectors:</u> 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.

<u>Segmented carbon markets:</u> the scenario assumes two distinct carbon markets, one for the EITE sectors and one for the power sector. 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. For the sensitivity analysis we also discuss a scenario named “fragmented carbon market”, where each EITE sector faces its own carbon tax to meet exactly the same sectoral CO2 emission reductions as in the regulation 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.

3. Decarbonization of power systems under alternative policies

We present results of scenarios on the decarbonization of power systems. 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.

In a nutshell, 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 and because they cause a rebound effect in energy demand.

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

A similar environmental target translates into very different magnitudes of policy tools across countries, reflecting differences in power systems and economic structures. 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 subsidies, 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 subsidies 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: Bau denotes the Business as usual (baseline). The carbon tax reported here is the additional price of CO2 relative to baseline needed to generate the same emissions for the power sector as under the “regulation” scenario. Feed-in subsidies also present subsidy rates as difference from baseline level. # The Economy wide CO2 emissions reductions are for the “regulation” scenario for the power sector defined in sub-section 2.2.

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 2. 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 2: Power scenarios: Changes in Power mix in 2030

(Percent of total electricity generation)

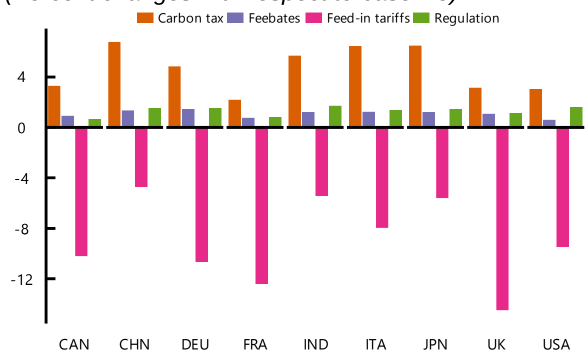
Source: IMF-ENV model.

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.[4] 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 subsidies. Carbon prices increase the electricity prices the most, despite making use of all the possible margins of adjustment, see Figure 3. 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 3*: Power scenarios: The effect of policies on electricity prices in 2030**

(Percent changes with respect to baseline)

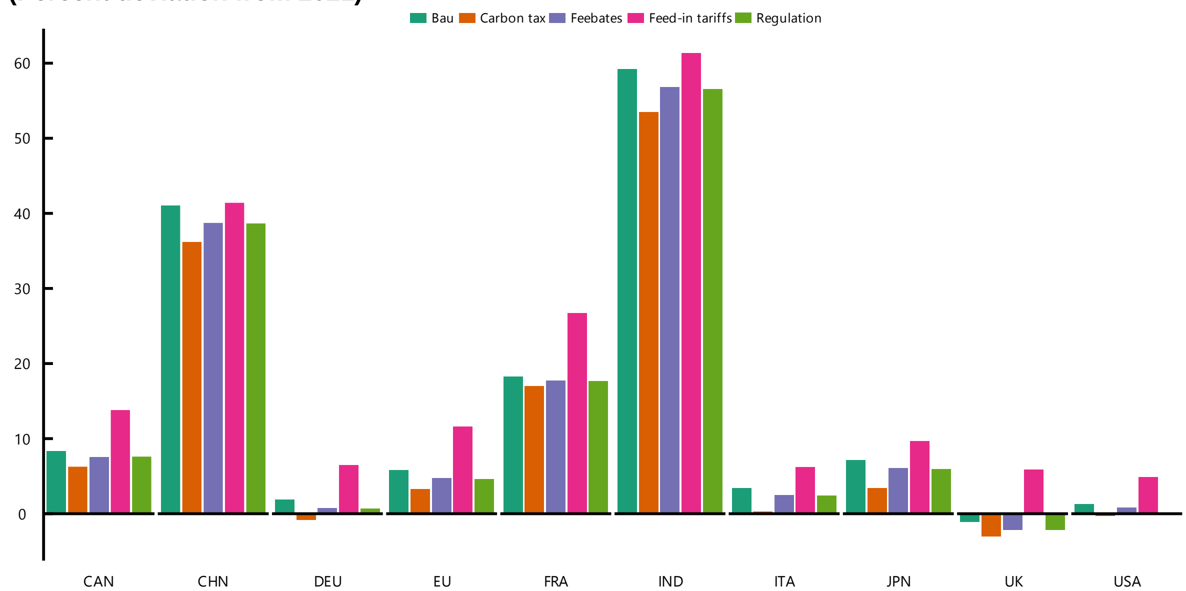


Source: IMF-ENV model.

Policies which increase electricity prices decrease electricity supply and vice versa. Figure 4 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.

[4] 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 4: 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.[5] **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.

[5] 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: Power scenarios: Tax changes for carbon tax and feed-in subsidy scenarios

	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	0.0 2	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 as easily substitute away from coal as the other regions considered. 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

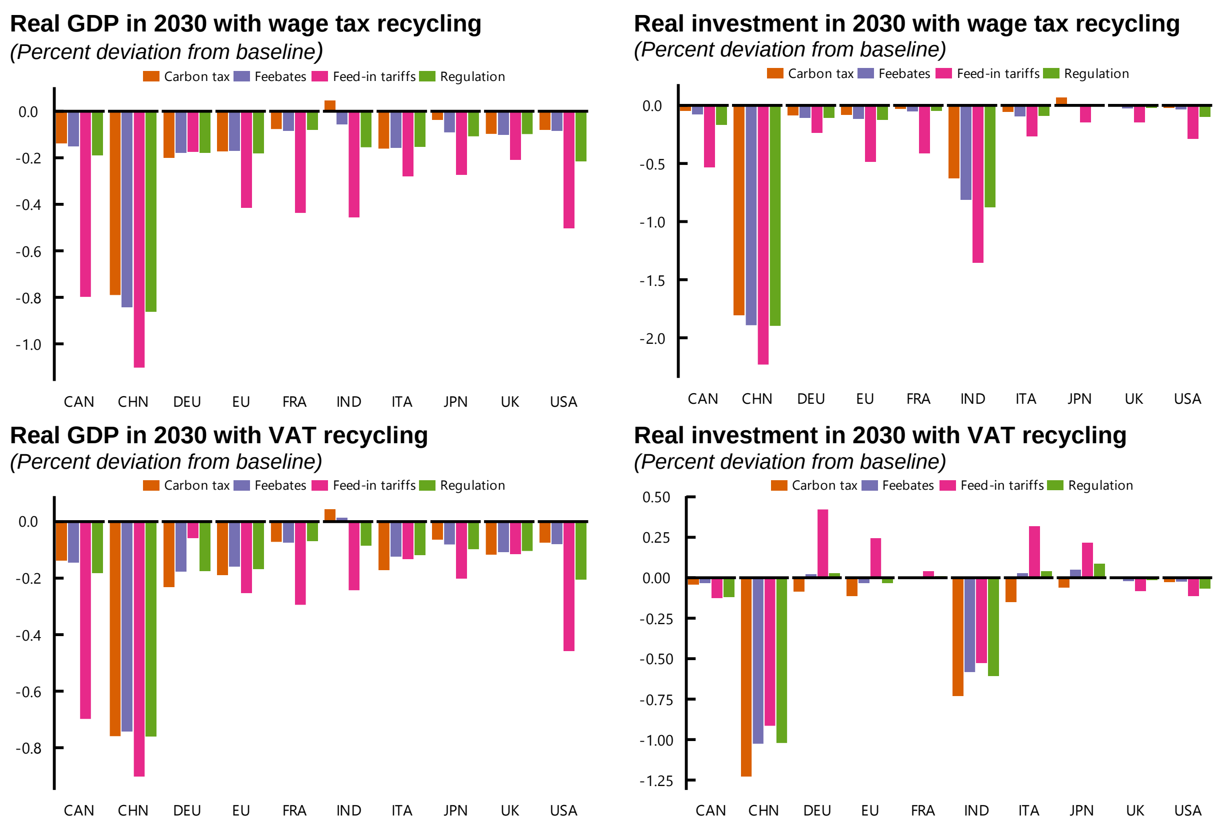
Economic costs are similar and small for the different policies, except for feed-in subsidies which are more costly. Figure 5 shows the effect of the different policies on GDP and investment when tax reductions (to recycle carbon tax revenues) or increases (to finance feed-in tariffs) are applied to 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.[6] This is for two reasons. First, the policy is less effective 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

[6] 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).

sources. The other policy options (carbon tax, regulation, and feebates) have overall similar and smaller economic costs.

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 5: 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 5**. 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 current savings less 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 6**. 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 subsidies 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. The ranking of policies for consumption and welfare follows in most cases that for employment, with feed-in subsidies being more costly options. However, the difference of outcomes between feed-in subsidies and other policies is less for consumption and welfare than employment, as the lower income of households is in part offset by lower electricity prices which benefit consumption and welfare.

Figure 6: Power scenarios: Household consumption, welfare, and employment

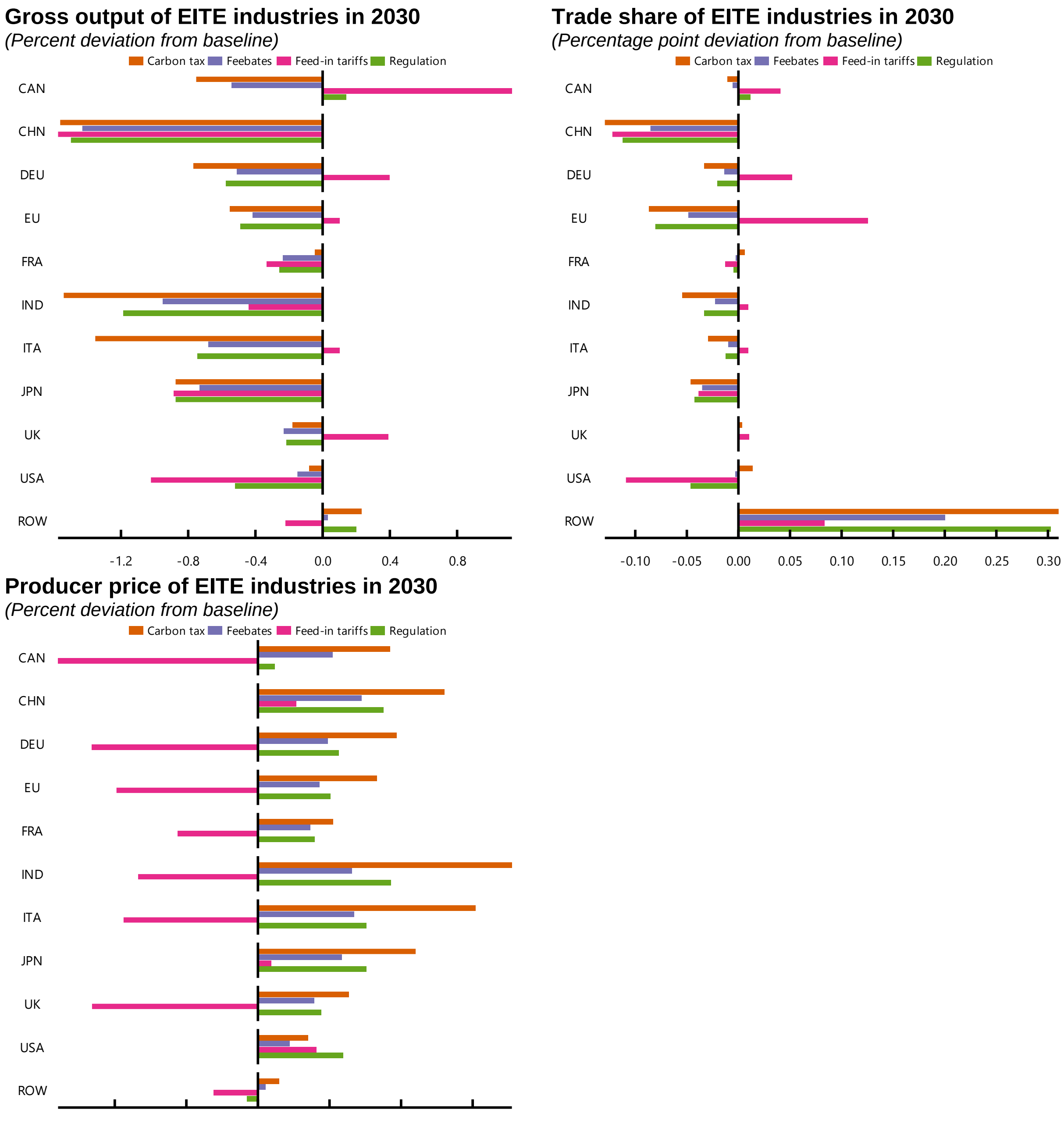
Note: # The welfare change presented here is the "*Hicksian* equivalent variation in income." It measures the income change, in monetary terms, that is equivalent to the price change in terms of the change in utility.
Source: IMF-ENV Model.

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 7**). 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 7**. However, losses are limited to 0.2 percentage points given electricity is only one component of production costs. Losses in market shares are only a bit larger under the carbon tax that increases electricity price the most. The exceptions are 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.

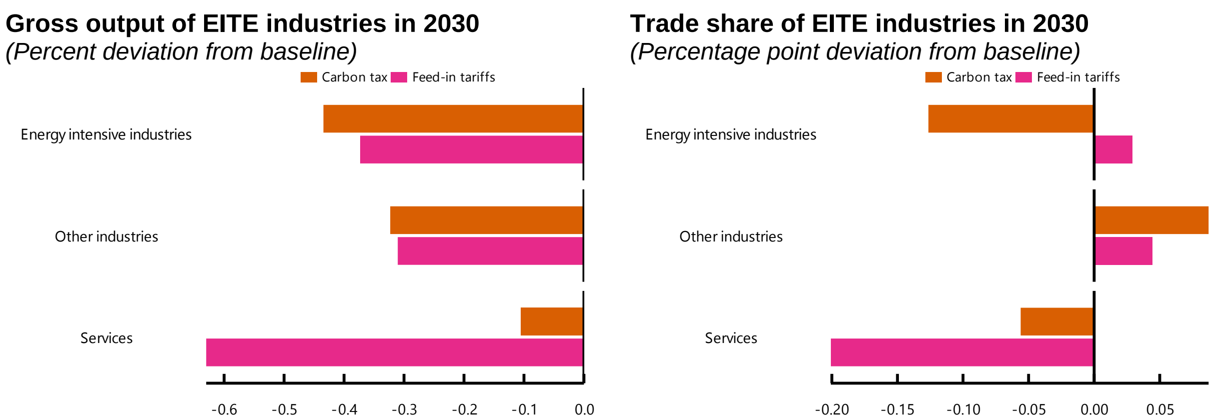
Figure 7: Power scenarios: Impact on EITE sectors



Source: IMF-ENV Model.

Feed-in subsidies support the EITE sectors at the expense of other sectors. Feed-in subsidies subsidize renewable energy and thus reduce energy prices. As we have seen above, this reduces producer prices for the EITE sectors. As a consequence, the output loss of the G7 in EITE sectors is lower than with carbon pricing and EITE sectors gain market share (**Figure 8**). However, the subsidies need to be financed. In our scenario, they are financed through higher labor taxes. This adds a burden to some other sectors, especially services. These sectors lose a higher share of output and more trade shares than they do under carbon pricing. Overall, the support obtained for the EITE sectors is gained at the expense of other sectors.

Figure 8: Power scenarios: Effect of carbon tax and feed-in subsidies on EITE and other sectors for G7

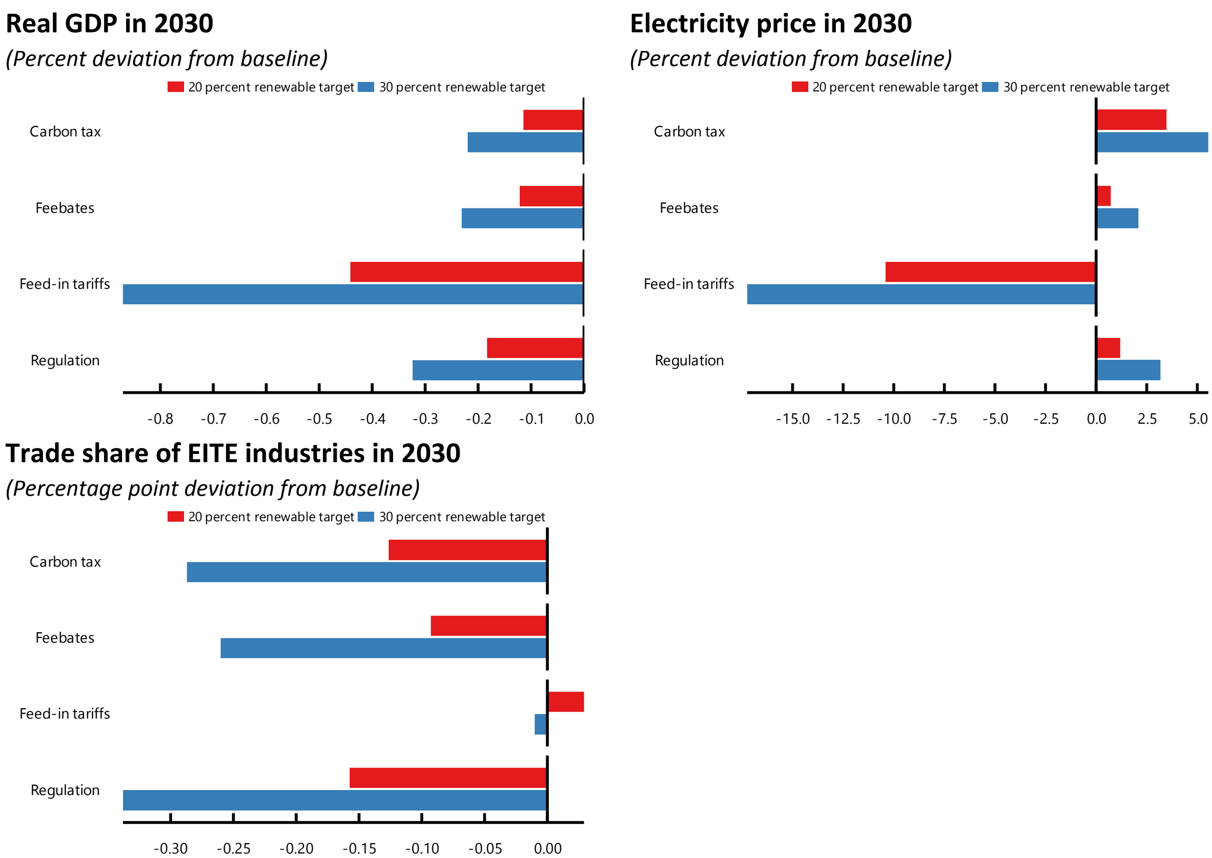


Source: IMF-ENV Model.

3.6. Ambition level

The ranking of policy options remains broadly the same for different ambition levels. Figure 9 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 points 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 stronger changes in the electricity price. Carbon pricing causes a somewhat smaller loss in trade shares than regulation for the G7 as a whole. However, for Canada, Germany, Italy and Japan, regulation is slightly better. For the EU as a group, regulation is slightly better in the 20 percentage point scenario (**Figure 7**), but carbon pricing is slightly better in the 30 percentage point scenario. The larger flexibility of the carbon tax proves to be a bit of an advantage on average, although carbon pricing and regulation results are very similar.

Figure 9: 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 industries' emissions and two types of carbon pricing 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. Table 3 shows the carbon prices required in each country and sector to achieve emission reductions equivalent to the regulation described above for each sector. Three levels of segmentation of carbon market are shown, a uniform carbon market, where all sectors face the same carbon pricing, a segmented scenario where Power sectors and EITE sectors as a whole face a different carbon price and fragmented carbon markets where each EITE sector faces its own carbon pricing. The latter reflect the sector-specific carbon price equivalents of the regulations.

Table 3: Power and EITE sectors scenarios: *Carbon prices in 2030 (2018 USD/t CO_2) by level of fragmentation of carbon market*

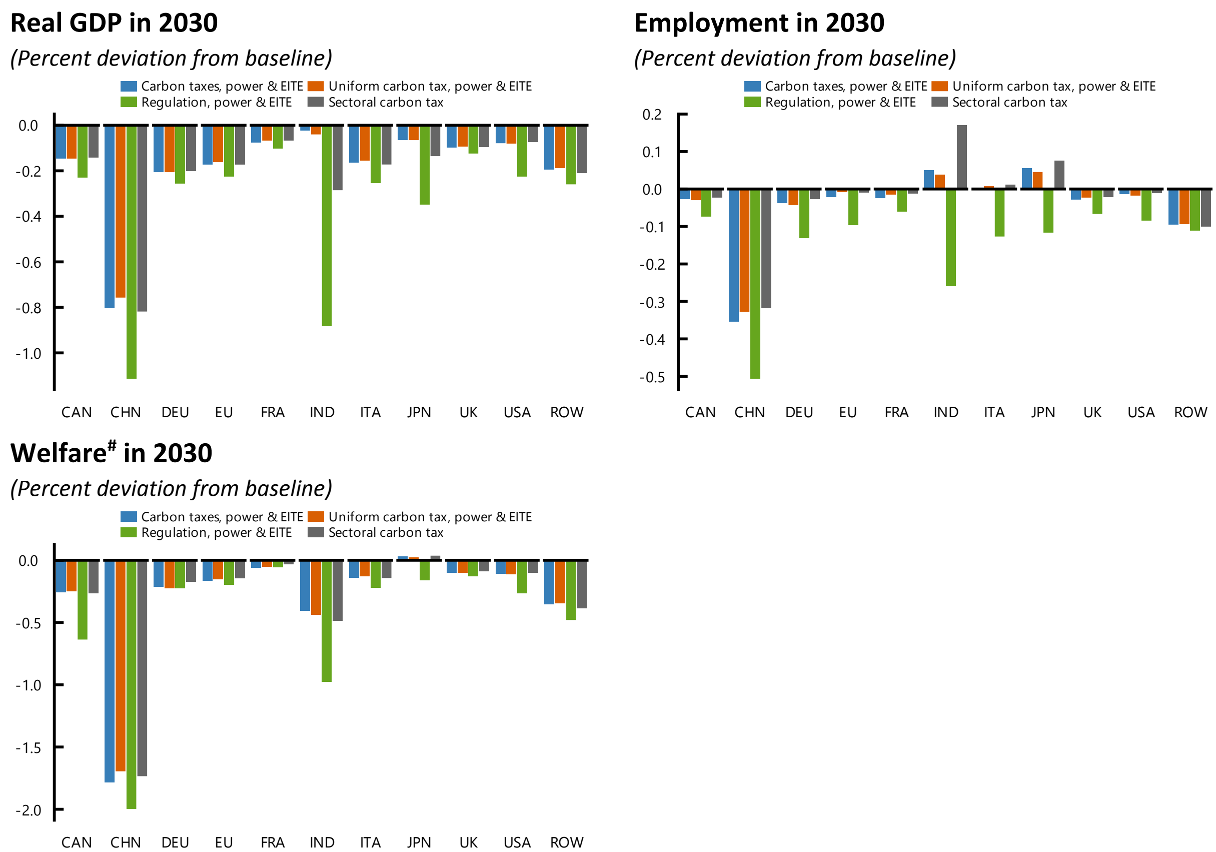
	Uniform carbon Tax	Segmented carbon markets		Fragmented carbon markets				
		Power sectors	EITE sectors	Power	Pulp & paper	Nonmetallic mineral	Iron & Steel	Chemicals
Canada	39	39	50	39	206	34	45	52
China	13	13	9	13	42	2	34	29
France	43	46	18	46	708	7	67	18
Germany	45	42	48	42	329	8	166	31
Italy	63	67	47	67	641	13	323	40
RESTEU	63	64	11	64	498	4	23	16
UK	67	62	34	62	198	16	167	16
India	15	16	19	16	78	1	197	1
Japan	38	38	42	38	356	2	49	138
USA	17	18	30	18	75	7	43	46

Source: IMF-ENV model.

4.1. Macroeconomic implications

Regulation generally causes higher economic cost than carbon pricing in the EITE sectors. As shown in **Figure 10**, 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 CO2 process emissions (left panel of **Figure 11**). 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 11**). Linking carbon markets (i.e., uniform CO2 tax scenario) or not (i.e., two distinct CO2 taxes scenario and EITE sectoral taxes scenario) is of secondary importance.

Figure 10: Power and EITE sectors scenarios: Macroeconomic impacts



Note: # The welfare change presented here is the "*Hicksian* equivalent variation in income." I It measures the income change, in monetary terms, that is equivalent to the price change in terms of the change in utility,

Source: IMF-ENV Model.

Note: Carbon tax, power and EITE refers to a scenario with two distinct carbon taxes, one for the power sector and one for EITE sectors. Sectoral carbon tax refers to a scenario where the power sector and each EITE sector faces its own carbon tax to meet exactly the same sectoral CO2 emission reductions as in the regulation scenario.

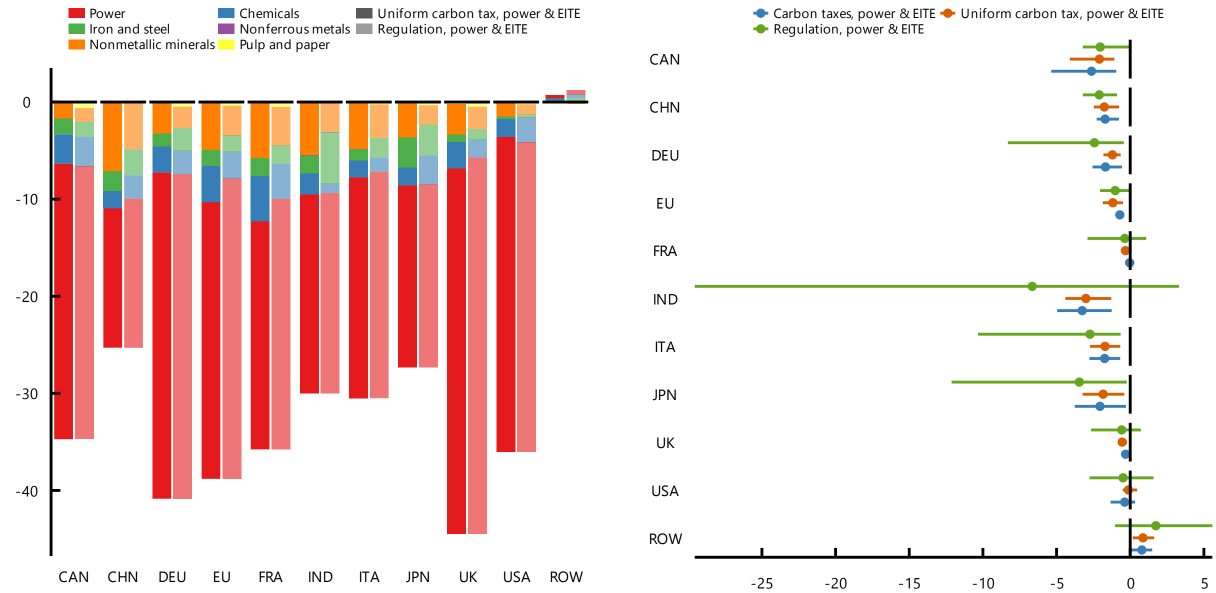
Figure 11: Power and EITE sectors scenarios: Sectoral results

Changes in power and EITE[#] sectoral CO_2 emissions in 2030 under uniform carbon tax vs. regulation

(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 10 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[7]. 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.

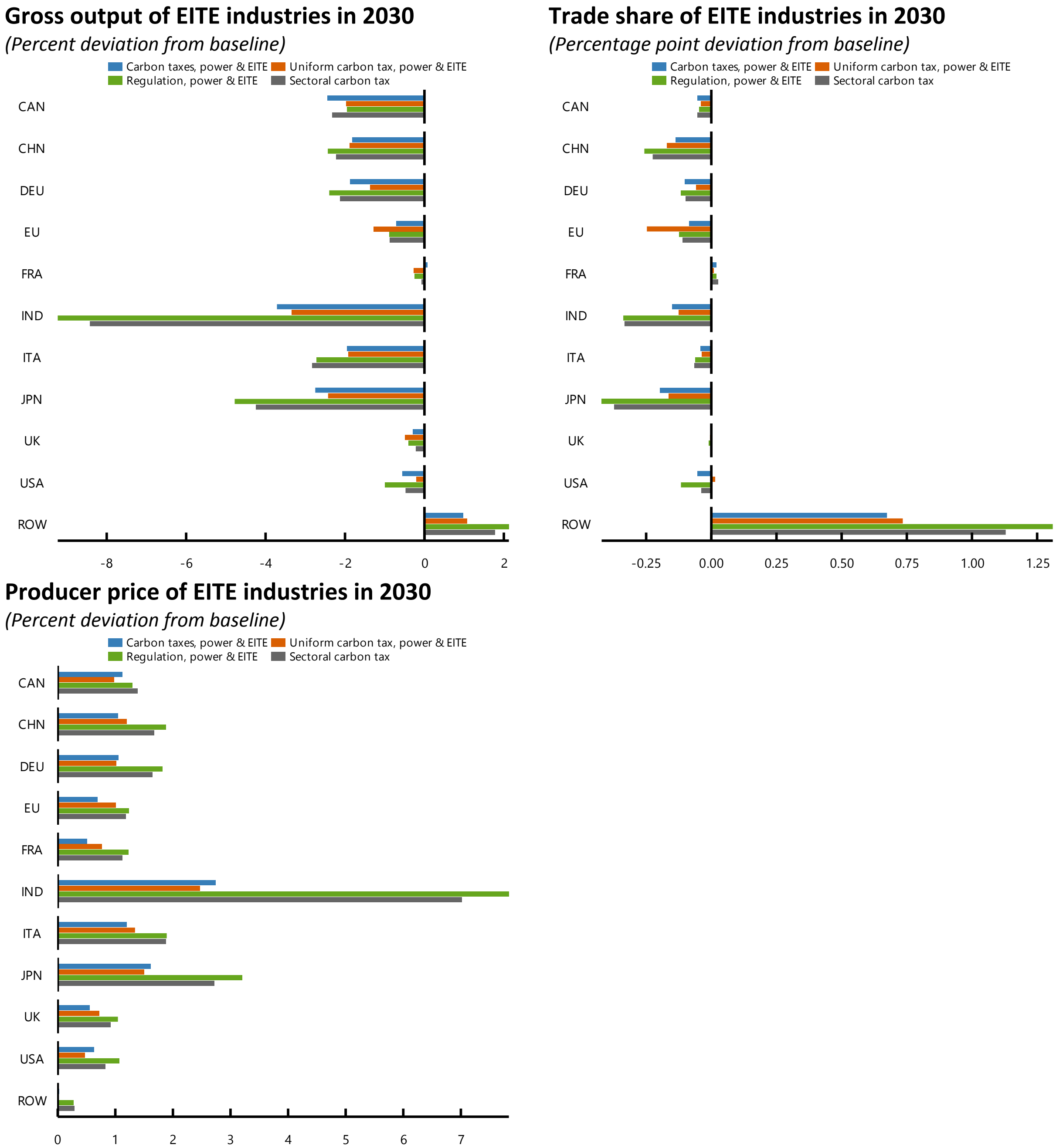
[7] It should be noted that for India the impacts for the scenario sectoral carbon taxes are strong and opposite for GDP and employment. This is because sectoral taxes are very important for Iron (and pulp and paper) in India and are not sufficient to curb sufficiently emission. Then the distortion is important (hence the large GDP cost) but since carbon tax is high and emission still important for iron then total carbon revenues are twice the level in the case of uniform tax and then income tax is more reduced and employment larger.

4.2. Competitiveness effects

The EITE sectors suffer larger losses in competitiveness when climate policy applies directly to them. **Figure 12** shows the effect of climate policy on gross output and trade shares in the EITE sectors. Compared to the case where climate policy is applied only in the electricity sector (**Figure 7**), losses in the EITE sectors are considerably larger when climate policy is implemented in both electricity and EITE sectors. Note that the scale in **Figure 12** is different from the scale in . One reason is that **Figure 12** shows the effect of climate policy in two sectors (electricity and EITE), while **Figure 7** 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.

Regulation is more damaging to competitiveness than carbon pricing, especially in Japan and India. 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 12**). 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 (when it applies to multiple sector) 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 than regulation in **Figure 7**.

Figure 12: Power and EITE sectors scenarios: Gross output and trade shares of EITE industries



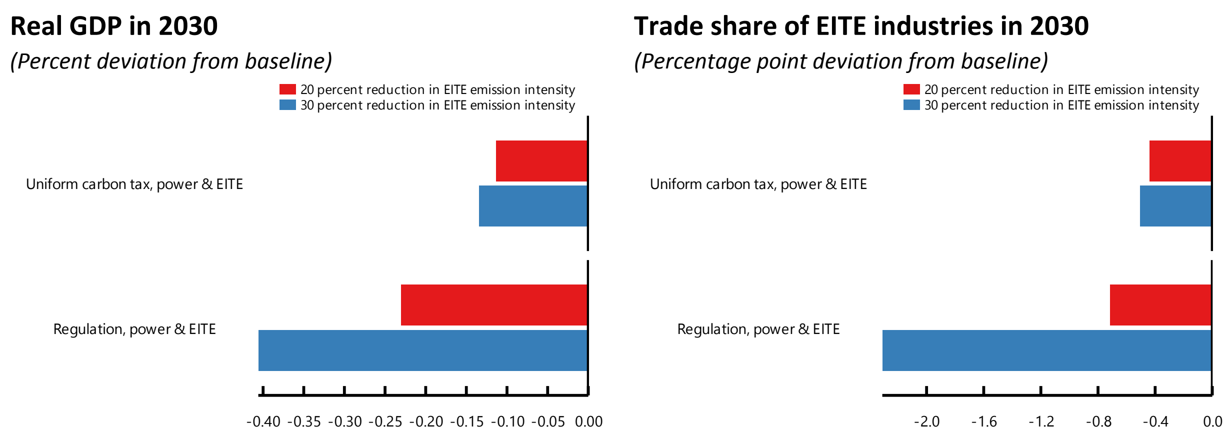
Source: IMF-ENV Model.

Note: Carbon tax, power and EITE refers to a scenario with two distinct carbon taxes, one for the power sector and one for EITE sectors. Sectoral carbon tax refers to a scenario where the power sector and each EITE sector faces its own carbon tax to meet exactly the same sectoral CO2 emission reductions as in the regulation scenario.

4.3 Ambition level

The efficiency advantage of the carbon tax over regulation increases with the ambition level. Figure 13 compares the effect of regulations for Power and EITE sectors vs. a uniform carbon tax scenario on GDP and EITE trade shares for two different ambition levels: a decrease of sectoral emission intensity for each EITE sector by 20 percent (base case) and a more ambitious decrease of 30 percent; in both cases the regulation on power sector is the same as in the base policy case (i.e., a 20 percent decrease in fossil fuel power shares). the higher ambition levels cause larger GDP losses and even larger losses in EITE trade shares in the case of regulation, while the increase of cost is only limited under the uniform carbon tax. The greater efficiency of the carbon tax over regulation is not only robust to a change in ambition level but is also more marked as the ambition level increases. For EITE sectors the marginal abatement costs increase dramatically with the ambition level and therefore the cost-smoothing property of carbon prices across EITE and Power sectors appears much more favorable.

Figure 13: Power and EITE sectors scenarios: The role of policy ambition level for the ranking of policies, for G7 countries



Source: IMF-ENV Model.

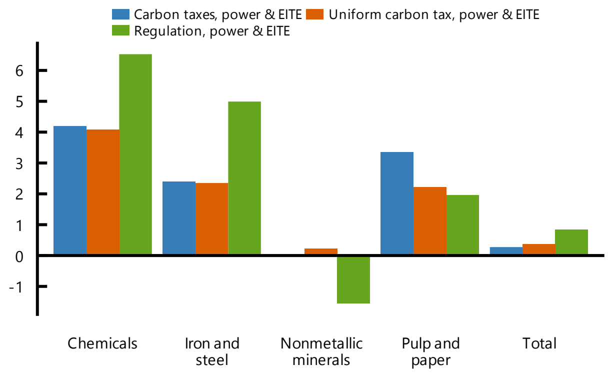
5. International Spillovers

In this section, we analyze in greater depth 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 14. The reason for the low leakage rates is mainly that the scenarios assume that countries representing two thirds of global CO2 emissions and a large part of global output in the sector 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 14: 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 decrease fossil fuel imports, with more decline in terms of value under regulation, helping increase energy security.[8] 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

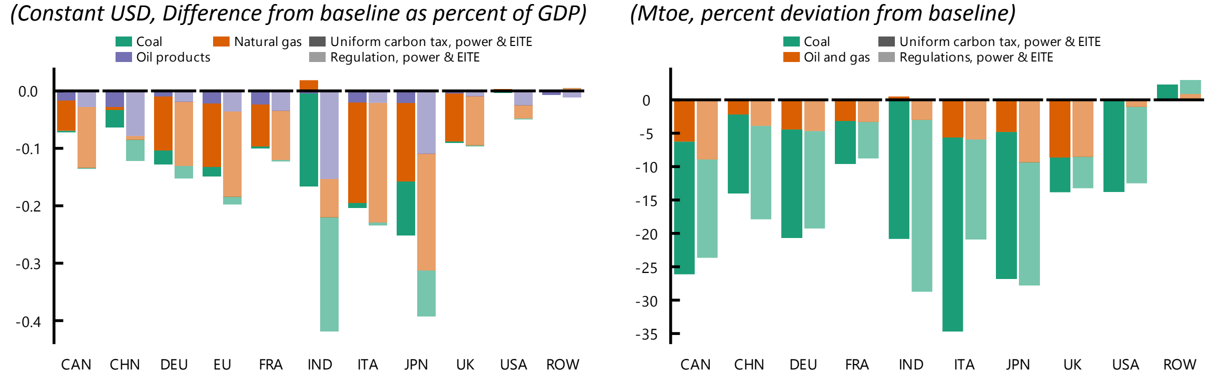
[8] The import bill of fossil fuels is only a first-order approximation of energy security. There are many other dimensions to energy security. For instance, in the current context of the Russian invasion of Ukraine, a switch from coal to natural gas could under some scenarios reduce energy security in countries that would become more dependent on gas import. Other factors that could affect the energy security of a country include access to "critical minerals" used in many low-carbon technologies (such as for renewable energy and electricity storage), because the extraction and processing of these minerals are highly concentrated in some countries.

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 15 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 15: Power and EITE sector scenarios: Fossil fuel imports

Changes in import bills in 2030 under uniform carbon tax vs. regulation
(Constant USD, Difference from baseline as percent of GDP)

Changes in import volumes in 2030 under uniform carbon tax vs. regulation
(Mtoe, percent deviation from baseline)



Source: IMF-ENV Model.

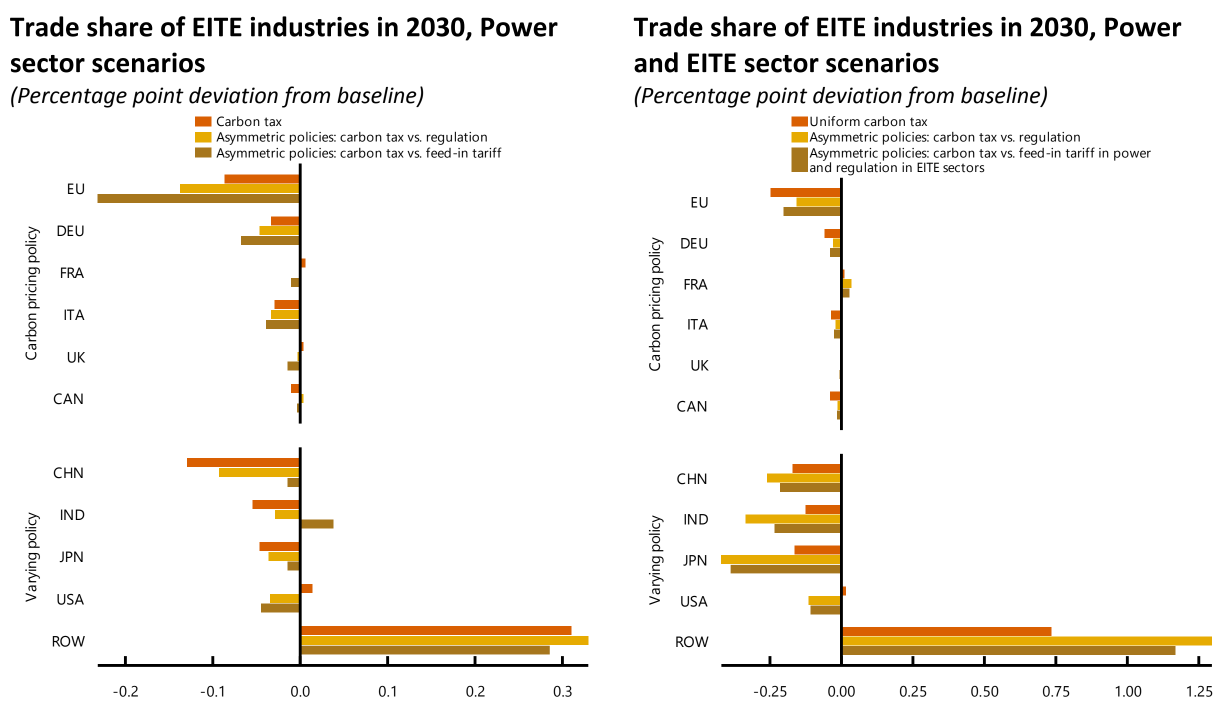
5.3. Diverse climate policies across countries

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 using different policy options in different countries we implement two “asymmetric policies” scenarios. The illustrative asymmetric policies scenarios assume that countries which are currently relying substantially on carbon pricing (notably, EU countries, Canada, and the UK) implement carbon taxation. Other countries are assumed to implement regulation and/or feed-in subsidies. While in practice countries use a mix of policies, the weight they put on different policies can vary in substantial ways. These are illustrative stylized scenarios to examine the cross-border effects that could arise from the use of very different policy approaches across countries. The first scenario 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 subsidies in the power sector and regulation in EITE sectors. As before, the ambition level of the policy is similar across all countries. *Figure 16* shows a comparison of the three scenarios, a carbon tax for all countries, and the two asymmetric policies 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 asymmetric policies 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 16*. 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.[9] In the second asymmetric policies scenario, where other countries implement feed-in subsidies, 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 asymmetric policies scenario in the right panel of Figure 16. 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 subsidies 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 16: Asymmetric policies scenarios: Effect of policies on competitiveness of EITE sectors



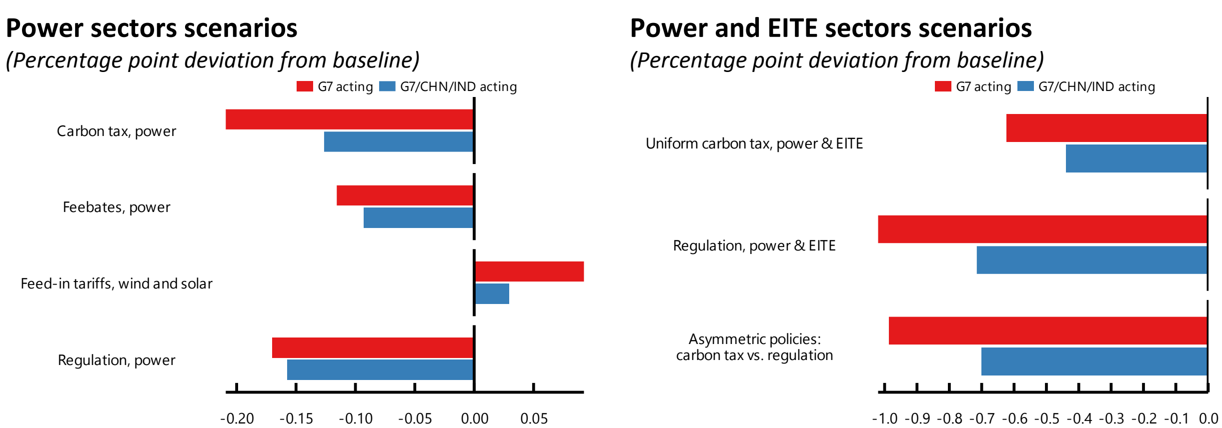
Source: IMF-ENV Model.

Note: In the left panel, the scenarios are for the power sector and countries that always implement a carbon tax are ordered at the top of the chart, while other countries implement either a carbon tax (red bar), a regulation (yellow bar), or a feed-in tariff (brown bar). In the right panel, the scenarios are for both the power and EITE sectors. Countries at the top always implement a uniform carbon tax for both power and EITE sectors while countries at the bottom implement either a uniform carbon tax (red bar), regulation for both sectors (yellow bar) or a combination of feed-in tariff for power and regulation for EITE sectors (brown bar).

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

Losses in competitiveness decrease in the size of the coalition. Figure 17 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 red bars show results when only the G7 implement climate policy and the blue 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 in 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 17: 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.

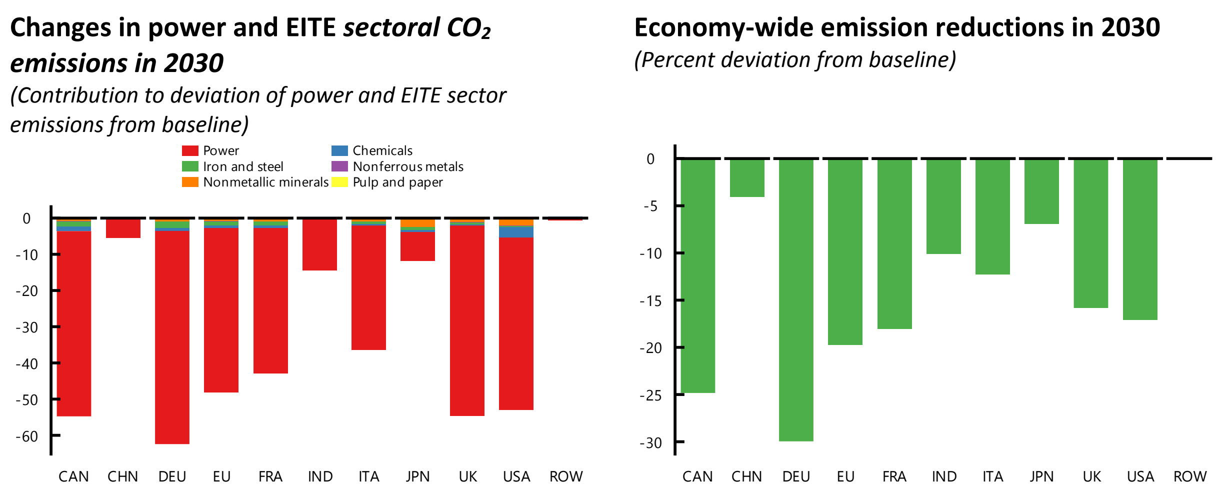
6. Sectoral climate policy

In an "implemented policies" scenario, we analyze selected climate policies which have already passed the legislative process. We model selected climate policies which the G7 countries, but also China, India, and South Korea, are planning to implement in the electricity and EITE industrial sectors. As in the rest of the paper, the focus is on policies that affect emissions in the power and EITE industrial sectors. Following (Black et al. 2022), these policies include: (i) explicit carbon pricing policies where planned; (ii) coal power phase-out plans; (iii) renewable share targets, implemented in the simulations as regulations and, for the US, also feed-in subsidies given the centrality of that policy in their strategy; and (iv) sector-specific emission intensity targets for the industrial sectors, implemented as a sector-specific carbon tax surcharge and, for the US, as feebates. This scenario does not assume carbon pricing for China, US, and India, given that these countries do not yet have national carbon pricing schemes implemented.

The scenario is illustrative as an exact representation of the implemented policies is not possible in the model. The climate policy packages are very specific and detailed, so that it is not possible to represent them exactly in the model. The model results in this section thus rely on simplification and approximation. While other G20 countries have also planned some sectoral targets, we do not consider these because either they are set for sectors beyond the scope of our analysis (transport and building), or they are (almost) met in 2030 in the baseline (as for renewable energy). See Annex 3 for a list of selected policies implemented in this scenario and a description on how policy in the US is implemented. Carbon pricing revenues are assumed to be used to reduce labor income taxes, while feed-in subsidies in the US are assumed to be paid by households with lump-sum tax.

Implemented policies are expected to reduce emissions considerably. The left panel of Figure 18 shows that policies planned in Canada, EU countries, the UK and the US would reduce combined emissions of the power and EITE sectors by more than 30 percent relative to baseline levels. In China, India and Japan emission reductions would be between 5 and 15 percent from the baseline levels. In the rest of the world, emission reductions would be minimal. For all countries, almost all emission reductions would come from the power sector with only minor contributions from the EITE industries. In terms of the total emissions of the country, the reductions amount to between 15 and 30 percent for the most ambitious countries (right panel of Figure **18**).

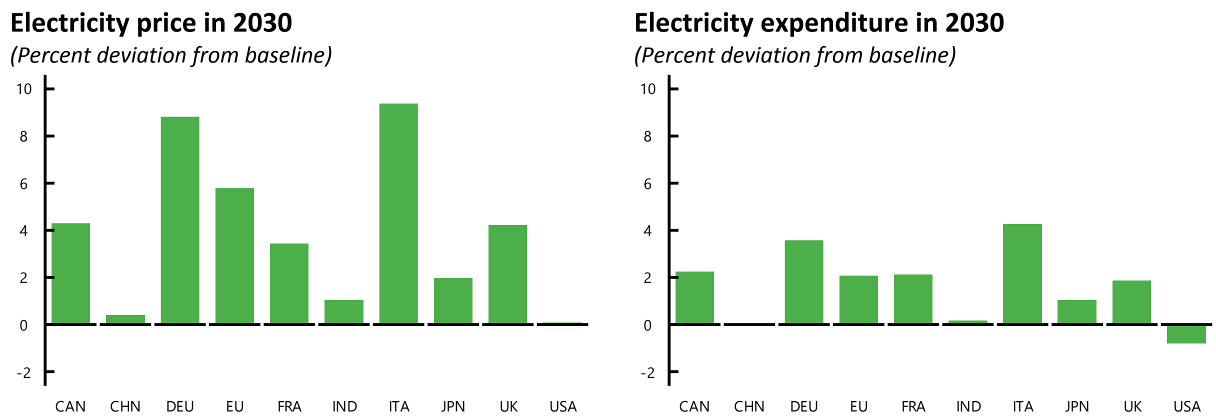
Figure 18: Effect of selected planned policies on emissions



Source: IMF-ENV Model.

Climate policy increases electricity prices, but energy efficiency gains mitigate the increase in energy expenditure. The countries with the higher ambition level in terms of emission reductions in Figure 18 tend to also have higher increases in electricity prices in Figure 19 (left panel), especially in countries using the carbon tax. The right panel of Figure 19 shows however that electricity expenditure increases much less than electricity prices. This can be explained by energy efficiency gains which the higher electricity prices motivate, resulting in lower electricity consumption. The total expenditure for electricity thus increases by 4 percent or less in all acting countries.

***Figure 19*: Effect of selected planned policies on electricity prices and expenditure in 2030**

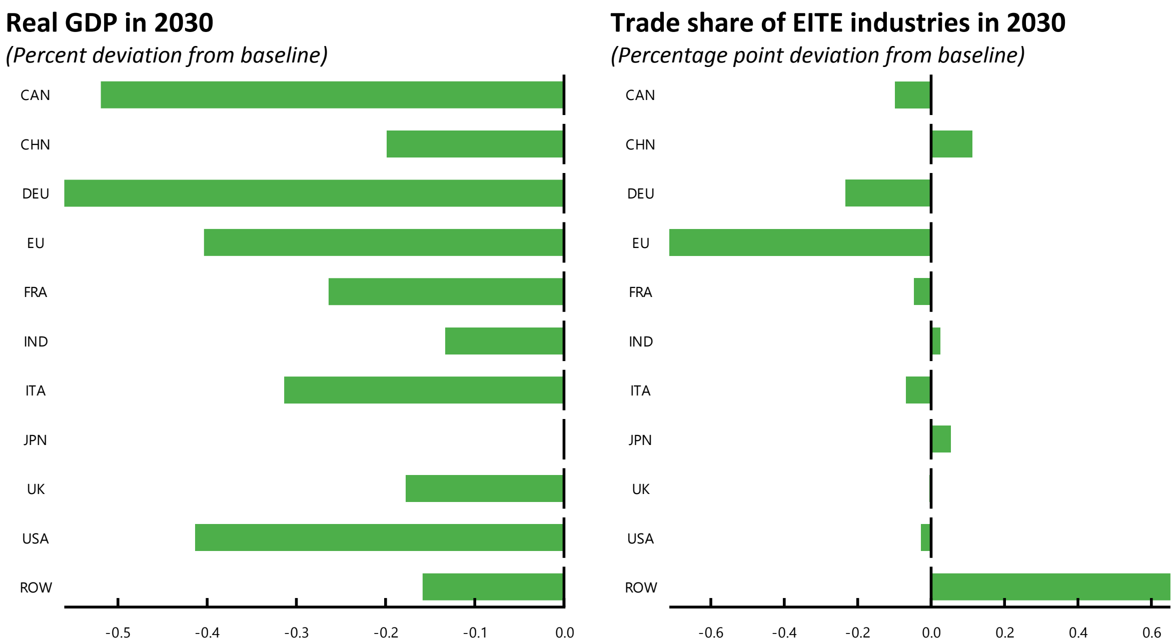


Source: IMF-ENV Model.

GDP effects are modest compared to the emission reductions achieved. Figure 20 shows that GDP losses are below 0.6 percent of baseline GDP for all countries. In general, relative GDP losses correlate with the relative strength of emission reductions.[10] China, India, and the rest of the world however also experience (non-negligible) GDP losses reflecting reduced demand from acting countries. Losses in trade shares are expected to be the strongest for the EU, while China and the rest of the world would benefit from increased competitiveness. The relatively high loss in trade share for the EU can be explained with a more ambitious climate policy than some other trade partners and the use of carbon pricing in the electricity sector. As we have seen earlier, the use of carbon pricing minimizes the loss in terms of GDP (Section 3), but countries using carbon pricing can lose some market share when trade partners use subsidies or regulation instead of carbon pricing in that sector (Section 5.3).

[10] Following (Black et al. 2022) the renewable targets for the EU, UK and Canada are more ambitious than the 20 percent increase discussed in section 3 (and are expressed in terms of renewables and not non-fossil, and as such exclude nuclear power).

***Figure 20*: Effect of selected planned policies on real GDP and trade shares**



Source: IMF-ENV Model.

7. Conclusion

There are good alternative policy options to carbon pricing, especially in industries where technological substitution possibilities exist. While carbon pricing is generally the first-best policy, the quantifications presented in this paper suggest that regulations and feebates are also good options in the power sector as they have GDP costs that are very close to that of carbon pricing and their effects on energy prices are more contained. A feed-in subsidy also performs well on energy prices (it actually reduces them) but would be much costlier if used on its own because it incentivizes energy consumption, does not limit the use of fossil fuels, and needs to be financed with higher taxes. Combining it with policies that directly reduce fossil fuels, such as carbon pricing or regulation, would be more effective.

In sectors with more rigidities, carbon pricing with broad sectoral coverage remains superior. In contrast to the power sector, EITE industries are characterized by higher and more heterogenous abatement costs, with some sub-sectors largely unable to abate. In such industries, carbon pricing proves advantageous relative to regulations that would be difficult to tailor to sub-sectors. This is because carbon pricing allows to allocate emissions reductions where abatement is the cheapest and to generate revenues to reduce distortionary taxes, keeping the aggregate cost lower.

Alternative policies also have different implications from a cross-border perspective, but carbon taxation is not necessarily more damaging to competitiveness. Differences policies can affect competitiveness of EITE industries in different ways. For instance, feed-in subsidies in the power sector can cause non-negligible changes in market shares of EITE industries by lowering the price of electricity—a key input. But contrary to common perception, a carbon tax does not necessarily put a country's competitiveness at a disadvantage relative to other countries using regulation, as the carbon tax can lead to more effective and flexible abatement and its revenue can be used to reduce other taxes. In EITE sectors, a carbon tax covering multiple sectors would be less costly for competitiveness than hard-to-tailor regulations, for the same reasons it keeps aggregate cost lower.

Different types of climate policy could be incorporated in the design of an international coalition on climate policy, with due attention to cross-border effects. Many countries prefer ambitious climate policy to be implemented simultaneously across countries to avoid carbon leakage and competitiveness losses. Proposals to form a coalition of countries acting jointly are often formulated in terms of carbon prices. One obstacle that has made the formation of such a coalition difficult is that some countries are not willing to introduce carbon prices, even though they are willing to implement other forms of climate policy. Explicitly accounting for all forms of climate policy while coordinating to limit substantial competitiveness effects from asymmetric policies where there is such risk would facilitate efforts to form a coalition.

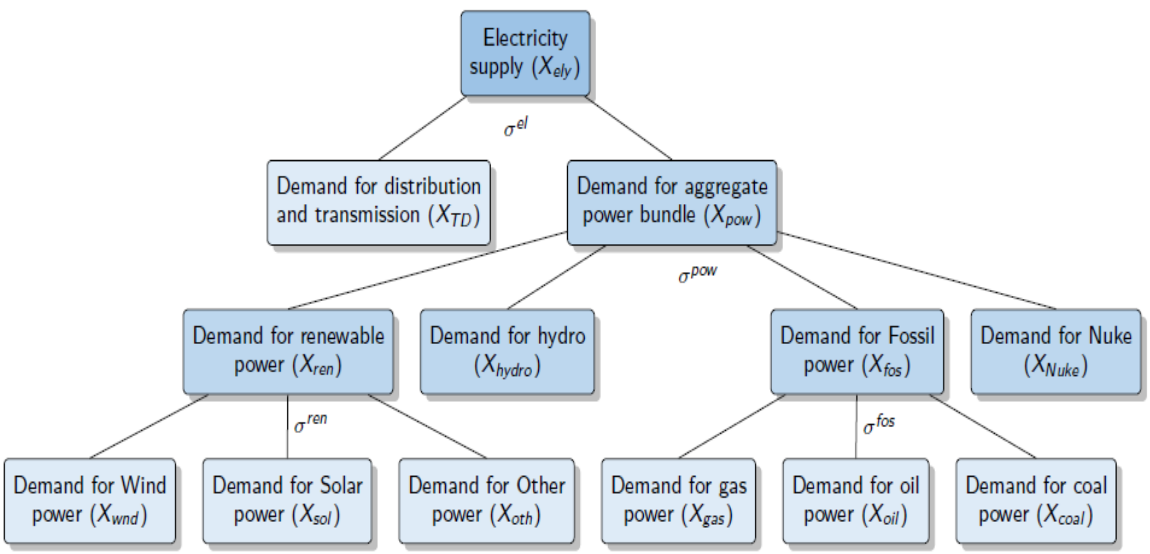
Annex 1. Representation of the power sector in IMF-ENV

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}:

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

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.*



Implementing Power Policies

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:

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

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 CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 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.

Implementing Regulations in Energy intensive industries

The regulation is implemented as an additional constraint on θ, defined as the CO_2 intensity or total CO_2 emissions to gross output, for each sector s,

The firm's optimization is to maximize its profit under production constraint ($F(\cdot)$ is the production function) and the CO_2 intensity constraint:

$$Max \sum_v X_{s,v} \cdot P_{s,v} - \sum_{i,v} x_s(i) \cdot p_s(i) - CarbonPrice \cdot procCO_{2,s} - \sum_v pk_{s,v} \cdot k_{s,v} - \sum_v w \cdot L_{s,v}$$

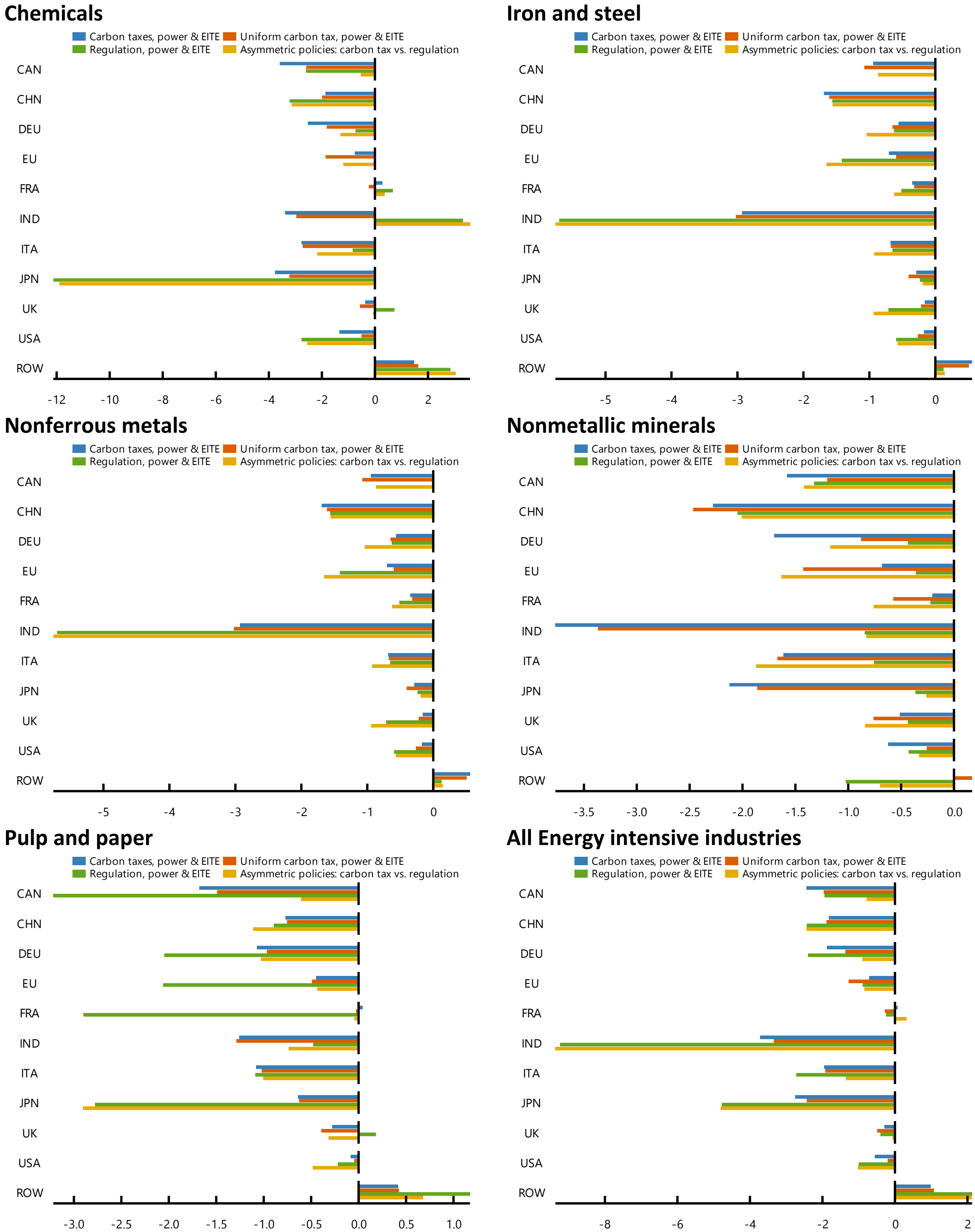
$$X_{s,v} < F_{s,v}\big(x_s(i), \dots, x_s(n), k_{s,v}, L_{s,v}, procCO_{2,s}\big)$$

$$procCO_{2,s} + \sum_f x_s(f) \cdot c_s(f) = CO_{2,s} < \theta_s \cdot \sum_v X_{s,v}$$

where $X_{s,v}$ is the gross output of sector s for vintage v, $x_s(i)$ the demand of intermediate input i, $k_{s,v}$ the demand for capital, L the demand for labor, and P_s, $p_s(i)$, $pk_{s,v}$ and w, their respective prices. Total CO_2 emissions from sector s are the sum of process CO_2 emissions ($procCO_{2,s}$) and CO_2 emissions from fossil fuel combustion, where $c(f)$ is a fixed coefficient of emission associated to the use of fossil fuel "f".

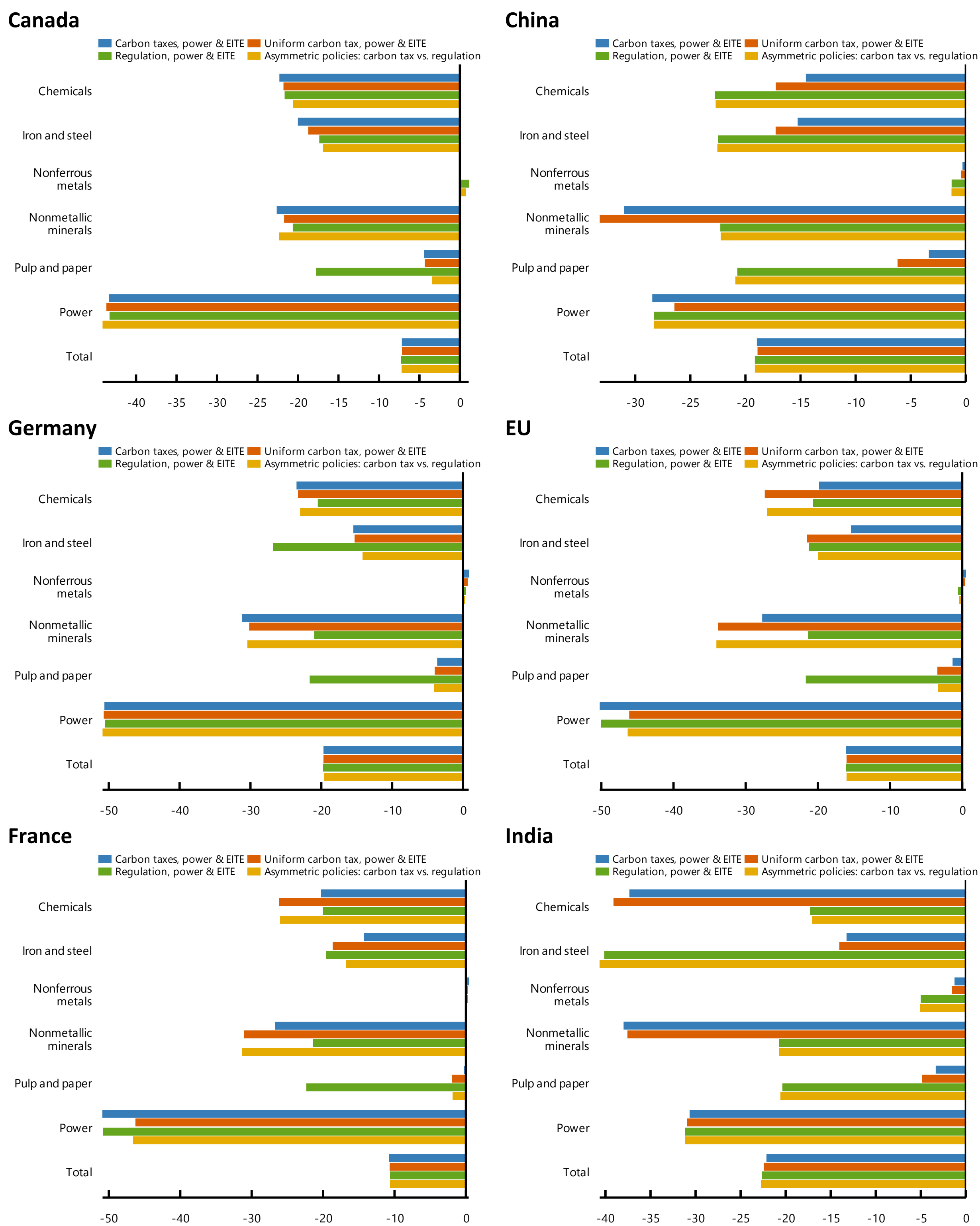
Annex 2. Detailed Figures

Figure 21: Power and EITE scenarios: Changes in 2030 Real Gross Output, detail by EITE sector and by country (Percent deviation from baseline)

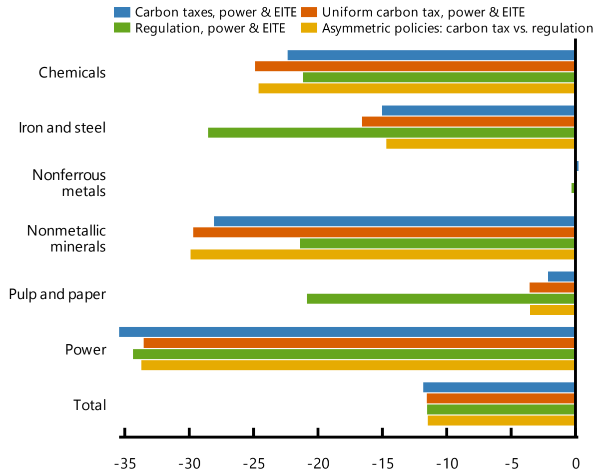


Source: IMF-ENV model.

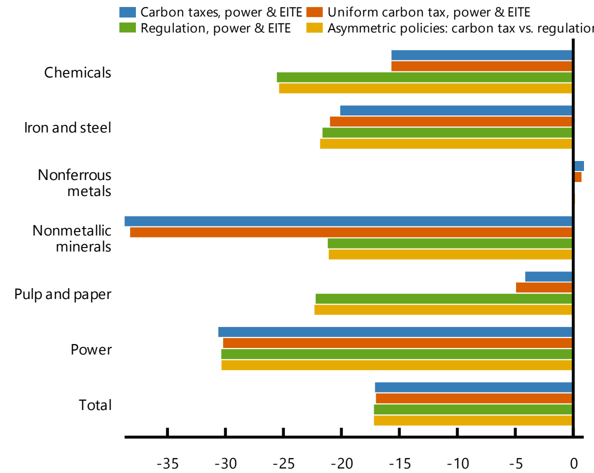
Figure 22 Power and EITE scenarios: Changes in CO2 emissions, detail by sector and country
(Percent deviation from baseline)



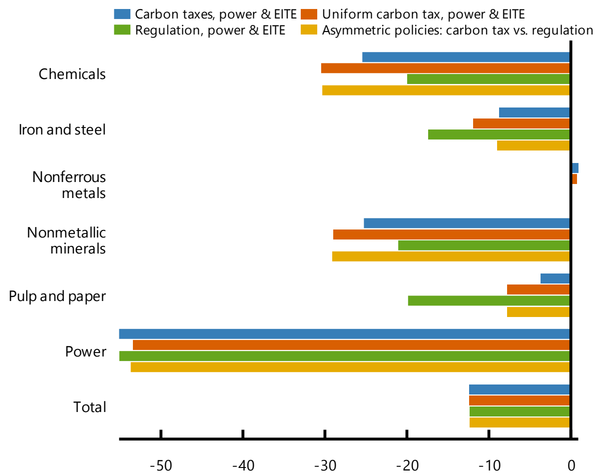
Italy



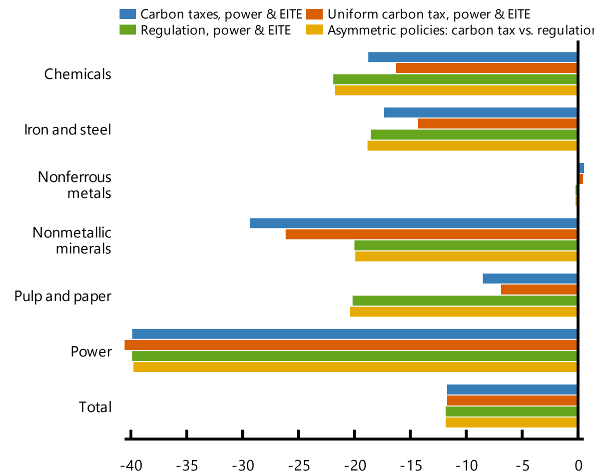
Japan



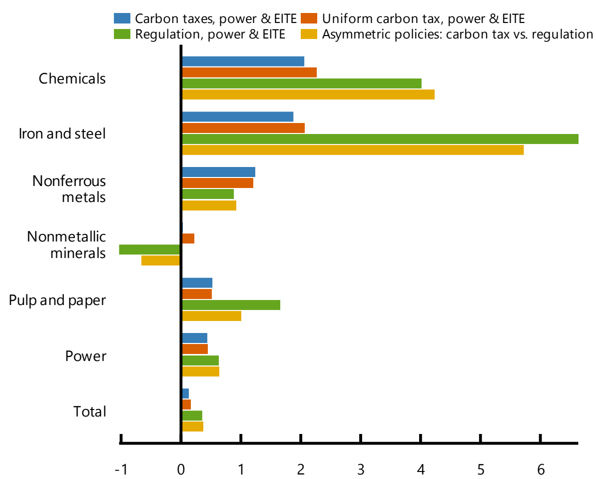
United Kingdom



United States

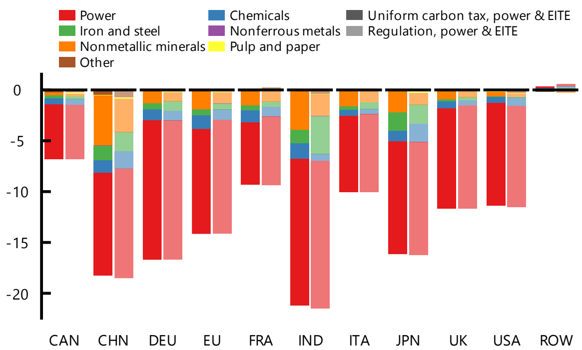


Rest of the world: Non-acting countries



Source: IMF-ENV model.

Figure 23: Power and EITE scenarios: Changes in economywide CO2 emissions in 2030, decomposition by sectors (Contribution to deviation of emissions from baseline) for uniform carbon tax vs. regulation scenario



Source: IMF-ENV model.

Annex 3. Planned policies

The below policies have been implemented for the scenario in Section 6.

Table 4: Explicit carbon pricing policies and sector specific targets, G7 Countries, China, India, and Korea

	Instrument/coverage (April 2022, 2030 prices, US $/ton)[a]	Power generation shares targets, % (year)		Sector specific emissions targets for the industrial sector
		Renewables	Coal	
Canada	Carbon tax/ETS for power, industry, transport, buildings (36, 140)[b]	90 (2030)	0 (2030)	
China	ETS for electricity to be expanded to industry (7, 7)[c]	80 (2060)		Peak aluminum and steel CO2 emissions by 2025, and reduce them 40 and 30 percent, respectively from that peak by 2040.
France	EU ETS for power/industry (100, 140), domestic tax for buildings/transport (87, 87)	40 (2030)[d]	0 (2022)	Reduce (all GHG) emissions from industry 37 percent by 2030 relative to 2019.
Germany	EU ETS for power/industry (100, 140), domestic ETS for buildings/transport (34, 60)	80 (2030)	0 (2030)	Reduce CO2 emissions 49-51 percent below 1990 levels by 2030
India		50 (2030)		
Italy	EU ETS for power/industry(100, 140)	55 (2030)	0 (2025)	
Japan	Carbon tax for all emissions (3, 3)	38 (2030)	19 (2030)	Reduce industrial energy consumption 1 percent a year.
Korea	ETS for power/industry/buildings (15, 15)	30 (2030)	0 (2050)	
UK	ETS for power/industry (69, 130)	100 (2035)	0 (2024)	Reduce CO2 emissions 67 percent below 2018 levels by 2035.
US		60 (2030)	5 (2030)	Reduction of industry CO2 emissions by 11 percent below 2005 levels by 2030 following (Larsen et al. 2022)

Sources: Black et al. (2022) based on WBG (2021), REN21 (2021); IEA (2021); Government websites; Climate Transparency; Climate Action Tracker: IEA; and IMF staff estimates.

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.
[d]EU wide target.

The US policies are based on (Larsen et al. 2022). In the electricity sector, they are modeled as a renewable energy target of 60 percent for the electricity mix in 2030. This target is obtained by a mix of regulation, a phase-out of coal power plants to 4.5 percent of total power generation in 2030 and a subsidy on output for wind and solar energy. In manufacturing industries, policies are modeled as feebates, which are a combination of a carbon tax and revenue neutral output subsidies. Total subsidies for 2022 to 2030 are 164.4 USD billions and are financed through lump-sum taxes.

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