INTERNATIONAL MONETARY FUND

A Comprehensive Package of Macroeconomic Policy Measures for Implementing China's Climate Mitigation Strategy

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WP/22/142

2022
JULY

WORKING PAPER

IMF Working Paper
Asia and Pacific Department

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Abstract

This paper presents ways for China to achieve its climate goals while also attain high-quality growth—growth that is balanced, inclusive, and green. Using a dynamic computable general equilibrium model that is calibrated to China, multiple scenarios are considered that incorporate a sequence of layered policies: (*i*) frontloading mitigation with an earlier emissions peak, (*ii*) power market reforms, and (*iii*) economic rebalancing. The results highlight that these policies can significantly contribute to the success of the climate strategy overall, including by lowering the shadow price of carbon as well as the associated mitigation costs. Distribution analysis offers proposals to lessen the impact on vulnerable households.

JEL Classification Numbers:	O53,Q54, O14, D58
Keywords:	Chinese economy; climate policy; carbon neutrality; rebalancing; Computable General Equilibrium model
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[1] The authors would like to thank Simon Black and Ian Parry for significant contributions to this paper. The paper has also benefited significantly from comments by Helge Berger and seminar participants at the IMF.

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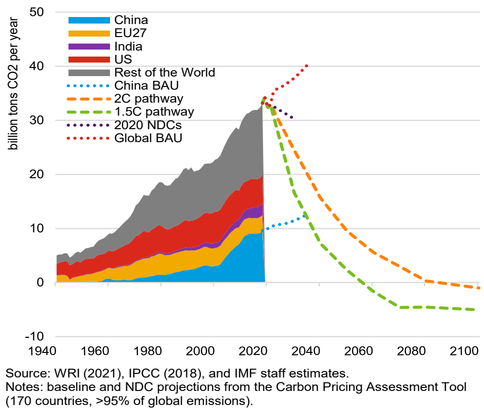
A. Introduction

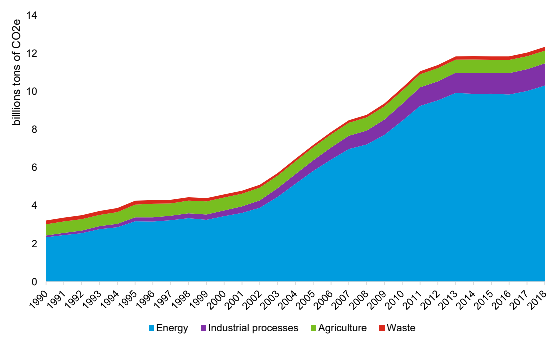
Climate mitigation in China is critical to ensuring the durability of its long-term development path. China is especially vulnerable to rising extreme weather events and its warming rate is outpacing the global average.[2] Higher temperatures have a direct effect on productivity and are strongly linked to more frequent and extreme weather events that pose risks to economic growth, health, livelihoods, food security, water supply, and human security, which are likely to affect the vulnerable the most (see Appendix 1). Moreover, local air pollution from fossil fuel combustion caused an estimated 1.2 million premature deaths in China in 2019, with coal, petroleum products, and gas accounting for 78, 20, and 2 percent of these deaths respectively.[3]

Figure 1. Global Energy-Related CO_2 Emissions Pathways



Source: WRI (2021), IPCC (2018), and IMF staff estimates.
Notes: baseline and NDC projections from the Carbon Pricing Assessment Tool (175 countries, >95% of global emissions).

Figure 2. Historical GHG Emissions



Source: WRI (2021), IMF staff calculations.
Note: GHG exclude land-use change and forestry (LUCF) and bunker fuels emissions.

Climate mitigation in China also has enormous global importance given the size of China's economy and its role as a major emitter. At the global level, CO_2 emissions need to be reduced by 30-60 percent below "business-as-usual" (BAU) levels in 2030[4] to get on track with containing warming to 1.5-2ºC—even if fully implemented, current mitigation pledges would only cut global emissions by 1/3 of what is needed for 1.5º C and 2/3 of what is needed for 2º C (Figure 1).[5] Greenhouse gas emissions (GHGs) in China grew 275 percent between 1990 and 2018 (Figure 2) and are projected to

[2] According to the latest China Meteorological Administration Blue Paper (2021), China is particularly susceptible to natural disasters such as heavy precipitation and extreme heat. Its annual average surface temperature has increased by 0.26 degrees Celsius every 10 years from 1951 to 2020, much higher than the global average increase of 0.15 degrees Celsius in the same period.

[3] Parry and others (2021a).

[4] That is a scenario with no new or tightening of existing, mitigation policies.

[5] See also Black and others (2021).

increase by 39 percent from 2018 to reach 18.7 billion tons in 2030 under the BAU scenario.[6] Under that same scenario, China would account for a third of global energy-related CO_2 emissions in 2030, about the same as the *global* emissions reduction required for a 1.5°C pathway. In per capita terms, China will be among the top five emitters in the G20. Actions to mitigate emissions in China therefore make a huge difference at the global level and confer large benefits on all countries. Additionally, action in China will likely catalyze mitigation action among other countries. Thus, China's achievement of its carbon neutrality goal before 2060—and the path it takes towards achieving that goal—will be critical to any successful global strategy to deliver the needed reductions in global emissions.

For China, attaining carbon neutrality before 2060 will require the full use of existing and new climate policy tools while forging ahead on the reform path toward high-quality growth—growth that is balanced, inclusive, and green. As most of China's CO_2 emissions are generated from power and industrial activities, owing to its high investment-intensive growth, any successful climate reform agenda will also require a significant transformation of the economy over the next 40 years. Continuing further on the path of unbalanced growth would not only drive up the already excessive investment share of GDP and accelerate the decline in returns to capital (see China's 2021 Article IV Staff Report), but also, due to the high carbon-intensity of investment, make it much more difficult to reach China's climate goals. Conversely, economic rebalancing towards more consumption offers more sustainable and equitable growth benefitting more households and helps the quest for carbon neutrality by reducing the tradeoffs between growth and climate goals.

The announcement of China's climate ambitions has set off a flurry of academic and policy work on potential ways for China to decarbonize by mid-century. Many studies have taken a sectoral approach in assessing the optimal emissions reduction consistent with a net zero goal. Very few studies to date, however, have integrated emissions reduction strategies with economic policies. In particular, the link between economic rebalancing and emissions reduction for China has so far been explored by only a few studies in a systematic way (e.g., IEA, 2017, Feng, Howes and Adams, 2014, He and Kujis, 2007). This paper takes a comprehensive and forward-looking quantitative approach and aims to evaluate the impacts of macroeconomic policies, including rebalancing, combined with climate policies on China's CO_2 emissions. A global dynamic computable general equilibrium (CGE) model—the IMF-ENV model[7]—calibrated to China's economic parameters provides a particularly well-suited framework to analyze the macroeconomic impacts of climate policies. It links economic activity to environmental outcomes and provides scenario analysis and quantitative policy assessments that are internally consistent.

To help quantify the economic and CO_2 emission impacts, the paper sets out to evaluate potential policy avenues reflective of China's climate goals and their resulting paths and cost of adjustments, using the IMF-ENV model. Specifically, there are four types of policy scenarios under consideration, the first one being a scenario that incorporates the announced policy actions so far, while the

[6] Despite accounting for a significant decline in the energy intensity of GDP. Other studies project emissions growth for China of around 15-30 percent over this period (e.g., CAT 2020, Den Elzen and others 2019, Li and Qin 2019, Tong and others 2018).

[7] The IMF-ENV model has been only recently operational at the IMF, but some aspects are still under development including the drafting of a documentation. Meanwhile, readers interested in the model can consult the documentations of the twin models IMF-ENV is built on: the "ENVISAGE" model (van der Mensbrugghe 2019) and the "OECD ENV-Linkages Model" (Château, Dellink, and Lanzi 2014).

subsequent scenarios reflect additional policies. All the policy scenarios are compared against a BAU baseline scenario:

- ***Base action:*** This scenario assumes that all countries implement carbon pricing consistent with reaching their 2030 NDC targets along with a move towards a world of net zero GHG emission (NZE) in 2050. In this scenario, Chinese GHG emissions would "peak" around 2028—consistent with China's NDC goals of peaking before 2030—and then start to decline drastically to reach net zero emissions by 2060. Technically, the model's timeframe ends in 2050, but the amount of CO_2 in 2050 is calibrated such that a continuation of the same policies for the next decade would yield a net zero result. In this "conservative" scenario, the Chinese power system is still characterized by some market imperfection while maintaining the current features of the broader Chinese economy (e.g., high investment in infrastructure, heavy industry predominance and investment-oriented growth).
- ***Earlier CO_2 emission peak (in 2023):*** Intensifying decarbonization efforts sooner than currently envisaged is likely to save costs and reduce unforeseen risks of delays. More intensive decarbonization efforts in the near term will allow for a smoother pace of adjustment that carries lower GDP costs as the climate benefits and positive technological spillovers from supporting green technologies will materialize earlier. An earlier peak would also reduce the risks of delay at the expense of future generations, especially if technology does not develop as expected, or China's overall growth path changes unexpectedly to the downside.
- ***Power market reforms:*** Reforms to the power sector would allow the cost of mitigation policies to be passed forward to electricity users by enabling generators to adjust quantities and electricity prices in line with demand and supply—including between renewable power generators and firms through direct electricity trading—as well as in response to the carbon price signal of the national Emission Trading Scheme (ETS).
- ***Economic rebalancing:*** Rebalancing from traditional, construction-heavy investment to more consumption-led growth would translate into a shift from heavy industry and construction towards less carbon-intensive sectors like services (including education and health) and *high value-added goods*. This structural change will reduce the energy and carbon emission intensities of output and, therefore, reduce overall CO_2 emissions while contributing to a more balanced growth path by lowering the investment as a share of GDP.[8] Decreasing the energy intensity of China's GDP through rebalancing would also lessen its energy demand and ease the pressure for energy security—in particular, the dependence on coal, the largest source of energy generation.

The bottom three scenarios have the significant advantage of allowing China to enhance its climate ambition and action while addressing sustainable growth objectives. The model simulations incorporate a sequence of layered policies based on the scenarios discussed above and provide projections for the path of a carbon price—or a shadow price of carbon if, in practice, the path would be met through a mix of pricing and non-pricing measures—compatible with China's envisaged transition to carbon neutrality. The comparison of these projected carbon price paths, along with the expected GDP costs associated with the transition across these policy scenarios, reveal the extent of China's climate ambitions. It must be noted, however, that model projections of costs and prices are inherently, and increasingly, uncertain over the medium to longer term—for example, the future viability and costs of "future" technologies (e.g., hydrogen, carbon capture and storage, and direct air

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[8] See Mano and Zhang (2018) and Zhang (2016) for a detailed analysis of China's investment-heavy growth model and the need for economic rebalancing from a growth perspective.

capture) are especially speculative. GDP costs are also sensitive to the use of potential carbon pricing revenues.[9]

The results of the model simulations are insightful, however, as they allow for comparing the impacts of policy mixes on the entire economy in equilibrium. The results highlight a gradual decrease in the associated shadow price of carbon reflective of each scenario's policy, indicating reductions in inefficiencies. At the same time, the average annual GDP cost in the policy scenario relative to the BAU case also declines as policies progress from the 2030 peak scenario to a more optimal scenario with early peak in emissions, reforms in the power sector, and economic rebalancing.

The paper also analyzes the distributional implications of the policy measures based on the associated shadow price of carbon. The incidence analysis uses household surveys and input-output tables to highlight the channels of how a carbon tax would affect households. First, calculations based on input-output tables show how higher energy prices induced by a carbon tax would lead to higher consumer prices in energy and non-energy related goods. Second, combining these higher consumer prices with household surveys, the analysis quantifies the negative impact on welfare based on the household expenditure bundles. Lastly, the analysis provides policies that could be implemented to compensate households, reduce inequality, and build support for adoption.

The main results of the paper are:

- By deploying a combination of climate policies centered around rebalancing, China can not only greatly reduce the cost of decarbonization, but this would also help it achieve high-quality growth. Specifically, simulation results based on a dynamic computable general equilibrium model show that the deviations in average annual GDP cost relative to a business-as-usual baseline can be almost cut in half based on the adoption of a sequence of policies including frontloading mitigation, making the best possible use of available carbon pricing mechanism while enhancing power market reforms, and economic rebalancing.
- Economic rebalancing (*i.e.* structural change) towards a consumption-led growth model itself will significantly reduce carbon emissions. A strong reform effort to shift away from heavy-industry, such as construction and metal production, and towards less carbon-intensive service sectors will reduce the energy and carbon intensity of output and, therefore, reduce overall CO_2 emissions. Rebalancing alone can help reduce carbon emissions by about 15 percent over the next three decades.
- The results from the incidence analysis show that regardless of the policy scenario, poorer households tend to be more disproportionately affected by carbon pricing policies compared to wealthier households. However, an illustrative example of using 85 percent of the revenues collected from the carbon tax on labor tax reductions and 15 percent of the revenues on cash transfers targeting the bottom 25 percent of households shows that the negative impact would be offset, and carbon pricing combined with the revenue recycling can support reducing poverty and regional inequalities.

The next section presents an overview of the sources of China's carbon emissions. Section C highlights the main climate targets that have been announced to date, followed by Section D that provides an overview of key climate policies that have been implemented so far. The subsequent Section E presents policy recommendations for a 'road to net zero' relying on the projections from the

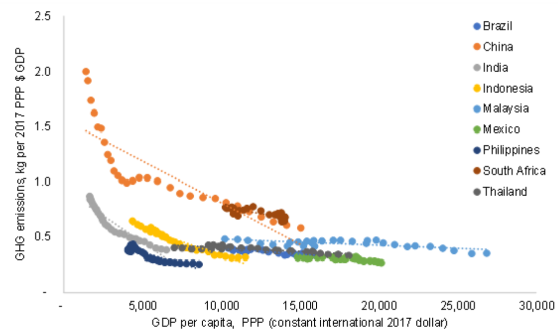
[9] GDP costs are different from emissions abatement or economic efficiency costs. The latter primarily reflect the annualized costs of using cleaner, but costlier, technologies while the former also include GDP effects arising from reallocations, adjustments, and aggregate changes in employment.

model simulations based on alternative policy scenarios. Section F provides the results of a distributive analysis based on the policy scenario simulations, and section G concludes with a discussion of the elements in the comprehensive policy package and provides some guidance on the implementation of these policies.

B. China's Investment-Intensive Growth Model and Resulting Carbon Emissions

China's rapid rise in CO_2 emissions is a consequence of China's investment-led growth model that for many years has relied predominantly on production from heavy industries. The latter's high energy intensity, coupled with dependence on carbon-intensive coal in power generation and industry, has resulted in China becoming, by far, the world's single largest CO_2 emitter. And although China's carbon intensity of GDP has declined rapidly since 1990, it remains high (see Figure 3) relative to most other emerging markets (EMs). This suggests that a successful climate strategy will have to significantly curb energy demand and, in particular, the high carbon content of energy supply.

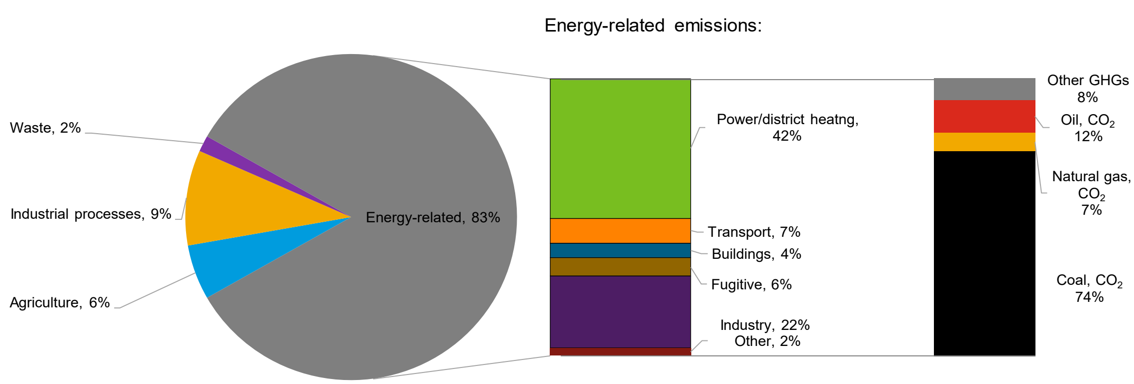
Figure 3. Carbon Intensity of GDP, Selected Countries



Sources: WRI (2021), WEO (2021)
Note: GHG excluding LULUCF, 1990-2018.

A breakdown of emissions reveals that energy-related CO_2 emissions accounted for 76 percent of China's 12.5 billion tons of GHG emissions in 2018 (see Figure 4). By sector, power generation/district heating accounted for 42 percent of China's GHGs. By fuel, combustion of coal, oil products, and natural gas accounted for 80, 13, and 7 percent of energy related CO_2, respectively.

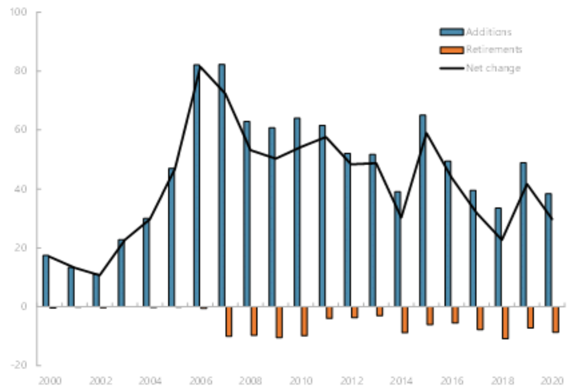
Figure 4. GHG Emissions by Sector and Fuel Type, 2018



Source: WRI (2021); IMF staff calculations.
Note: GHGs exclude emissions from LULUCF and international transportation.

The main reason for the high share of energy-related CO_2 emissions is China's heavy reliance on coal for its power generation, representing almost 70 percent of power generation, in comparison to only 3 percent for gas, whereas (carbon-free) hydro, nuclear, wind, and solar accounted for 17, 4, 5, and 2 percent, respectively.[10] The lion share of energy consumption went to industry, accounting for 76 percent of electricity consumption in 2018, while households consumed 14 percent, transportation 2 percent, and other energy use made up 9 percent of usage.

Figure 5. China's Newly Added and Retired Coal-Fired Capacity by Year, GWh



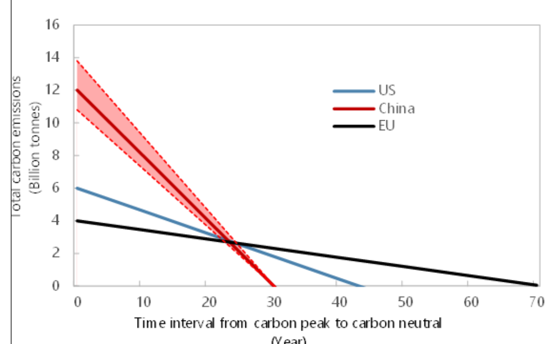
Source: Global Energy Monitor and IMF staff calculations

As a result, China's consumption and production of coal is the biggest in the world. In fact, in 2019, China's consumption of coal exceeded the amount consumed by the rest of the world combined (Sandalow, 2020). Substantial construction of new coal-fired power plant capacity continued throughout 2020 (Figure 5), with about 7.5 GW of net new capacity added in the first half of 2021 (though this is less than one percent of its existing coal generation capacity). This heavy reliance on high-energy intensity production, coupled with the dependency on coal for fuel, poses a challenge to China's long-term climate ambitions and has recently contributed to frictions between China's climate goals and its power system (see next section). Going forward, any plans to decarbonize China will have to factor in a careful phasing out of its high coal consumption and inevitably force a rethink of China's high-energy intensive growth model.

C. Overview of China's Climate Targets

President Xi Jinping's announcement of China's commitment to net-zero CO_2 emissions by 2060 on September 22, 2020 in front of the United Nations General Assembly marked a significant turning point in China's climate ambitions.[11] While China had announced a goal of CO_2 emission peaking before 2030 earlier, the carbon neutrality ambition was unexpected and important.[12] Compared to other major polluting countries, the time between emissions peak and net zero, however, is more compressed for China (Figure 6).

Figure 6. Illustrative Efficiency Frontier



Sources: Our World in Data, World Bank, CICC Research, Tsinghua University

Notes: t=0 represents the time when carbon peak is reached. The range in China's peal CO_2 emission for 2030 is based on values from 2020 CO_2 emissions (low) and projected 2030 CO_2 emissions by Tsinghua University

As of date, more concrete details on how exactly China intends to fulfill its carbon neutrality goal have yet to be revealed. The Chinese government has

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[10] IEA (2021a).

[11] Net zero implies that some sectors can still emit positive amounts of emissions if they are offset by negative emissions elsewhere (e.g., through forest carbon storage or direct air capture). In addition, the target is limited to CO_2 emissions and excludes, for example, methane releases from agriculture and waste.

[12] China's Pledge to Be Carbon Neutral by 2060: What It Means - The New York Times (nytimes.com)

so far published a high-level overarching working guidance on how to achieve carbon neutrality, with more sector-specific directives to follow. Together, they make up the so-called “1+N” policy framework, with “1” referring to the overarching plan spanning ministries and sectors, and “N” indicating the number of plans covering sectoral-specific policies. As of now, these plans only contain China’s main climate objectives, as stated in the most recent Five-Year-Plans—a comprehensive policy blueprint released by China every five years to guide its overall economic and social development over the medium-term—specifically, for the 14th Five-Year Plan (FYP) period (2021-2025) and the 15th FYP period (2026-2030).

Relying on medium-term policy frameworks is an established way for China to implement its policy objectives. This approach also applies to its climate goals, which have been featured in the medium plans since the 12th Five-Year Plan (2011-2015) in the form of binding reduction targets for energy intensity, total energy consumption, and carbon intensity. The latest 14th FYP contains key interim climate targets. Specifically, the 14th FYP plan stipulates the following binding targets:

- 13.5 percent reduction for energy intensity between 2021-2025,
- 18 percent reduction of CO_2 intensity of GDP between 2021-2025, and
- An improvement of the forest coverage rate from 23.4% in 2020 to 24.1 percent in 2025.

So far, China has adhered to its binding FYP climate targets in each of the two preceding 5-year periods, but the pandemic has brought complications.[13] The unbalanced nature of China’s recovery from the pandemic recession has led to a significant jump in energy consumption in 2021. Heavy industries like steel, non-ferrous metals, chemicals, and building materials like cement and glass have led the charge to satisfy increased manufactured export demand and the boom in domestic construction and infrastructure investment. As the recovery in consumption and services continues to lag, the share of the secondary industry—with its much higher energy intensity in GDP—has increased in both 2020 and 2021. This posed difficulty in fulfilling annual climate targets at the provincial level and, together with other factors, contributed to temporary power crunches across several provinces in the second half of 2021.[14]

The announced climate targets also indicate a slow and incremental start in the reduction of CO_2 emissions in the near term and leave the heavy lifting until after 2030. Hypothetically, assuming that GDP growth evolves roughly in line with the IMF WEO projections, even if carbon intensity falls by the targeted amount, there is a risk that CO_2 emission levels could still increase and force a much more intensive decarbonization effort after 2030. For example, allowing coal capacity to increase in the near term could require sharp capacity reduction down the road. The absence of absolute caps on coal use—new coal plants might be forced to retire early given their average lifespan of around 50 years—and carbon emissions leaves room for emissions to increase over the next several years, implying sharper policy shifts later on—and if the availability and costs of clean technology alternatives like solar do not evolve as expected, or future growth paths change unexpectedly on the downside, China will have made it even tougher for future generations to curb emissions.

[13] These national targets are generally translated into provincial and annual targets. For instance, the target of cumulative reduction in energy intensity for the 14th FYP translates to about 3 percent per year and was further disaggregated into binding annual provincial targets. Similarly, the target for average annual growth in total energy consumption was set at 2 percent.

[14] At the height of the power shortage in October, factories in 20 provinces experienced either slowdown in or suspension of production, while the bulk of the Chinese population that lived and worked in those regions also suffered from electricity blackouts.

D. Other Climate Mitigation Initiatives

In addition to the medium-term climate targets discussed above, China has a host of existing initiatives to foster low-carbon development. This section highlights several of them that will likely play an important role in achieving the authorities' climate agenda but will also require substantial reforms and improvements to foster low-carbon development.

Carbon Pricing

A central component of China's efforts to implement its mitigation objectives is the recently launched national emissions trading scheme (ETS). In its first cycle in 2021, the system is applied downstream at the point of fuel combustion to 2,225 entities in the power and district heating sector, with annual emissions exceeding a threshold level.[15] Currently, the ETS covers about 40 percent of China's CO_2 emissions—reportedly, the government intends to extend coverage to cement and aluminum next, followed by iron and steel, nonferrous metals, petroleum refining, chemicals, pulp and paper, and aviation (which would extend coverage up to about 70-80 percent). The national ETS will progressively replace six regional pilot ETSs that have been operating since 2015. Since the opening of the allowance trading market in July 2021, prices have been hovering at around $6-8 per ton (see Figure 7).

Figure 7. ETS Trading Prices and Volumes

Source: Shanghai Environment and Energy Exchange (CNEEEX)

Unlike other ETSs (e.g., in the EU, California, and Korea) the cap in China's ETS is not set exogenously; instead it varies endogenously with production levels and other factors. The cap is built up from allowance allocations that are linked to recent production levels and benchmark emission rates per MWh, where (to ease burdens on coal intensive regions) benchmarks are much higher for coal plants than natural gas. The emissions cap is also adjusted ex-post based on actual production levels and higher future production, increasing future emissions caps. Declines in capacity utilization can also increase future emissions caps, as extra allowances are awarded to plants operating with low load factors. Coal plants are only required to cover emissions up to 20 percent above benchmark allocations with allowances—beyond this, their emissions can expand without any need to acquire allowances for the extra emissions. In short, there is currently no guarantee that aggregate emissions covered by the ETS will stabilize, let alone decline over time. See Annex 2 for further details on the ETS.

In its current setting, emissions reductions under China's ETS are unlikely to be cost effective.[16] The Chinese ETS implicitly subsidizes electricity output using an intensity-based benchmark rather than caps, which limits the use of output-reduction as a channel for reducing emissions. It also gives

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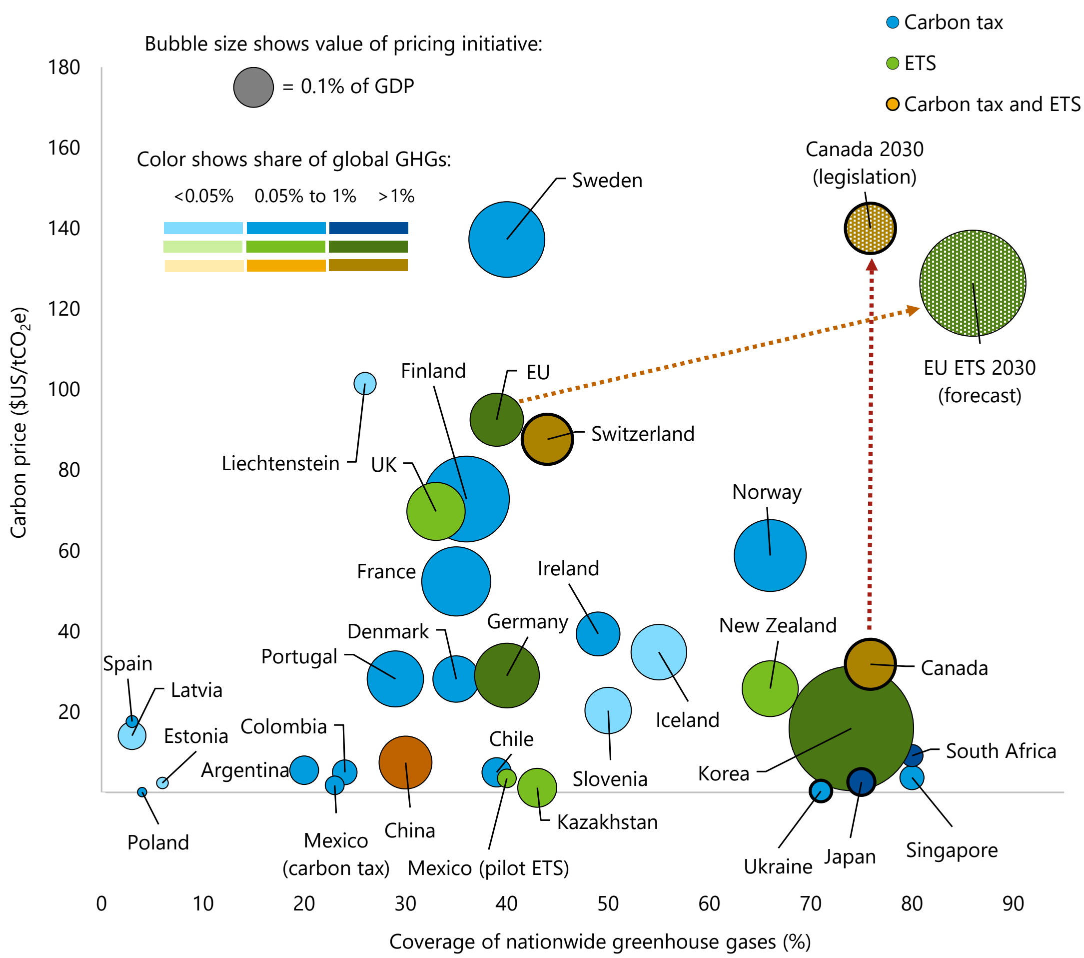
[15] 26,000 tons of CO_2, which is roughly equivalent to the annual emissions of a small 5 MW coal-fired power plant.

[16] See Goulder and others (2021) for further discussion of these inefficiencies.

power plants with especially low emissions-output ratios incentives to expand output relative to baseline levels. The use of differing benchmarks also compromises cost-effectiveness by distorting relative production levels and by lowering the cost-reducing potential of allowance trading. For example, since allowance allocations adjust based on actual output, only units with emissions intensity above the benchmark will have incentives to reduce CO_2 emissions by curtailing output.

Figure 8. Selected (National and EU Level) Carbon Pricing Schemes in 2021



Sources: An update of Figure 1 in Parry and others (2021c), Figure 1.

Institutional features of the power sector in China may further undermine mitigation responses and cost effectiveness. In China, power dispatch and pricing are commonly determined by administrative mechanisms, as power generators receive multi-year contracts to supply certain amounts of energy at specified prices. China generally lacks markets for trading power, making it difficult for provinces with a lot of coal fired plants to purchase renewable generation from other provinces. These obstacles are further exacerbated by a lack of reliable transmission lines. And, as most coal-fired power plants are state owned enterprises (SOEs), the burden of carbon pricing may be largely reflected in losses for local governments rather than higher electricity prices for industry and households. Nonetheless, the sector has been undergoing continual reform since 1985, when the state monopoly ended, and currently about a third of electricity output is sold at market prices.[17] Spot market trading was introduced during the Five-Year Plan for 2016-2020 for a few select provinces, and there has been more market trading activity in longer term contracts, though competition remains lacking in general. Further reforms might be initiated in the upcoming 5-year plan of the National Energy Agency.

Most other national carbon pricing schemes have greater coverage and higher emissions prices than in China, though in part because other schemes were established earlier (and have since been strengthened). Of the 30 national pricing schemes and the EU scheme (illustrated in Figure 8), 22 have greater coverage than China's scheme and 19 have higher carbon prices. Indeed, global momentum for carbon pricing is increasing. Aside from the launch of China's scheme, a major pricing scheme was recently implemented in Germany, prices in the EU ETS have risen above US $90 per ton, and Canada has announced its minimum carbon price will rise to US $135 per ton by 2030.

Fuel taxes

China has taxes in place on most fossil fuel products (see Table 1)—most notably for coal—which would be straightforward (from an administrative perspective) to ramp up to reinforce mitigation incentives. Most of the CO_2 reductions under an economy-wide CO_2 price would come from reductions in coal use (see below), with a far more moderate contribution from reduced use of oil products and natural gas; taxing coal alone is therefore a relatively effective way to cut nationwide emissions. China has an excise tax on coal which is effectively on consumption. The tax is levied at the mine-mouth coal plants, but it also covers imported coal and is rebated for exported coal. For power and industrial coal consumption, however—together accounting for 77 percent of economy-wide CO_2 emissions—the excise is equivalent to only a modest charge of $3-4 per ton of CO_2. Indeed, local air pollution damages from coal are around 25 times the current tax.[18] China has a higher tax on power and industrial use of natural gas—equivalent to $70 per ton of CO_2—but they only account for 5 percent of economy-wide CO_2 emissions. Gasoline and diesel taxes are higher still—$168 and $65 per ton of CO_2, respectively—though again, road fuels are a relatively modest share, 8 percent, of nationwide CO_2 emissions, and (as in other countries) these taxes fall well short of the full range of environmental costs of vehicle use.[19]

Table 1. Effective Carbon Tax Rates in China, 2020

	Power			**Industry**			**Transport**			**Residential**	
Sector/fuel type	coal	natural gas	other fossil fuels	coal	natural gas	other fossil fuels	gasoline	diesel	other products	coal	natural gas
Share in CO_2 emissions, %	47	1	0	30	4	3	4	4	1	2	1
Effective carbon tax equivalent, $ per ton tCO_2	3	70	6	4	70	35	168	65	27	-3	-24

Source: IMF staff calculations
Note: Tax rates include fuel excises and subsidies. VAT is excluded as it applies to all consumer goods

[17] Ho, Wang, and Yu (2017).

[18] Parry and others (2021a), Figure 1.

[19] Including local pollution, traffic congestion, accidents, and road damage. See Parry and others (2021a).

E. Policy Simulations for China's Road to Net Zero

What strategy will lead to Net-Zero emissions? Ideally, a robust carbon price reflecting China's climate goals would be the approach of choice to rein in carbon emissions because it provides the right incentives for all market participants to seek and implement the most cost-effective ways of reflecting these goals. For political and other reasons, however, it is not a feasible strategy for China at this point. A *best-available* strategy, combining existing and new economic policies with innovative climate policy instruments, could provide the necessary economic incentives to reduce emissions. Given China's investment-led growth model, with heavy reliance on energy-intensive sectors and powered by coal, macroeconomic policies and market-based reforms will have to play an important role in reducing the energy intensity of growth while incentivizing the transition out of coal. This section explores the effects of a combination of policies that include an earlier emissions peak, economic rebalancing towards a more consumption-based growth model, and the use of existing carbon pricing tools under improved market conditions.

This paper uses the IMF-ENV model to conduct simulations on a variety of scenarios, each associated with a specific policy. IMF-ENV is a recursive dynamic neo-classical, global, general equilibrium model, built primarily on a database of national economies and bilateral trade flows.[20] It is well suited for the analysis of climate mitigation policies over a long-time horizon because the detailed representation of economic sectors allows capturing the structural changes of the economy resulting from implementation of the policies. Moreover, the model also includes a full set of bilateral international trade flows, allowing assessing trade and competitiveness impacts of (coordinated or uncoordinated) global climate actions. The model also includes vintage capital stocks, implying both time-to-build adjustment cost for investment and limited substitution possibilities between inputs in the short run relative to the long run.

The choice of model comes with certain tradeoffs. In the very long run, the model may overestimate the cost of decarbonization since it does not consider radical technology innovations that could materialize at this longer horizon—such as hydrogen, carbon capture, and storage technology, among others. Moreover, currently, the model does not account for long run benefits of moderating global temperature changes. At the same time, in the short run, the cost of the transition dynamics could be underestimated since most commodity markets (electricity excluded) as well as the labor market are assumed to be almost perfectly competitive; in the case of labor market, it implies that workers can move from any job to another without any cost. Moreover, the model has representative agents making it difficult to assess the distributive impacts of the scenarios (see section VI). Lastly, while the model can show the impact of policies on air pollutants, the corresponding co-benefits of reducing air pollutants are not directly incorporated in the model. To complement the macroeconomic analysis, in a later section, the CPAT model is used for the distributional and incidence analysis on the impacts on households.

The world economy in the IMF-ENV model is disaggregated into 10 separate regions, including China, India, Japan, and the United States and 55 economic sectors. The main sectors contributing to GHGs emissions are modeled separately, including five fossil fuel goods (coal mining, crude oil, refined oil, gas extraction, and gas distribution), eight power generation sectors (coal, oil and gas-powered electricity, hydro power, wind, solar, nuclear, and other power), and five energy-intensive

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[20] See Appendix 3 for more details on the model. A complete description of the model, its calibration and baseline projection will be released soon in a forthcoming WP.

and trade exposed (EITE) industries (iron and steel, non-metallic minerals, chemicals, pulp and paper, and non-ferrous metals).[21]

After feeding the different policies into the IMF-ENV model, it captures the shadow price of carbon compatible with China's envisaged transition to carbon neutrality and maps the different sources of GHG emissions directly into the associated economic activities. The model then shows a comparison of economic costs across scenarios, measured by deviations in real GDP. It also projects structural changes in the sectoral composition of the economy and changes in international trade patterns.

This paper compares four main policy scenarios against a business-as-usual (BAU) baseline. In particular, apart from the first policy scenario, all subsequent policy scenarios are nested, with each one building on the policies of the previous scenario. The main indicators under evaluation across all policy scenarios are the projected path of carbon price, the real GDP costs, and path of CO_2 emissions. While the results are presented up to 2050 for expository purpose, projections after 2035-2040 are highly speculative since disruptive technological innovations (e.g., hydrogen, carbon capture and storage, direct air capture, advanced nuclear, among others) could materialize at longer horizons but are not explicitly incorporated in the current simulations. Therefore, results after 2035-2040 are indicative and should be interpreted more in qualitative than precise quantitative terms.

I. Baseline (BAU) Scenario

Macroeconomic projections for the BAU scenario are based on the April 2021 WEO up to 2025 and longer-term growth projections assume that country income levels (e.g., GDP in PPP per capita) converge towards those of most developed economies. Other assumptions are chosen to project changes in sectoral production and demand patterns (including those implied by accelerated population ageing in China) in line with known stylized facts. Income elasticities for energy and other goods ensure that increases in GDP per capita reduce budget shares for necessary goods like electricity and food. Over time, income elasticities are assumed to converge towards those for advanced countries as income per capita rises. Similar assumptions are made for conditional convergence towards the production cost-structure and sectoral productivity of more advanced countries. This BAU scenario acts as the base "layer" for the subsequent policy scenarios.

II. Base Action Scenario

The first policy scenario is constructed assuming all countries implement carbon pricing and public investments in the power sector and transmission/distribution of electricity consistent with reaching their 2030 NDC goals, along with a move towards a world of net zero emission (NZE) in 2050. In this scenario, Chinese emissions would "peak" around 2028—consistent with China's NDC goals of peaking before 2030—and then start to decline drastically to reach zero emissions in 2050.[22] In this conservative policy scenario, the broader Chinese economy is projected as investment-focused, reflecting China's relatively high investment in infrastructure, large share of heavy industry, and generally investment-oriented and export-oriented growth pattern. In addition, the IMF-ENV model includes some of the existing imperfect market functioning in China's power sector owed to state-ownership and regulations through an ad-hoc markup on electricity selling price, calibrated based on

[21] See Appendix 3 for more detailed calibration of the model.

[22] As discussed earlier, while China's climate goal envisages zero emissions only by 2060, it is also assumed that the remaining CO2 will be eliminated through the decade between 2050-2060, including a 20 percent reduction through carbon capture storage utilization (CCUS). The very large uncertainty especially around technology towards the end of the simulation horizon make the earlier endpoint chosen here less of an issue.

information provided by IEA (2019), where the extra "pure profit" is retained by the government budget. By incorporating an approximation of the price rigidities in the power sector into the model, the projected shadow price also captures important real-word limitations in market-based approaches to reducing carbon emissions in China.

III. EARLY EMISSIONS PEAK SCENARIO

The "Early Peak" policy scenario assumes CO_2 emissions peak in 2023 while all other assumptions remain the same, including the power market rigidities. Carbon pricing is the main instrument that drives the emissions' pathway in this policy scenario. While this scenario assumes the same *cumulative* amount of CO_2 as the base action scenario, more intensive decarbonization efforts in the near term allows for a smoother pace of adjustment. This implies lower GDP costs from reaping earlier benefits of positive technological spillovers from supporting green technologies.

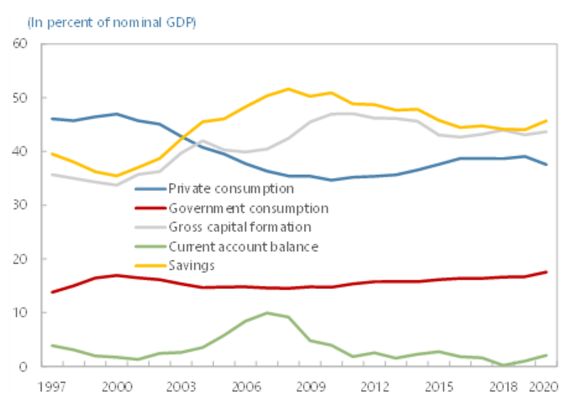
IV. POWER MARKET REFORMS SCENARIO

In addition to the early peak in emissions, this scenario also assumes market-based power sector pricing. Market reforms to the power sector can make carbon pricing more efficient by allowing a better pass-through of prices onto final consumers. By reducing the rigidities in the power sector and letting electricity prices adjust more freely, the simulation results are expected to yield a lower shadow price that is needed to accomplish a similar net zero carbon path.[23] More generally, a regulatory framework to effectively mobilize power system flexibility would ensure that carbon pricing would be passed through onto final consumers, thus reducing the demand for energy as well as incentivizing a shift away from fossil fuels towards renewable energy sources. In practice, power market reforms might include establishing spot markets, allowing short-term energy trading between provinces, and upgrading transmission connectivity to bring more renewable energy online.

V. ECONOMIC REBALANCING SCENARIO

The last policy scenario adds economic rebalancing to the existing policy mix of early decarbonization and power market reforms. The share of investment in China's GDP remains high, pointing to continued domestic

Figure 9. Aggregate Demand and Current Account



Sources: IMF World Economic Outlook, IMF staff calculations

[23] Incorporating the exact rigidities of the Chinese power market into the IMF-ENV model is beyond the paper's scope. Technically, it is assumed in both the power market reforms and the economic rebalancing scenarios that the same climate policies as in the "Early Peak" scenario are implemented but under a different economic environment where the electricity market is not characterized by market power in electricity supply.

imbalances.[24] While the share of private consumption has been rising during the last decade, it remains significantly below its end-1990s level (Figure 9) and that of peer economies. A key driver of the domestic imbalances is China's unusually high household saving rates, partly reflecting precautionary savings needs related to gaps in the coverage and limits in the adequacy of the social protection system. Continued very-high investment, including in construction, will likely mean falling productivity and lower efficiency, driving up already-high debt and further elevating financial risks.[25]

Rebalancing will also support high-quality growth while reducing carbon emissions. A shift away from heavy-industry such as construction and metal production and towards less carbon-intensive service sectors will reduce the energy and carbon emission intensity of output and, therefore, reduce overall CO_2 emissions. Rebalancing towards a more consumption and services-based economy has been a consistent priority in the last several FYPs.

In the model, the rebalancing scenario assumes a significant decrease in the investment share of GDP—by about 15 percentage points over the next three decades—to levels more similar to those in advanced economies in the region, while the share of consumption in GDP increases over this period (2020-2050).[26] The channel to achieve the economic rebalancing is primarily through the decrease of household savings. But other channels of the Chinese economy's transformation are assumed, following chapter 15 of the "2017 World Energy Outlook" report (IEA, 2017), such as a higher contribution of services both in the production process (servicification of industries) and in total value added (driven by increasing needs in education and health).[27]

VI. Simulation Results

This section presents the simulation results with each of the four policy scenarios described in turn.

Base Action Scenario. The relatively late peak in CO_2 emissions in this scenario (in 2028) highlights the backloaded nature of China's decarbonization path compared to countries that have much longer time horizons between their emissions peak and net zero goals. Figure 10 illustrates the CO_2 emission paths associated with the respective scenarios. For ease of comparison, the cumulative carbon emissions for the base action and early peak scenarios are set to similar levels.

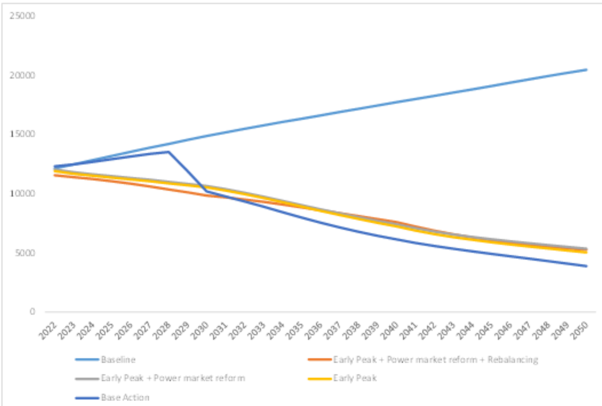
[24] See more details about the reasons behind China's high savings rate in Zhang and others (2018), "China's High Savings Rate: Drivers, Prospects, and Policies."

[25] See IMF China Selected Issues Paper 2021, "Adequate Social Protection for All."

[26] The starting point is in line with China's high investment share compared to other countries with similar growth rates (see Zhang and others, 2018). Moreover, China is also widely expected to become a high-income country during this period between 2020-2050, which would also help increase the consumption share of GDP.

[27] The macroeconomic analysis on China's economic rebalancing provided in the 2017 IEA World Energy Outlook has been performed with the OECD ENV-Linkages which is a very similar to the IMF-ENV model and therefore similar assumptions have been adopted here.

Figure 10. CO_2 Emission Paths by Policy Scenario
(Million Tonnes of CO_2)



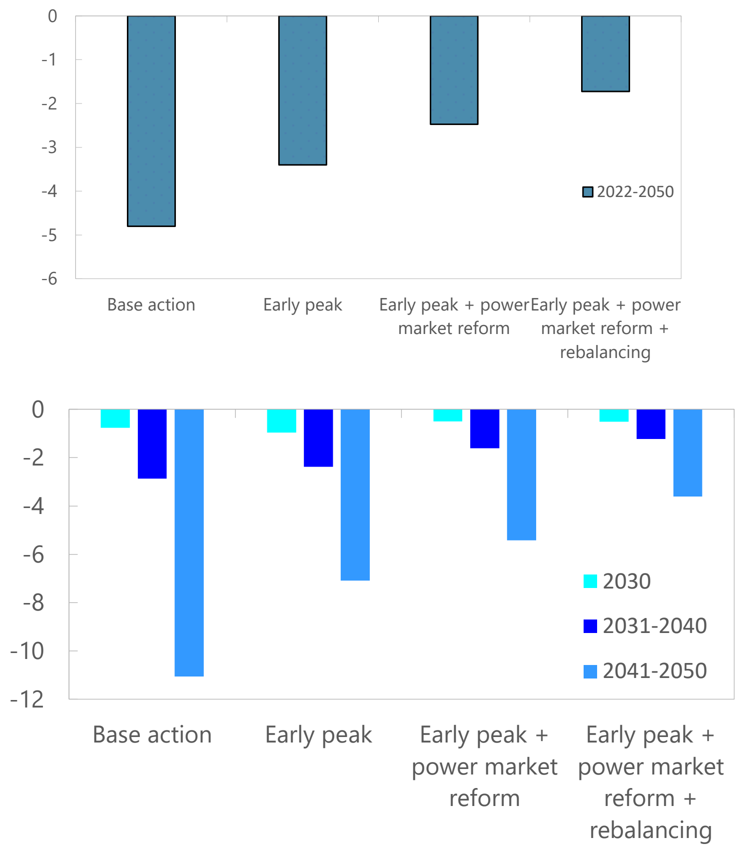
Notes: CO_2 includes all sources, including LULUCF.
Sources: IMF-ENV model; IMF WEO; and IMF staff calculations

Based on the simulation results for this scenario, the relatively delayed path of decarbonization comes with higher abatement cost. As illustrated in Figure 11, while the average annual deviation in real GDP associated with this base action scenario is almost 5 percentage points across the whole time period (2022-2050), it tends to be especially large in the last decade—around 11 percentage points between 2041-2050. The larger cost reflects the shift in the decarbonization efforts to later years, and thus, the need to compress the efforts into a shorter timeframe, making it harder to defray the adjustment cost over time. In turn, the costs in year 2030 is lower in the base action scenario compared to that in the early peak scenario, reflecting the inactions in the former scenario that bear a higher price in later decades. While the associated carbon price in the base action scenario starts at a lower level, it rises at a steeper rate after 2028 compared to the carbon price trajectory reflecting the earlier peak scenario and continues its steep increase throughout the later decades (Figure 11).

Note that the average annual deviation in real GDP tends to increase in later decades regardless of the policy scenario. While these costs might be lower in the real world as the model is limited by technologies that are available today while not incorporating technologies that are introduced in later periods potentially contributing to cost reductions, it should also be noted that the introduction of new technologies in later periods take time to develop, and gains are not certain to be realized in time, especially in the case where no serious mitigation policies are put in place early on, e.g., in the base action scenario of late emissions peak.

Figure 11. Abatement Costs by Policy Scenario and Time Range

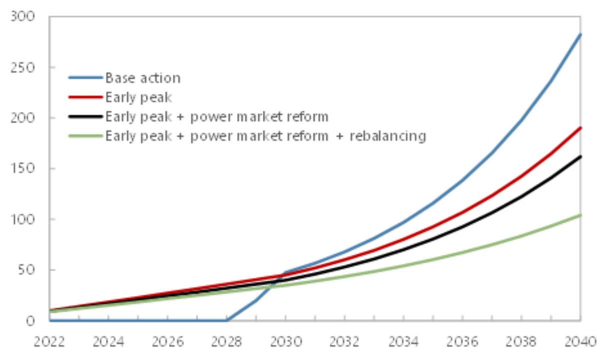
(Average Annual Deviation in Real GDP from BAU in Percentage Points)



Sources: IMF-ENV model; IMF World Economic Outlook; and IMF staff calculations.

Notes: Numbers based on simulations using a dynamic computable general equilibrium model and are average real GDP deviations between the respective scenario vs. business-as-usual. Early peak assumes a peak emission in 2023. Scenarios without power market reforms assume price rigidities, and rebalancing assumes shift from investment share to consumption share of GDP.

Figure 12. Carbon Price by Policy Scenario
(USD/Ton of CO_2)



Sources: IMF-ENV model; IMF WEO; and IMF staff calculations

Early Emissions Peak scenario. Keeping the cumulative emissions over 2022-2050 and other policies unchanged, delaying the peak results in a more intensive decarbonization effort later—as exhibited by the steeper slope of the emissions projection into the outer years (Figure 12). An earlier emissions peak also results in lower abatement cost as well as a lower shadow price of carbon—that is, the necessary carbon price commensurate with NZE by 2050—compared to a later peak. While it is slightly more costly in the immediate years, the extra effort in decarbonization in the earlier years is more than compensated by the larger reduction in abatement cost in the later decades (Figure 11 bottom panel). The earlier emissions peak scenario has an average annual deviation from the BAU baseline of about 3.4 percentage points of GDP across the entire time period, which is 1.4 percentage points lower than in the base action scenario. The difference is mostly driven by the much lower abatement cost of the early emissions peak scenario during the last decade of the reduction effort of almost 4 percentage points of GDP. In contrast, the difference in cost for 2030 is only around 0.2 percentage points.

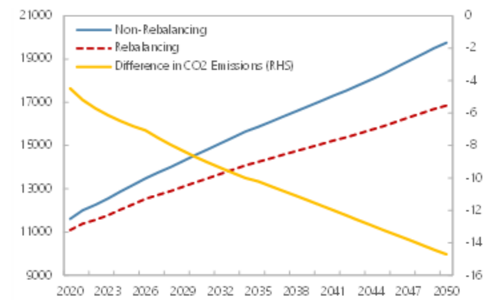
Power Market Reforms. On top of the early emissions peak, the addition of power market reforms that ensure a market-based setting of pricing and quantities yields further efficiency gains and cost reductions to the decarbonization process. The implementation of the national ETS in the power sector with an additional improvement of price signals to final consumers raises incentives for consumers to lower overall energy demand and fossil fuel-based energy sources. It also leads to increasing investments into renewables. For the entire period of 2022-2050, the average annual deviation in real GDP from the BAU baseline decreases by almost 1 percentage point from the early peak scenario and a little over 2 percentages points compared to the base action scenario. Again, it is the latest decade that contributes to the major cost reductions. Similarly, the carbon price associated with the addition of power market reform is lower than those in the base action and in the early peak emission scenarios, respectively.

Economic Rebalancing. Finally, adding economic rebalancing—a significant shift from investment to consumption as share of GDP—to the previous policies of early peak and power market reforms further lowers abatement cost and the associated carbon price consistent with NZE in 2050 (Figure 11 and Figure 12). Compared to the base action scenario, the average deviation in real GDP from the BAU baseline over the entire time period is more than halved when combining early peak, power market reforms, and economy rebalancing, representing a reduction of over 3 percentage points. Here as well, the largest reduction occurs in the last decade, with the combined policy mix scenario able to reduce the GDP costs of more than 7 percentage points compared to that in the base action scenario for 2041-2050. The change is also pronounced when comparing the respective carbon pricing associated with the different policy scenarios. The 2040 carbon price, reflective of the base action scenario with a peak in 2028, is almost three times as high as the carbon price reflective of the combination of early peak, power market reform and rebalancing scenario.

A separate simulation helps to illustrate the importance of economic rebalancing in China's quest for climate mitigation. The rebalancing scenario assumes a reduction of 15 percentage points in the investment share of GDP and an increase of similar magnitude in the consumption share of GDP, while the current account is assumed to steadily trend towards zero. To help identify the impact of rebalancing, the path of GDP growth is kept constant across the rebalancing and non-rebalancing scenarios. The results show that rebalancing alone can significantly contribute to a reduction in CO_2 emissions, translating into a 15 percent reduction after three decades under the given assumptions (Figure 13). The fall in global CO_2 emissions would be around 4.5 percent compared to the non-rebalancing scenario.

Figure 13. Rebalancing vs. Non-Rebalancing: CO2 Emissions Projections

(LHS – Metric Tons of CO2, RHS – in Percent)



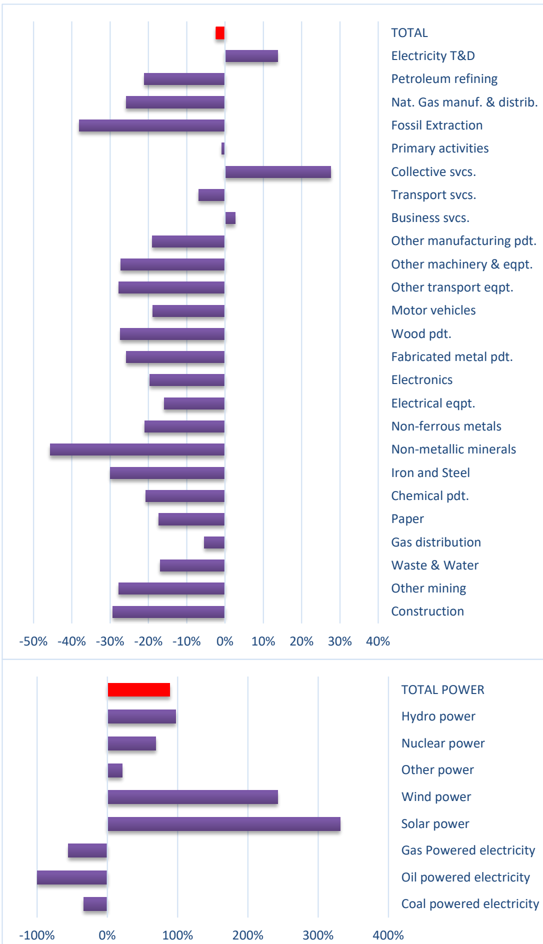
Sources: IMF-ENV model; IMF WEO; and IMF staff calculations.

VII. Sectoral Impacts

While the previous section evaluated the carbon price and real GDP costs of the policy scenarios at the aggregate level, the policies also prompt transitions and shifts in the economy, with differentiated effects across sectors. This section will highlight the sectoral impacts of the full policy scenario that incorporates all proposed policies and rebalancing. The aggregate adjustment cost for the full policy scenario relative to the BAU in terms of GDP deviation is around 2.3 percent in 2040 (Figure 11, lower panel), but economic sectors are affected very differently. Figure 14 below shows how the full policy scenario affects real value added at the sectoral level. While most sectors grow relative to 2019, emission-intensive sectors grow less quickly than in the baseline, and low-carbon sectors benefit from the changed incentives. Compared to the baseline, value added in fossil fuel extraction and transformation sectors decline by more than 40 percent. Energy-intensive sectors like EITE industries (i.e., chemicals, iron and steel and non-metallic minerals, pulp and paper) and construction are the most affected by both carbon policy and the economic rebalancing. The electricity sector benefits from the policies, as it adds renewable energy and improvements to the electricity grid. For services sectors, the picture is less clear. Publicly provided services (including education and health) expand relative to the baseline as they are not very energy intensive and benefit from the rebalancing of the economy, but transportation services that rely on fossil fuels are more negatively impacted despite the increase of electrification.

Figure 14: Changes in Sectoral Composition of Real Valued Added (at factor cost) in 2040

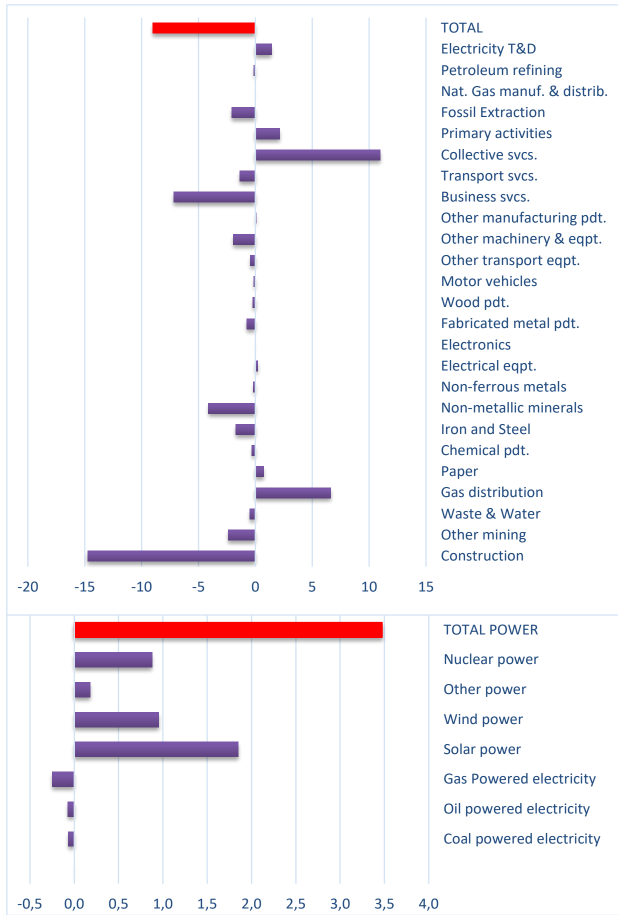
(Percent Changes of the Full Policy Scenario with Respect to Baseline)



Source: IMF-ENV Model

Figure 15. Changes in Sectoral Composition of Employment in 2040

(Difference in Millions in the Full Policy Scenario with Respect to Baseline)



Source: IMF-ENV Model

The power sector is particularly affected (bottom panel of Figure 14). Non-fossil fuel power generation expands to replace almost entirely fossil fuel power generation in 2040. These sectoral reallocations can create difficult transitions for firms and workers that will require careful policy planning.

Following these changes in value added, a significant reallocation of employment across sectors is shown in Figure 15. Construction and, to a lesser extent, fossil fuel sectors will lose substantial fractions of employment relative to today. Employment in total EITE industries in 2040 is also projected to be lower than today, while global employment was already projected to fall in some of these sectors under the baseline scenario due to China's large structural and demographic changes. In contrast, employment in the non-fossil fuel power sector increases by large amounts following the pattern of output changes in Figure 14. The service sectors also increase employment, as these sectors are labor intensive and benefit from the rebalancing of the economy.

VIII. Distributional Analysis

As indicated in the previous section, the sectoral shifts in production and employment imply significant distributional impacts on household incomes, creating important challenges, especially for the poor and most vulnerable households. This section evaluates household incidence impacts and discusses measures that could counteract the negative impact of carbon pricing on those most affected.

As the IMF-ENV model relies on representative agents, it cannot capture distributive impacts, thus, the main tool of analysis in this section relies on the Carbon Pricing Assessment Tool (CPAT).[28] The analysis is based on a two-step approach to assess the distributional impacts of the reforms: firstly, using input-output tables to calculate the effect of carbon pricing on different categories of consumer goods; secondly, mapping price increases to data on budget shares for different goods by household income group using household expenditure surveys that are embedded in CPAT.

Figure 16. Mean Effect on Consumption Deciles, *before* Revenue-Recycling by Policy in 2030

(% Change in Household Consumption Relative to Pre-Policy)

Early Peak + Power Market Reforms + Rebalancing

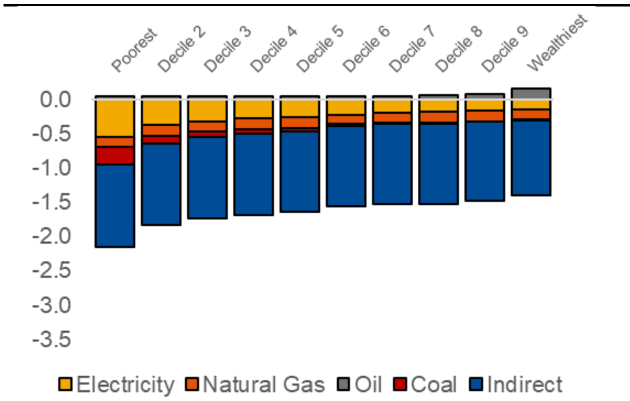
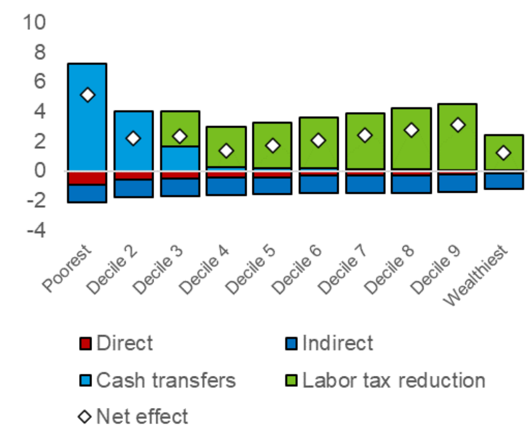


Figure 17. Mean Effect on Consumption Deciles, *after* Revenue-Recycling by Policy in 2030

(% Change in Household Consumption Relative to Pre-Policy)

Early Peak + Power Market Reforms + Rebalancing



Source: IMF Staff calculations.
Note: the panel shows relative to consumption impact of the carbon pricing scenarios on consumption deciles before revenue recycling through increases in prices of energy and non-energy goods.

The results (Figure 16) from the incidence analysis on the full policy scenario show poorer households tend to be disproportionately affected by carbon pricing policies compared to wealthier

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

households (this also holds true across other policy scenarios), consistent with long-established results that the impact on households from carbon pricing tends to be regressive.[29]

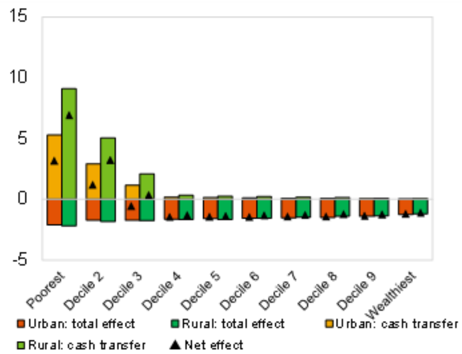
While the impacts from higher electricity prices are large (0.14-0.55 percent of consumption over 2020-2030), especially for lower income households, they are relatively small compared to indirect effects, with the latter being driven by increases in the price of general consumption goods due to higher energy costs in industries. Note that indirect effects are distributionally-neutral.

To the degree that the full policy scenario builds on the use of a carbon tax or similar approaches creating new fiscal revenue, revenue recycling (Figure 17) would offset the negative impact of carbon pricing on households, while targeted recycling could even make the reforms pro-poor. For example, if 85 percent of carbon tax revenues were used on general labor tax reduction and 15 percent on targeted cash transfers for the bottom 25 percent of households, all reforms would become progressive and pro-poor. Lower income households would be better off on net by around 2 to 7 percent of pre-policy consumption.

Figure 18. Mean Consumption Effect on Consumption Deciles, after Revenue-Recycling using Cash Transfers, by Policy in 2030

(% Change in Household Consumption Relative to Pre-Policy)

Early Peak + Power Market Sector + Rebalancing



Source: IMF Staff calculations.

Note: the panel shows relative to consumption impact of the carbon pricing scenarios on consumption deciles by urban and rural population, assuming 15 percent of revenues would be used for a cash targeted transfer (assumed targeting bottom 25 households with a 90 percent coverage and 10 percent leakage rate).

Lastly, revenue recycling can also be designed to enhance regional equity, since the rural poor households targeted by cash transfers would benefit more than urban households. In a different setup, for example, cash transfers might add from 10 to 13 percent of total consumption to the poorest rural households, bringing net effect of the reforms to 7-10 percent of consumption (Figure 18). The impact on the poorest urban households is lower: the net effect would be around 3 to 5 percent of total pre-policy consumption.[30]

IX. Policy Implications

Model simulations suggest that combining *(i)* an earlier emissions peak in 2023, *(ii)* power market reforms, and *(iii)* economic rebalancing will not only increase efficiency gains but also reduce the costs of climate mitigation. Implementing these goals will require a package of existing and new policies to provide the necessary economic incentives to reduce emissions. In particular, the package should include policies for improving and expanding the national ETS, complementary power market reforms, and macroeconomic policies to enhance economic rebalancing towards a more consumption-based growth model.[31]

While a pure carbon tax like the one in the model simulations might not be feasible, a next-best solution is to improve the national ETS. This includes extending to other sectors beyond power,

[29] See Appendix 4 for the outcome of the distributional analysis on the other scenarios.

[30] The analysis includes only the impact of cash transfers (15% of carbon revenues) targeting bottom 25 percent of households and assuming 90% coverage and 10% leakage. The analysis does not include the labor tax reduction.

[31] See the 2021 China Article IV Staff Report for a detailed roadmap of available policies.

consolidating multiple benchmarks into an absolute cap on emissions that is commensurate with an earlier peak or alternatively, through the implementation of a price floor that rises at a steady state aligned with China's mitigation objectives, and auctioning off allocation permits with revenues recycled via transfers to compensate vulnerable households and invest in green development.[32] Market reforms in the power sector can further enhance the effectiveness of the ETS by allowing generators to adjust quantity and electricity prices more freely to demand and supply.[33]

Policies to advance economic rebalancing need to address the high savings rates as well as the high investment rates. Greater fiscal support focused on strengthening social protection would reduce households' precautionary savings and facilitate the transition to consumption-driven and inclusive growth. Instead of traditional and brown infrastructure investment, shifting the composition of fiscal support towards vulnerable households could make countercyclical fiscal stimulus more effective. Similarly, a gradual and orderly transition of China's real estate sector—a big source of energy-intensive production and carbon output—towards a new sustainable growth path would also support economic rebalancing. More generally, economic rebalancing can offer more sustainable and equitable growth benefitting more households and helps the quest for carbon neutrality.

Given uncertainties over the future progress of institutional reforms to make carbon pricing more effective, an additional channel is to combine the ETS with a progressive increase in the coal tax—this is technically straightforward and is effective at reducing CO_2 and local air emissions but (like carbon pricing) may have challenging distributional impacts due to its effect on energy prices.

Carbon pricing could also be reinforced by other, less efficient but likely more acceptable, sectoral mitigation instruments. The detailed discussion in Appendix 5 focuses mostly on revenue-neutral feebates across many sectors, which provide a sliding scale of fees on products or activities with above average emission rates and a sliding scale of rebates for products or activities with below average emission rates. These reinforcing measures are less efficient than carbon pricing as they avoid significant increases in energy prices and therefore do not promote the full range of mitigation responses (e.g., they do not encourage people to drive less) that could be promoted by carbon pricing.

The distributional analysis shows that without any revenue redistribution, the effects of carbon pricing tend to be mildly regressive. However, a redistribution of revenues from auctioning allowances and any complementary revenue-raising instruments like the coal tax can make the reform both progressive and pro-poor overall. Assisting the most vulnerable households, workers, and provinces can help ensure a just transition towards a green economy.

Lastly, the decarbonization efforts towards net zero will also require large financing needs, including the development and deployment of renewables, update of the electrical power grid system, and advancement of carbon abatement technologies. The Chinese authorities have indeed signaled the need to leverage green finance, making up a significant share of the total financing needs, which they expect to mobilize through private sector sources. While it is beyond the scope of this paper, measures to strengthen green finance include improving data collection and disclosure requirements and aligning green bond issuance practice to international standards as well as stronger prudential

[32] See Karplus (2021) for an excellent overview of the Chinese ETS and potential improvements.

[33] See detailed plan for the transformation of China's energy sector in IEA (2021), "An energy sector roadmap to carbon neutrality in China."

policies for climate risk to support financial stability and reinforce green-friendly credit allocation.[34] Lastly, having solid climate policies that bolster the credibility of the climate goals should also help China attract green finance.

A. Concluding Remarks

China will need a comprehensive strategy to transition towards carbon neutrality while ensuring high-quality economic growth. This paper provides a framework to assess a package of mitigation policies consisting of early emissions peak, power market reforms, and economic rebalancing. The distributional analysis also illustrates the incidence costs of climate mitigation and potential ways of redistribution to alleviate the cost to the most vulnerable households.

Economic rebalancing emerges as the key channel for China to attain high-quality economic growth as well as achieving its climate goals. Transitioning to a greener economy through rebalancing will also reduce tradeoffs between climate goals and sustainable growth. As a shift towards more consumption-led growth will reduce energy and carbon emission intensity of output, it will lessen the country's energy demand and thus, ease the pressure for energy security.

Finally, while this paper focused on macroeconomic policies to achieve China's climate work, future work could usefully delve into more detailed analyses on specific aspects of China's transition to net zero emissions. For instance, the coal sector plays an outsized role as the main supplier of energy in China. A better understanding of how to transition out of coal while minimizing disruptions to energy security is of critical importance. Other potential focal areas include detailed analysis of the power sector and best ways to implement market reforms that would enable energy trading and sharing across provinces.

[34] See the 2021 China Article IV Staff Report for more details on green finance policies.

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APPENDIX 1. IMPACTS OF EXISTING AND PROJECTED CLIMATE CHANGE

Heat waves. Extreme heat waves, such as the deadly one that occurred in the Pacific Northwest and Canada in summer 2021, are already about five times more likely to occur with existing warming of 1.2ºC. At 2ºC warming, this frequency increases to 14 times as likely to occur. Heat waves are getting hotter, and with 2ºC of warming, the hottest temperatures would reach nearly 3ºC higher than previous heat waves.

Droughts. Climate change is increasing the frequency and severity of droughts, such as the summer 2021 drought affecting the Western United States. Severe droughts that used to occur an average of once per decade are now occurring about 70 percent more frequently. If warming continues to 2ºC, these droughts will occur between two and three times as often.

Flooding. Climate change is intensifying the water cycle on both sides. While more intense evaporation will lead to more droughts, warmer air can hold more water vapor to produce extreme rainfall (as played out dramatically in Western Europe and China in summer 2021). On average, the frequency of heavy downpours has already increased by about 30 percent and they contain about 7 percent more water.

Hurricanes. Hurricanes are growing stronger and producing more rain as global temperatures increase. It has already been observed that, globally, a higher percentage of storms are reaching the highest categories (categories 3, 4 and 5) in recent decades. This is expected to continue as temperatures climb.

Sea level rise. Sea level is rising around the world, and the rate is increasing—even if warming is kept below 2ºC, sea levels are projected to rise 2-3 meters by 2300 and by 5-7 meters with greater warming. Higher sea levels are worsening high-tide flooding and storm surge. By 2100, once-in-a-century coastal flood events will occur at least once per year at more than half of coastlines across the world.

Weather whiplash. Climate change is not just increasing the severity of extreme weather, it is also interrupting the natural patterns, leading to 'weather whiplash'—wild swings between dry and wet extremes. This has been experienced recently in California, with 'atmospheric rivers' causing destructive floods one year and extreme drought causing water shortages the next.

Source. IPCC (2021).

APPENDIX 2. CHINA'S ETS: DESIGN DETAILS

Design issue	Details
Trading Periods	The ETS came into effect on 1 February 2021 and on July 16, 2021 trading commenced. Currently there are no defined trading periods--current regulations apply only to the 2019 and 2020 compliance period (other ETSs have distinct phases with trading within a phase).
Coverage	2,225 power sector enitites, including combined heat and power, as well as captive power plants of other sectors. Inclusion thresholds: Entities with annual CO_2 emissions at least 26,000 tons in any year from 2013-2019. Only CO_2 is included. Coverage will later include petrochemicals, chemicals, building materials, steel, nonferrous metals, paper, and domestic aviation, though there is currently no timeline for this expansion.
Emissions Cap	The cap is calculated using a bottom-up approach as the sum of the total allowance allocations to the covered entities. The 2021 cap is expected to be 30 percent of nationwide GHGs, or over 4,000 billion tons of CO_2. Allowances can be purchased and cancelled voluntarily.
Allowance Allocation	There are 4 benchmarks for free allowance allocation expressed in tons CO_2 per MWh: 0.877 for conventional coal plants producing less than 300 MW; 0.979 for conventional coal plants producing more than 300 MW; 1.146 for unconventional coal plants; and 0.392 for natural gas plants. Allowance allocations equal 70 percent of entities' 2018 output multiplied by the respective benchmark factor. Allocation will be adjusted to actual 2019 and 2020 ouput later. A load correction factor can allocate additional allowances for entities running at less than 85 percent of capacity.
Auctions	Allocation is done through free allocation though legislation provides for the possibility of auctioning in the future.
Carbon Price	The ETS launched with an opening allowance price of $7.41 on July 16th 2021 and closed with a trading price of $7.89, higher than the average price of previous regional pilots.
Banking and Borrowing	The ETS is expected to allow for banking but not for borrowing, though rules have not yet been established.
Market Stability Provisions	Adjustment mechanisms, risk prevention, and control mechanisms are being developed to constrain irregular price fluctuations and avoid market manipulations.
Offsets	Entities can offset up to 5 percent of their emissions using the China Certified Emissions Reduction (CCER) projects.
Monitoring and Enforcement	Entities must submit the previous year's emission reports by the end of March. Reporting failures are subject to fines between $1,449 and $4,347 and compliance failures fines of $2,898-$4,347. Gas-fired plants do not face compliance obligations. Other plants are obligated to surrender allowances covering up to 20 percent of verified emissions above the free allocation received. Gaps between the compliance obligation and foregone allowances will be deducted from the following year.
Institutions Involved	Chinese Ministry of Ecology and Environment (MEE) surpervises the ETS; Provincial level MEE subsidiaries organize the verification of emission reports and system implementation; Shanghai Environment and Energy Exchange (SEEE) operates the trading platform; municipal-level authorities have some local management duties.

Sources: ICAP (2021a, b), WBG (2021).

APPENDIX 3: BRIEF DESCRIPTION OF THE IMF-ENV CGE MODEL

The model is a recursive dynamic neo-classical, global, general equilibrium model, built primarily on a database of national economies and set of bilateral trade flows. The central input of the model is the data of the GTAP V10 database.[35] The database contains country-specific input-output tables for 141 countries and 65 commodities and real macro flows. The database also represents world trade flows comprehensively for a given starting year. The currently used version 10 is based on data from 2014. The model describes how economic activities and agents are inter-linked across several economic sectors and countries or regions. The model is based on the activities of the key actors: firms, households, and markets. Firms purchase inputs and primary factors to produce goods and services. Households receive the factor income and in turn demand the goods and services produced by firms. Markets determine equilibrium prices for factors, goods, and services. Frictions on factor or product markets are limited, except as described below. Only real economic flows are considered in the model; in addition, heterogeneity of firms and households are not considered.

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

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

The model also links economic activity to environmental outcomes. Emissions of greenhouses gases and other air pollutants emissions are linked to economic activities either with fixed coefficients, like for emissions from fuel combustion, or with emission intensities which decrease (nonlinearly) with carbon prices—Marginal Abatement Cost (MAC) curves. This latter case applies to emissions associated to non-energy input uses (*e.g.,* N_2O emissions resulting from fertilizer uses) or to output processes (like CH_4 emissions from waste management or CO_2 emissions from cement manufacturing). In the very long run, the model may overestimate the cost of decarbonization, since it

35 https://www.gtap.agecon.purdue.edu/

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

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

The model distinguishes between 55 sectors. Since the focus of the analysis is on climate mitigation policies, the main sectors contributing to GHGs emissions are modeled separately. This includes four fossil fuels goods (coal mining, crude oil, refined oil, gas extraction, and distribution), eight power generation sectors (Coal, oil and gas-powered electricity, Hydro power, Wind, Solar, Nuclear, and other power) and five Energy-Intensive and Trade Exposed (EITE) industries (iron and steel, non-metallic minerals, chemicals, pulp and paper, and non-ferrous metals). For this paper, five countries are modeled individually—China, USA, Australia, Japan and India—and the remaining countries are grouped into five aggregate regions (included EU) based on regional proximity.

List of sectors

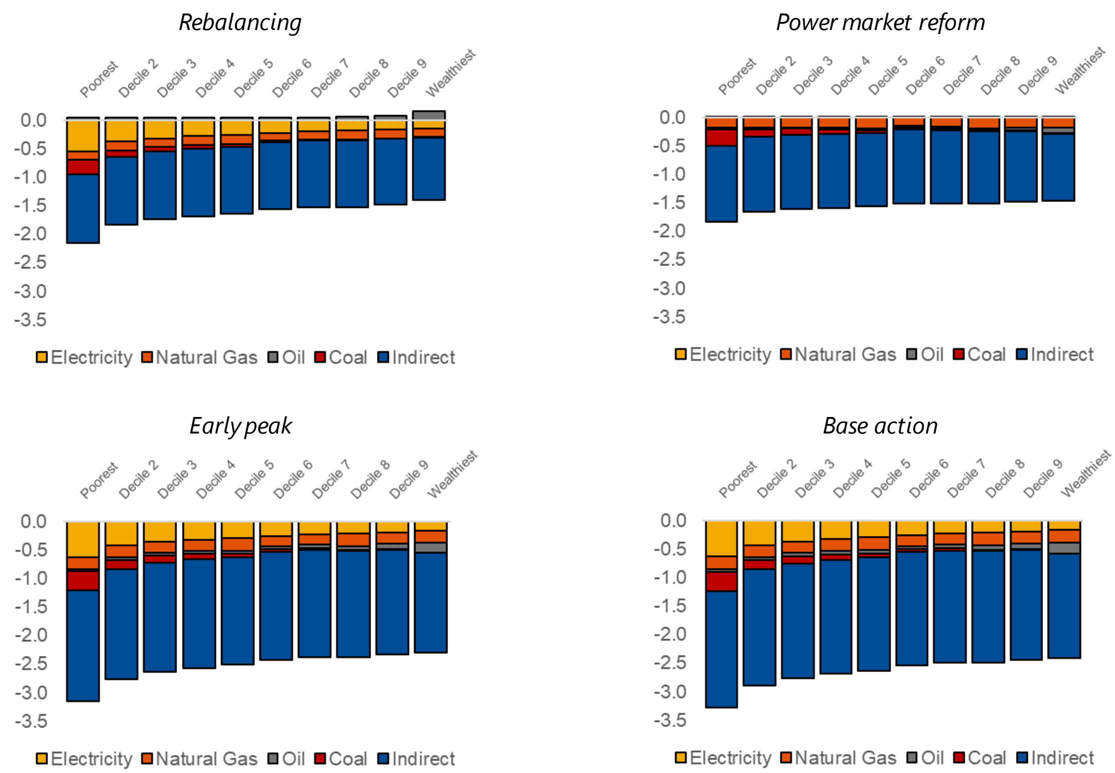
pdr-a	Paddy Rice
wht-a	Wheat and meslin
gro-a	Other Grains
v_f-a	Vegetables and fruits
osd-a	Oil Seeds
c_b-a	Sugar cane and sugar beet
pfb-a	Plant Fibres
ocr-a	Other Crops
cow-a	Livestock: Cattle and Raw Milk
nco-a	Livestock: other animals
frs-a	Forestry
fsh-a	Fisheries
coa-a	Coal extraction
oil-a	Crude Oil extraction
p_c-a	Petroleum and coal products
gas-a	Natural gas: extraction

gdt-a	Natural gas: manufacture & distribution
omn-a	Minerals n.e.s.
etd-a	Electricity transmission and distribution
clp-a	Coal powered electricity
olp-a	Oil powered electricity
gsp-a	Gas Powered electricity
nuc-a	Nuclear power
hyd-a	Hydro power
wnd-a	Wind power
sol-a	Solar power
xel-a	Other power
wts-a	Water supply; sewerage; waste management and remediation activities
osc-a	Other Financial services (including Dwellings, insurance, real estate)
trd-a	Trade (including accommodation, warehousing)
obs-a	Other Business Services nec. and communication
edu-a	Education
hht-a	Human health and social work
osg-a	Other collective services
cns-a	Construction
atp-a	Air Transport
wtp-a	Water Transport
otp-a	Transport n.e.s.: Land transport and transport via pipelines
ppp-a	Paper & Paper Products
crp-a	Chemical products
bph-a	Basic pharmaceuticals
rpp-a	Rubber and plastic products
fdp-a	Food Products
txt-a	Textiles
nmm-a	Non-metallic minerals
i_s-a	Iron and Steel
nfm-a	Non-ferrous metals
fmp-a	Fabricated metal products
ele-a	Electronics
lum-a	Wood products
otn-a	Other transport equipment
omf-a	Other manufacturing (includes recycling)
ome-a	Machinery and equipment n.e.s.
eeq-a	Electrical equipment
mvh-a	Motor vehicles

APPENDIX 4. DISTRIBUTIONAL ANALYSIS OUTCOMES BY SCENARIO

Figure A1. Mean Consumption Effect on Consumption Deciles, before Revenue-Recycling by Policy in 2030

(% Change in Household Consumption Relative to Pre-Policy)

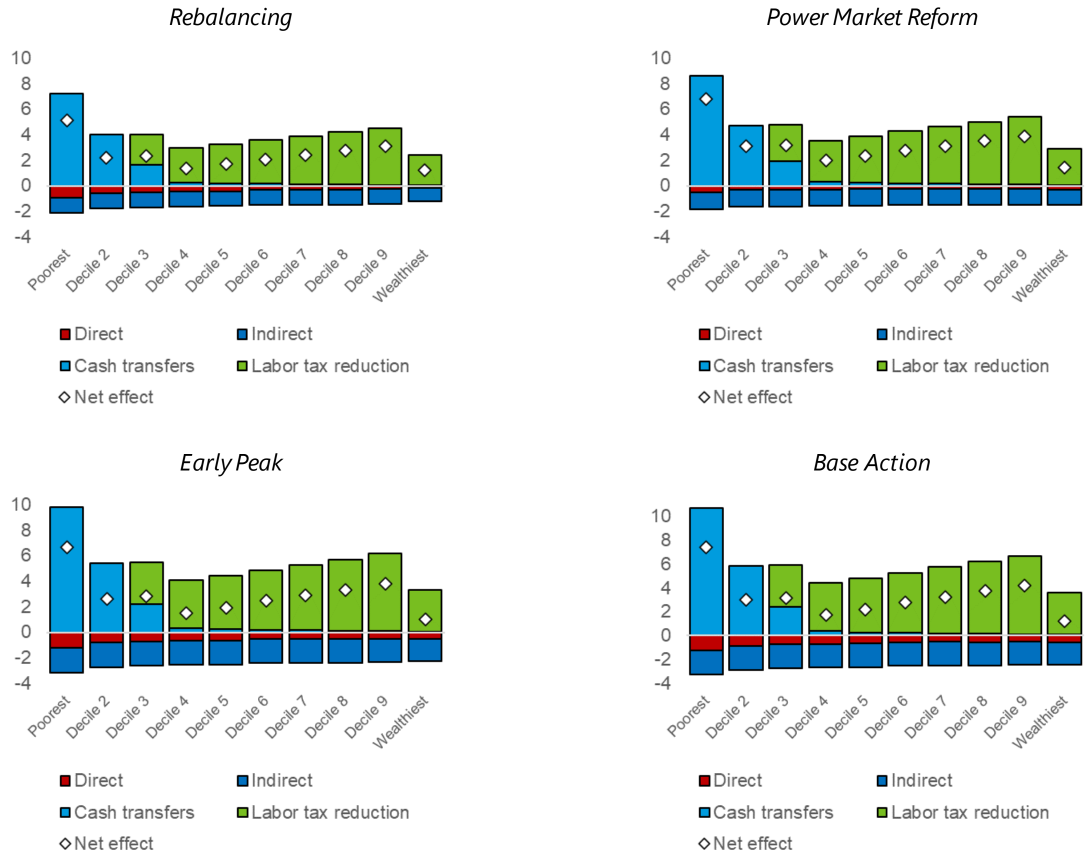


Source: IMF Staff calculations.

Note: the panel shows relative to consumption impact of the carbon pricing scenarios on consumption deciles before revenue recycling through increases in prices of energy and non-energy goods.

Figure A2. Mean Consumption Effect on Consumption Deciles,
after Revenue-Recycling by Policy in 2030

(% Change in Household Consumption Relative to Pre-Policy)

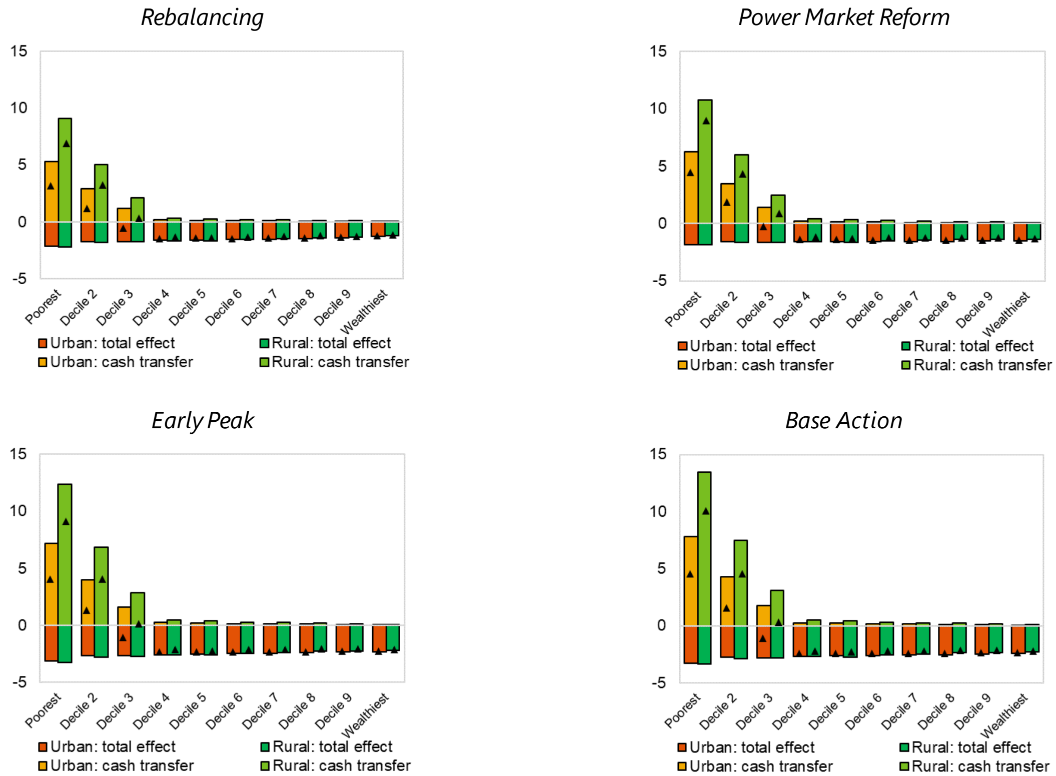


Source: IMF Staff calculations.

Note: the panel shows relative to consumption impact of the carbon pricing scenarios on consumption deciles assuming 15 percent of revenues would be used for a cash targeted transfer (assumed targeting bottom 25 households with a 90 percent coverage and 10 percent leakage rate) and 85 percent for reducing labor taxation.

Figure A3. Mean Consumption Effect on Consumption Deciles, after Revenue-Recycling using Cash Transfers, by Policy in 2030

(% Change in Household Consumption Relative to Pre-Policy)



Source: IMF Staff calculations.

Note: the panel shows relative to consumption impact of the carbon pricing scenarios on consumption deciles by urban and rural populaiton, assuming 15 percent of revenues would be used for a cash targeted transfer (assumed targeting bottom 25 households with a 90 percent coverage and 10 percent leakage rate).

Appendix 5. Other Sectoral Policies

Transportation

1. Electric and other low carbon vehicles are a priority in China. It is difficult to promote these vehicles through carbon pricing or higher road fuel taxes alone due to the relatively modest impact of these policies on retail fuel prices and public resistance to higher road fuel prices—China has therefore focused on other approaches. China met its goal of one million new electric vehicles (NEVs) sold by 2018 (two years ahead of schedule) and is requiring manufacturers to progressively increase the share of NEVs in new vehicle sales to 25 percent by 2025 and 40 percent by 2030, meanwhile previous consumer subsidies for the purchase of NEVs are phasing out given their high fiscal costs.[36] China is also introducing fuel economy standards for light- and heavy-duty commercial vehicles starting in 2021 (averaged across manufacturers' sales fleets)—the light vehicle standard for 2025 is 4 liters per 100 km, or 90 grams CO_2 per km.[37] The sales share and fuel economy requirements are not compatible instruments however, in that sense that with higher NEV sales shares manufacturers may offset the fuel savings by increasing their sales shares for low fuel economy vehicles and still meet a given average fuel economy requirement—this is one reason to consider adding a feebate to the existing policy mix.[38]

2. Integrating a (revenue-neutral) feebate into the vehicle purchase tax system (currently 10 percent) would enhance incentives for NEVs and other low emission vehicles, while avoiding a fiscal cost to the government. Under a feebate, each new vehicle would be subject to an additional fee given by:

$$CO_2 \text{ price} \times [CO_2\text{/km} - CO_2\text{/km of the new (industry-wide) vehicle fleet}] \times [\text{average lifetime vehicle km}]$$

Emission rate data by model type can be inferred from data currently used to administer the fuel economy standards. The feebate:

- Promotes the full range of behavioral responses for reducing emission rates, as there is always a continuous reward (lower taxes or higher subsidies) from switching from any vehicle with a higher emission rate to one with a lower emission rate;[39]
- Is cost effective, as the reward is always proportional to the reduction in the emission rate; and
- Maintains (approximate) revenue neutrality—by definition, fees offset rebates as the average emission rate in the feebate formula is updated over time.

[36] The targets are ambitious given the NEV sales share was 5 percent in 2019. China's recent economic stimulus package includes funding for NEV charging stations, high-speed rail, and electric public transport systems. See CAT (2021).

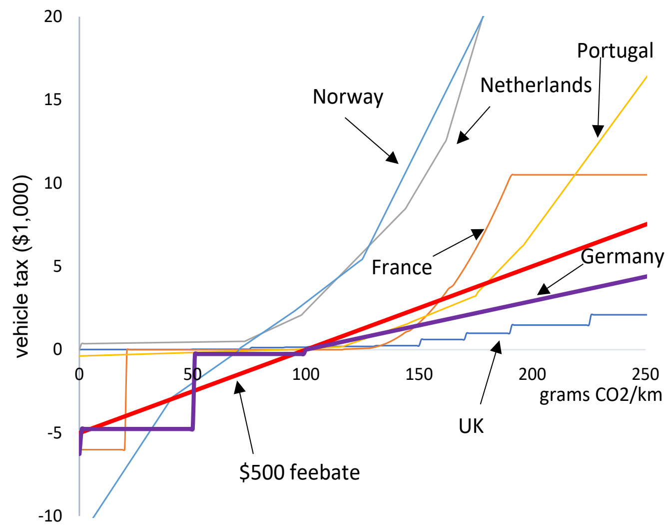
[37] For comparison, the current EU standard is 95 grams CO_2 per km though it is set to ramp up sharply by 2030. See IEA (2020).

[38] See Krupnick and others (2010), Ch 5.

[39] Vehicle manufactures are therefore rewarded for going beyond prevailing fuel economy standards (and penalized for not meeting them)—in this way, the feebate is fully compatible with, and reinforces, the existing standards.

3. **For illustration, a feebate with a price of $500 per ton of CO_2 would provide a subsidy of $5,000 for NEVs and apply a tax of $5,000 to a vehicle with 200 grams CO_2/km (see Figure A4).** Many European countries impose higher taxes on emissions intensive vehicles (though the share of these vehicles in sales fleets is declining rapidly). Subsidies for NEVs would decline over time as the average fleet emission rate declines, which is appropriate as the cost differential between these vehicles and their gasoline/diesel counterparts falls over time (e.g., with improvements in electric vehicle battery technology).

Figure A4. CO_2-Based Components of Vehicle Taxes, Selected Countries



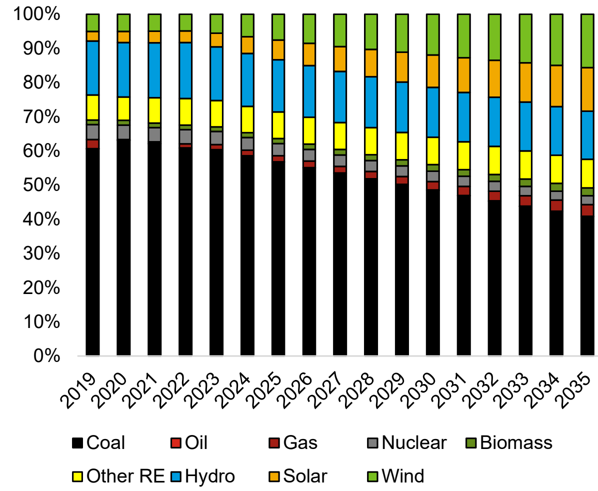
Sources: ACEA (2018); IMF staff calculations.
Notes: Feebate assumes a fleet average emission rate of 100 grams CO_2/km. Circulation taxes for Germany are expressed on a lifetime basis.

Power Generation

4. **Ideally a complementary instrument for the power sector—that avoids a significant increase in electricity prices—would cost-effectively exploit all behavioral responses for reducing the emissions intensity of generation.** These responses include: (i) shifting from coal to gas; (ii) shifting from coal and gas to renewables; (iii) shifting from coal and gas to nuclear and fossil fuel plants with carbon capture and storage (these two responses however are excluded from IMF staff modelling); and (iv) efficiency improvements which lower the use of coal and gas required to generate a kWh of electricity (e.g., by reducing heat loss during fuel combustion).

5. All these behavioral responses can be promoted under carbon pricing. Combined they account for about 88 percent of the CO_2 reductions below BAU levels in the power sector under a \$50 carbon price in China in 2030 with market reforms—the other 12 percent comes from reductions in electricity demand. Emissions reductions are cost effectively allocated across all these responses (with market reforms) as the carbon price provides the same reward for reducing an extra ton of CO_2 across each response.

Figure A5. Projected Electricity Generation Sources (\$50 Carbon Price)



Source: IMF staff calculations.

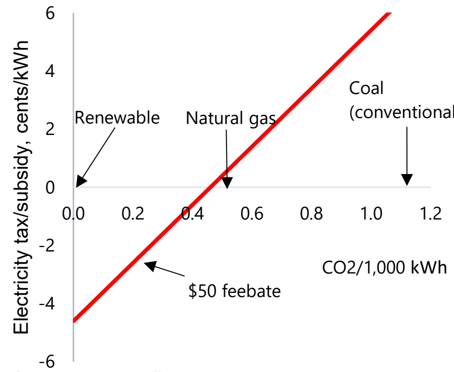
Thus, the cost-effective generation mix in 2030 is 48 percent coal, 15 percent hydro, 3 percent nuclear, 9 percent solar and 12 percent wind (see Figure A5). Regulations or fiscal incentives to promote renewable power generation (like feed-in-tariffs recently phased out for solar PV and onshore wind) promote a much narrower range of behavioral responses compared with carbon pricing—they only promote response (ii) above and they do not reduce electricity demand.

6. Like carbon pricing, a feebate could also cost-effectively reduces the emissions intensity of generation. Under a feebate SOEs would be subject to a fee depending on the average emissions across their generation plants given by:

$$CO_2 \text{ price} \times [CO_2/\text{kWh} - \text{pivot point } CO_2/\text{kWh}] \times \text{electricity generation}$$

In principle, this scheme provides SOEs with incentives to exploit any behavioral response that lowers their average emission rates—this reduces fees implicit in plants with emission rates above the pivot point rate and increases rebates implicit for plants with emission rates below the pivot point. As with carbon pricing, the efficient allocation of responses is promoted (with market reforms), as any response that cuts CO_2 by an extra ton leads to the same benefit. Feebates can be (approximately) revenue neutral if the pivot point reflects the recent (economy-wide) average emission rate. And an exogenous trajectory of future pivot point emission rates can be set based on expected declines in future emission rates, to preserve approximate revenue neutrality for the sector. Capacity requirements for implementing a feebate are minimal given that generation emissions are already monitored under China's ETS.

Figure A6. Illustrative Feebate for Power Sector



Source: IMF staff calculations based on 2018 data.

7. For illustration, a feebate with price $50 per tonne CO_2 would apply fees equivalent to 6.6 and 0.2 cents per kWh for coal and natural gas generation, while providing a subsidy of 4.8 cents per kWh for renewables (Figure A6). Fees for coal would increase, and subsidies for renewables decline, as the pivot point emission rate is updated over time.

Industry

8. Energy-intensive trade-exposed (EITE) industries such as steel, chemicals, metals, cement, glass, and paper generate most industrial GHGs in China,[40] but presently there are no major policies to de-carbonize these sectors. As the ETS is extended to cover industry, measures will be needed to address the international competitveness impacts of carbon pricng —see Annex IV. Here the discussion is about the potential use of feebates to complement carbon pricing and reinforce incentives for reducing emission rates per unit of output in these industries (but without a reduction in output levels). Under feebates, firms within an industry would be subject to a fee given by:

$$[CO_2 \text{ price}] \times [CO_2/\text{output} - \text{industry-wide average } CO_2/\text{output}] \times [\text{firm output}]$$

9. The feebate, which would apply to emissions from fuel combustion and process emissions (e.g., released during conversion of clinker to cement), avoids a first-order allowance purchase requirement on the average producer as they pay no charge on their remaining emissions. This helps to alleviate concerns about competitiveness compared with a pricing scheme that charges for remaining emissions. Again, the scheme could build off existing procedures for monitoring industrial firm emissions that are being established under the ETS.

Buildings

10. Coal, oil, and gas combustion in homes accounts for only 4 percent of China's GHG emissions, but counting indirect emissions from residential electricity consumption would increase this share to 12 percent—reducing energy use in buildings is therefore a potentially important component of China's mitigation strategy. Improving the energy efficiency of buildings through better insulation and cleaner and more efficient heating equipment, including electric heating, is one channel for reducing energy use. Other energy reduction channels include energy-efficient lighting and appliances, digitalization to "smart" homes (such as optimal automatic adjustment of heating temperatures), and renewable energy-based water heating systems.

[40] UNFCCC (2021).

11. Various feebate schemes could complement existing efforts to promote energy efficient buildings.[41] For example, sales of refrigerators, air conditioners, and other energy-consuming products could incur a fee given by:

$$CO_2 \text{ price} \times CO_2 \text{ per unit of energy}$$
$$\times \text{ [energy consumption per unit} - \text{industry-wide energy consumption per unit]}$$
$$\times \text{ number of units}$$

For refrigerators, for example, the energy consumption rate would be kWh per cubic foot cooled (and the number of units would be cubic feet). A similar scheme applying taxes to fossil fuel-based heating systems (for existing buildings), and a subsidy for electric heat pumps, could help accelerate the transition to zero-carbon heating systems for pre-existing buildings. Feebates could also be linked to the energy performance of new buildings to encourage energy saving investments.[42]

Fugitive Emissions from Coal Extraction

12. 95 percent of fugitive emissions in China are from coal mining, where the main emissions source is venting of methane.[43] Potential abatement measures include recovery of methane for pipeline injection or on-site power generation, flaring (to convert methane into less potent CO_2), and catalytic or thermal oxidation of ventilation.[44]

13. Pricing schemes for fugitive emissions could promote the full range of responses for reducing emission rates and could be applied using default emission rates with rebating for entities demonstrating lower emission rates. Emissions monitoring technologies[45] generally provide only discrete measurements at a limited number of sites, though technologies are improving. Fuel suppliers might be taxed based on a default leakage rate with rebates to firms demonstrating lower leakage rates than the default rate through mitigation and installing their own continuous emission monitoring systems. Fugitive emissions are released within Chinese borders, and therefore should be priced regardless of whether coal is sold domestically or on world markets. Pricing approaches are more flexible and cost-effective than mandates requiring all producers to use the same mitigation technique regardless of which technique is least costly for them. For illustration, a price of $50 per ton on the CO_2 equivalent

[41] These include energy efficiency regulations for new buildings and requirements for retrofitting existing buildings.

[42] Arregui and others (2020) discuss a variety of other complementary measures for the building sector.

[43] UNFCCC (2021).

[44] US EPA (2019).

[45] Including satellites, aircraft, drones, and remote sensing from vehicles.

from fugitive emissions would apply charges equivalent (prior to mitigation) of approximately $7 per ton of coal.[46]

Forestry

14. Forestry and land use policies should promote, nationwide, the main channels for increasing carbon storage. These include: (i) reducing deforestation; (ii) afforestation; and (iii) enhancing forest management (e.g., planting larger trees, fertilizing, tree thinning, increasing rotation lengths). To the extent forest coverage is expanded this can, moreover, generate other environmental co-benefits beyond carbon storage such as reduced risks of water loss, floods, soil erosion, and river siltation. China's forestry policies focus on recovering native forests, protecting ecologically sensitive zones, and banning trade in illegal logs, though there are concerns these patchwork efforts might cause leakage and exacerbate forest clearance in other regions of China,[47] which underscores the need for a nationwide approach.

15. A national feebate program could cost-effectively promote all responses for increasing carbon storage without a fiscal cost to the government. The policy would apply a fee, most importantly for land parcels at the agricultural/forestry boundary, given by:

[CO_2 rental price] × [carbon storage on the parcel of land in a baseline period – stored carbon in the current period]

This scheme would reward all three channels for enhancing carbon storage, either through reduced fees or increased subsidies (unlike an afforestation subsidy which just rewards one channel). Periods here could be defined as averages over multiple years given that carbon storage might be lumpy during years when harvesting occurs. Feebates can be designed—through appropriate scaling of the baseline over time[48]—to be revenue-neutral in expected terms (again, unlike an afforestation subsidy). Feebates have not previously been used in the forestry sector but they bear partial resemblance to environmental services payments programs that were first introduced in Costa Rica.[49] Forest carbon inventories in different countries are being developed through a combination of satellite monitoring, aerial photography, and on-the-ground tree sampling.[50]

16. Feebates should involve rental payments (rather than large upfront payments for tree planting), given that changes in carbon storage may not be permanent (e.g., due to fires). Rental payments should equal the product of the carbon price times the interest rate and

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[46] IMF staff.

[47] CAC (2021).

[48] See Parry (2020) for details.

[49] See, for example, www.fonafifo.go.cr/en. Costa Rica's scheme involves payments to develop and maintain forests (but does not apply fees for reductions in forest coverage).

[50] See for example www.forestcarbonpartnership.org.

the number of years in a period.[51] The carbon price would need to rise over time to provide ongoing (rather than one off) increases in carbon storage. Partial exemptions from fees may be warranted for timber harvested for wood products because the carbon emissions (released at the end of the product life) will be delayed, perhaps by several decades or more.

[51] Sedjo and Marland (2003).