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COUNTRY CLIMATE AND DEVELOPMENT REPORT

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Acknowledgements

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Overview

The China Country Climate and Development Report (CCDR) provides analysis and recommendations on integrating the country's efforts to achieve high-quality development with the pursuit of emission reduction and climate resilience. Without adequate mitigation and adaptation efforts, climate risks will become a growing constraint to China's long-term growth and prosperity, threatening to reverse development gains. Conversely, if efforts to tackle climate risks lead to a significant decline in growth and rising inequality, they would deprive millions of people of development and likely erode support for the reforms necessary to achieve a lasting economic transformation. Hence, China will need to grow and green its economy at the same time. This report offers policy options to achieve these dual objectives by easing inevitable trade-offs and maximizing potential synergies between China's development and climate objectives.

Table 0.1. Different Measures of China's Carbon Footprint

	CO_2 Emissions per Capita	Emission Intensity	Total GHG Emissions
(Unit)	(Tons per person)	(kg per PPP $ of GDP)	(Mt of CO_2e)
Brazil	5.0	0.13	1057.3
China	9.0	0.46	12705.1
India	2.5	0.26	3394.9
Indonesia	3.7	0.19	1002.4
Philippines	2.2	0.14	234.3
Russia	17.2	0.39	2476.8
United States	18.3	0.23	6001.2
Vietnam	4.7	0.33	450.1
European Union	7.6	0.13	3383.4
OECD	10.7	0.18	14551.2

Source: World Bank World Development Indicators (WDI). Data refers to total GHG emissions and the year 2019.

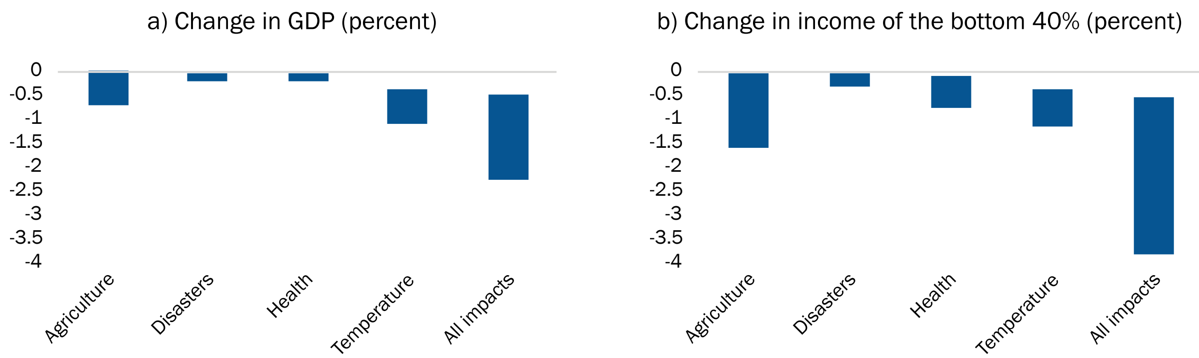
China's development and climate change are deeply and increasingly intertwined. The country is both a contributor to rising global greenhouse gas (GHG) emissions causing climate change and severely affected by its adverse impacts. Although China is not the main source of historical cumulative emissions, it today accounts for 27 percent of annual global carbon dioxide and a third of the world's greenhouse gases emissions (Table 0.1). Alongside other larger emitters, China's contribution to reducing global climate risks is therefore crucial. Reducing greenhouse gas emissions in its relatively carbon-intensive industrial economy will not be easy, posing transition risks but also opening new opportunities for development. At the same time, large parts of China's population and economic infrastructure are heavily exposed to climate risks. China, like other countries, will have to adapt and build resilience to protect human life and avoid economic losses from the effects.

The CCDR is firmly anchored in China's own development and climate aspirations. China aims to sustain sufficient economic growth to double per capita income and become a high-income country by 2035. Simultaneously, recognizing the long-term threat climate change poses to its own and to global development, China has also made ambitious commitments to peak carbon emissions before 2030 and achieve carbon neutrality before 2060. This report is, therefore, not about whether China should act to address climate change but how it can do so while safeguarding development gains and ambitions.

China's climate ambition and development opportunity

Climate change poses a significant threat to China's long-term growth and prosperity. Rising sea levels and risks related to coastal flooding, storm surges, and coastal erosion threaten China's densely populated low-elevation coastal cities, which account for a fifth of China's population and a third of its gross domestic product (GDP). Meanwhile, interior provinces in northern and western China are exposed to more frequent and extreme heat waves and droughts which intensify water security risks and impact agriculture—a major source of income, especially among China's rural poor. No longer threats in a distant future, these risks are already starting to materialize today, as evidenced by recent floods and droughts that have devastated large parts of the country. Direct annual losses from natural hazards are estimated to have averaged US$76 billion over the past five years. Studies indicate that these effects will only intensify, with estimates suggesting that climate change could result in GDP losses of between 0.5 and 2.3 percent, as early as 2030. Worryingly, these impacts will disproportionately hit the bottom 40 percent of the income distribution, who could incur losses of up to 4.7 percent of their income by 2030, in the most severe climate scenario (Figure 0.1.a and b).

Figure 0.1. Climate change poses a major threat to China's economy and livelihoods



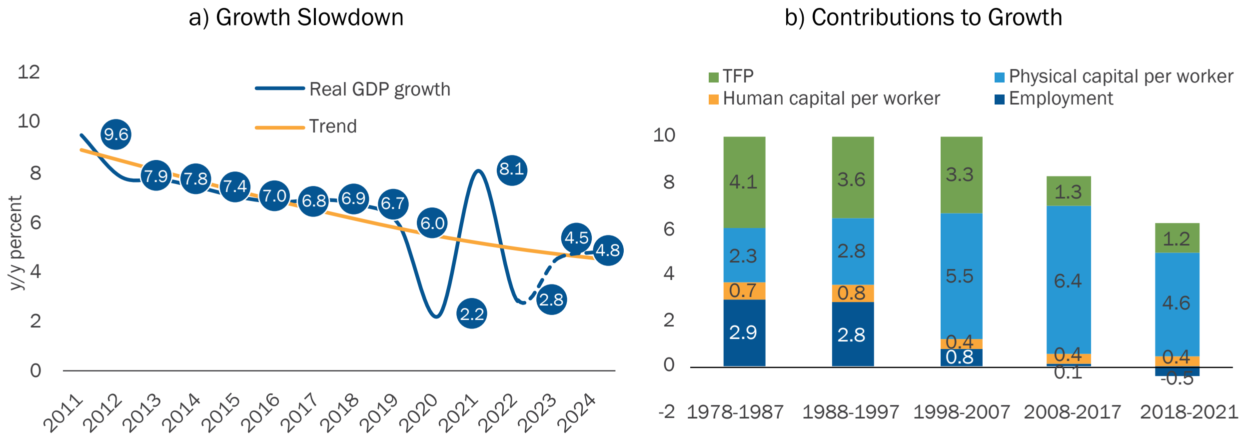
Source: Hallegatte et al. (2017), Shockwaves modeling for China.

Note: The bars in each graph represent ranges that correspond to alternative socio-economic and climate change scenarios.

Meanwhile, China's economy is also confronting growing economic imbalances that constrain future growth. After decades of high-speed growth, China's growth has gradually slowed over the past decade, reflecting looming demographic headwinds and a sharp decline in productivity growth (Figure 0.2.a). The economy has become overly reliant on investment, especially in carbon-intensive infrastructure and real estate, with rapidly diminishing economic returns (Figure 0.2.b). China's economy also remains more dependent on industry than do countries at similar levels of per capita incomes, partly due to the large presence of state dominated heavy industries—in the steel, cement, and other construction materials sectors—and partly because of its dominant role in many global value chains. Aiming to shift from high speed to high quality growth, China needs to rebalance its growth model—from traditional infrastructure investment to innovation, from exports to domestic consumption, from industry to high-value services, from high to low carbon intensity, and from state-led to more market-driven allocation of resources.

Figure 0.2. China's Growth Challenge

China's increasingly factor-driven growth model is facing constraints

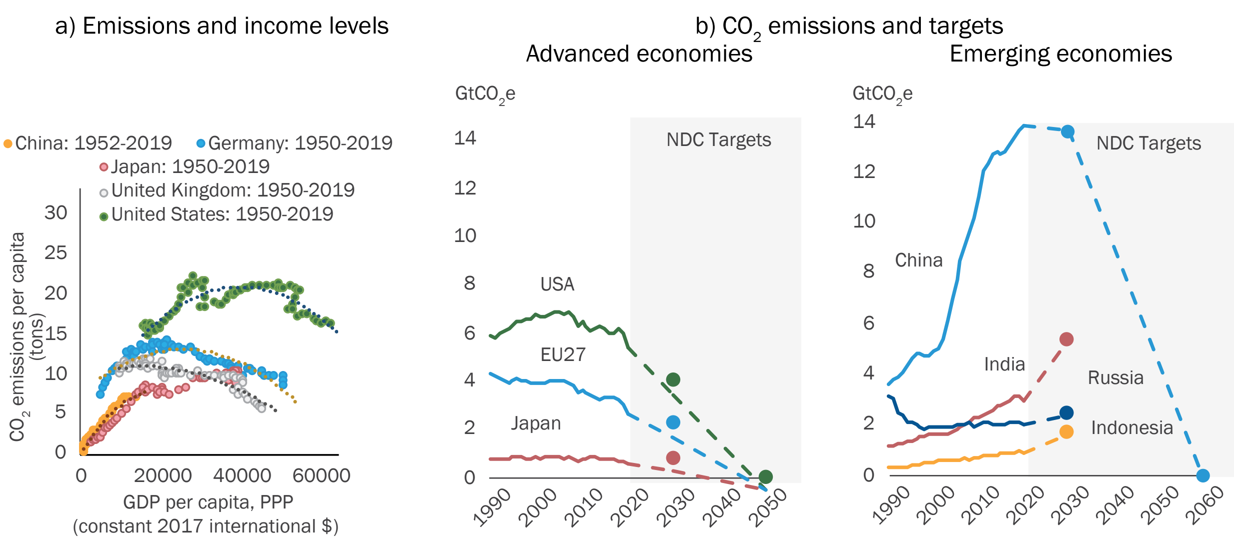


Source: World Bank staff, based on Penn World Tables (PWT) and China National Bureau of Statistics (NBS) data.

The transition to carbon neutral and resilient development will create transition risks. While addressing climate risks is imperative to securing long term development, achieving China's climate and development goals will be uniquely challenging: it will require decoupling economic growth and emissions at a faster pace and at a lower income level than in advanced economies (Figure 0.3.a). This will entail fundamental structural changes of the economy: China's energy, industrial and transport systems, its cities, and land use patterns will have to undergo dramatic transformations. Energy prices will likely increase—at least in the short run—with detrimental impacts on consumers and firms. A large part of China's existing carbon-intensive capital stock will become obsolete, and job losses will occur in polluting industries, many of which are concentrated in some of China's poorer interior provinces. The resulting disruptions and dislocations–and their impact on growth and inclusion—are serious concerns that need to be addressed to move forward on an economically, socially, and politically viable decarbonization path. The good news is that aggregate adjustment costs and distributional impacts depend at least partly on the policy mix adopted.

Figure 0.3. China's Climate Challenge

China's transition to carbon neutrality will require decarbonization at a lower income level and at a faster pace than other major economies



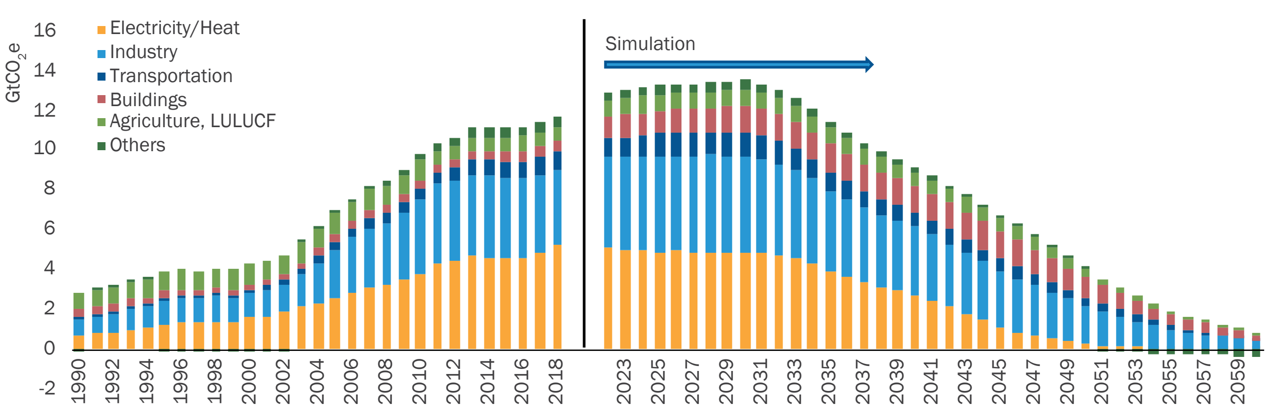
Source: World Bank staff, based on CIATWorld Development Report (WDR), Climate Tracker.

Yet, China is also well positioned to turn climate action into an economic opportunity. Like previous transformations on the scale envisaged, the transition to reduced carbon intensity and climate adaptation in China and the rest of the world will unlock new sources of economic growth, innovation, and job creation, with the added benefit of lowering China's reliance on imported fuels and enhancing its energy security. As a global manufacturing hub, China—and especially its private sector—is uniquely positioned to take advantage of these shifts. China is at the forefront of advancing low-carbon energy supply and mobility. It has one-third of the world's installed wind power and a quarter of its solar capacity. Already today over 4 million jobs—more than half of the global total in renewable energy—are in China. Fueled by its large domestic savings, China is also becoming a leader in green finance, being home to the world's largest green bond and credit markets. These opportunities are also real. But, as in the case of transition costs, whether they will be realized crucially depends on policies.

Charting pathways to resilient, carbon-neutral growth

Model-based simulations, consistent with China's "30-60 goals" and Nationally Determined Contribution (NDC), show that the pace of emissions reduction will vary across sectors, with important implications for sequencing (Figure O.4). The low-carbon transition of the power sector—the largest source of emissions—would need to come first to achieve a rapid decline in emissions over the next two decades. Frontloading the decarbonization of the power sector is also important to meet growing electricity demand, including from electrification of demand sectors, such as transport, buildings, and industry without increasing emissions. Investments in available least-cost options in domestic solar and wind, supported by expanded energy storage would steadily reduce coal use in the power sector. In the industrial sector, reduction of excess production capacity, energy efficiency improvements, and electrification would lower emissions in the short term, but innovations such as green hydrogen and carbon capture, usage, and storage (CCUS) would be required to achieve deep decarbonization in the long term. In the transport sector, carbon intensity would be reduced through continued investments in public mass transport systems, electrification as well as innovations in low-carbon fuels for hard-to-electrify modes. Direct CO_2 emissions from buildings would be mitigated through electrification, clean district heating, and energy efficiency. Finally, carbon sequestration—negative emissions—from nature-based solutions (NbS), including expanded forest coverage, will enable carbon neutrality by offsetting significant residual emissions in hard-to-abate sectors while simultaneously favoring resilience to floods, droughts, and sea-level rise.

Figure O.4. Pathway to Carbon Neutrality



Source: World Bank staff estimates using integrated modeling framework with MANAGE CGE, TIMES China, and LEAP.

Note: The pathway is consistent with China's 30/60 goal and its revised NDC.

Decarbonization will require significant investments in a massive green infrastructure and technology scale-up. Specifically, our sectoral models suggest that China would need a total of about US$14 trillion in additional investments from now until 2060 for the power and transport sectors alone, equivalent to 0.97 percent of GDP during that period (see Table 0.2).[1] To avoid locking-in carbon intensive assets and meet China's NDC targets, a large part of these investments would need to be frontloaded, requiring about US$2.1 trillion (equivalent to roughly 1.1 percent of GDP) in the next decade. Under an accelerated decarbonization scenario that would allow emissions to peak earlier than 2030, reducing cumulative carbon emissions until 2060 by almost 55 billion tons and smoothing the impacts on GDP over time, investment needs would increase by US$3 trillion to a total of US$17 trillion. While overall investment needs are largest in the transport sector, many of the investments in the sector are expected to bring about significant energy efficiency gains and operating cost savings that would make these investments not only economically viable but financially attractive. In addition, technological progress may lower some of these costs, and individual investments and the policies to encourage them may be prioritized (or de-prioritized) taking also into account specific cost-benefit considerations. Public investments will be necessary but not sufficient to meet the overall investment needs. They will need to be complemented by good sector policies, broad-based regulatory reform, and new standards to fully tap the potential and incentivize private sector investment and innovation in these sectors.

The aggregate macroeconomic impacts of decarbonization are manageable and crucially depend on policy choices. The model-based simulations suggest cumulative GDP losses/gains of between -2.0 and 0.3 percent, depending on the specific policy choices and model specifications to achieve carbon neutrality before 2060. Beyond these estimates that are subject to high uncertainty, three policy relevant findings emerge from the modeling: First, aggregate economic impacts of decarbonization are likely to be manageable. Importantly, the results suggest that growth impacts of achieving China's NDC in the next decade could be marginally positive, reflecting the availability of low-cost abatement options in the power sector and industrial energy efficiency. Second, the simulations also suggests that adjustment costs could be reduced significantly if labor market frictions are addressed, reinforcing the importance of complementary structural reforms. Finally, the upper bound of the estimates illustrates that decarbonization policies could even boost growth if labor productivity gains from improved air quality and public health are accounted for.

Table 0.2 Investment needs to achieve China's NDC and carbon neutrality

Incremental investment over reference case

(in US$ billion)		2021-25	2026-30	2031-40	2041-50	2051-60	Total	NPV (6%)	NPV (Risk-free)
Electricity (Generation and Grid)		336	368	1,386	1,992	200	4,282	1,757	2,588
Transport	Low-carbon mode Infrastructure	9	49	77	33	18	187	90	124
	Fuel and operating efficiency	-224	413	1,471	370	-102	1,928	843	1,263
	Electrification and fuel switch	282	897	3,029	1,951	1,242	7,403	2,979	4,419
Total		403	1,727	5,964	4,347	1,359	13,800	5,668	8,394

Source: Bank internal analysis. GDP projections are the same as in the baseline CGE scenario.

Note: NPV (Risk-Free) is calculated based on the yield curve of China's treasury bonds, ranging from 2.0 percent for the 1-year bond to 3.4 percent for the 50-year bond.

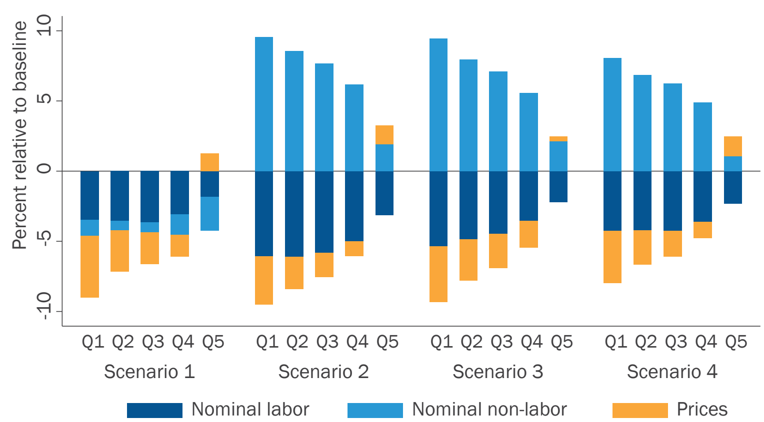
1 Other estimates which include other sectors (building, agriculture, industry) estimate total investment needs at US$22 trillion. CICC Research, CICC Global Institute. (2022). Guidebook to Carbon Neutrality in China: Macro and Industry Trends under New Constraints (1st ed. 2022 ed.). Springer.

The relatively benign aggregate impacts are no cause for complacency about transition risks. The model simulations show that costs of the low-carbon transition affect the poor disproportionately and are regionally and sectorally concentrated. Higher energy prices lead to a substantial loss in households' purchasing power across the distribution with poorer households facing larger impacts (Figure O.5). Lower employment and earnings among agricultural workers will affect low-income households, whereas job losses, and lower earnings in industry will impact households in the richer quintiles. Some of China's poorest regions, which are more dependent on carbon-intensive economies, will be hardest hit. The north and northwestern provinces of Xinjiang, Inner Mongolia, Shanxi, Shaanxi, Ningxia, and Liaoning would experience the greatest emissions declines, negative employment, and output effects. By contrast, the low-emissions provinces of Tianjin, Guangdong, Jiangsu, and Zhejiang face the best outcomes, closely followed by Beijing and Shanghai. Recycling part of the carbon tax revenues into social support to households, workers, and communities negatively affected by the transition could help stem rising inequality.

Figure O.5. Distributional Impacts of Decarbonization

Regressive impacts of climate action can be addressed

Welfare impacts by income groups, 2060 (% relative to baseline). Decomposition by income source.



Source: World Bank staff estimates based on MANAGE.

What we recommend

Balancing China's development and climate objectives will require broader structural and market reforms to complement climate action. Climate policy action is necessary to adjust relative prices–either through explicit carbon pricing or regulation and foster low-carbon innovation and technology adoption. Government policies will also have to foster investments–both private and public–in climate-proving infrastructure and social safety nets. But the effectiveness of these policies depends on competitive markets to create the right incentives for market participants to undertake investments and stimulate innovation in green products and technologies. Although China's economy has become more market-driven, there are remaining distortions in both factor markets and key product markets (for example, energy). These distortions have contributed to misallocation of resources and stifled competition, weighing on productivity growth but also contributing to relatively high carbon intensity. Unless addressed, they could become impediments for an efficient transition process. Structural reforms to promote a market-based allocation of capital, labor, and land and to facilitate the smooth entry and exit of companies would enable the economy to adapt more efficiently to changing price signals and regulations, thereby lowering adjustment costs. They would also help enhance the economy's shock absorption capacity to physical risks. Adopting climate actions within such comprehensive policy framework would help ease the inevitable trade-offs and maximize the potential synergies between China's climate and development objectives. The specific policy options presented in this report can be structured around *six interconnected policy packages.*

Policy Package 1: Accelerate the power sector transition with market reforms and investments in renewables

The low carbon transition in power and heat generation between now and 2030 is pivotal in driving decarbonization. This transition is both feasible and necessary. It is feasible because of the availability of increasingly cost-competitive renewable energy technologies. And it is necessary because electrification in end-use sectors–transport, housing, and industry–will require a growing supply of clean electricity to achieve indented emission reductions. While investments in the rapid scale-up of renewable capacity are essential, structural reforms to create more integrated and efficient electricity markets would help ensure efficient utilization and integration of renewable generation assets. It would also help attract more private sector investment and innovation.

- **Implement scale up of solar and wind power generation capacity to 1,200 GW by 2030, in line with China's Nationally Determined Contribution (NDC).** While this envisaged scale up is ambitious, analysis undertaken for the CCDR shows that adding more renewable energy capacity, up to 1,700 gigawatts (GW), could advance emissions peaking to earlier than 2030 and result in a significant reduction in cumulative emissions. To do so, China would need to add up to 120 GW of solar and wind capacity every year by 2030, 1.5 times the annual average during 2016–20 and 20 percent more than the capacity addition in 2021. This would enable China to meet incremental electricity demand with renewable energy and reduce coal-based generation from 2025 onwards. This is an ambitious target. Achieving it would require a strong global supply response and increased production capacity for battery and solar/wind components to reduce pressure on prices for these technologies.
- **Adopt international best practices in system planning, reliability regulations, and variable renewable energy (VRE) generation forecast and dispatch to reduce the need for additional coal-fired generation capacity.** Increasing the capacity value for VRE in line with standards used internationally would result in less need for additional new coal capacity. Moreover, VRE dispatch can be further optimized by adopting advanced short-term weather forecasting and digitalization at the provincial grid level.
- **Accelerate the integration of provincial and regional power markets to optimize overall capacity usage.** Integrating provincial grids would allow one province to take advantage of reserve capacity in other provinces and reduce the need for additional coal power capacity. This would require both physical investments in interprovincial transmission lines and reforms to move dispatch operation and responsibility from the provincial to the regional or national level. The authorities are aiming for a unified national power market by 2030. Accelerating market integration could help reduce the costs of the energy transition.
- **Expedite electricity market reforms.** China has gradually moved toward a greater role for market-based transactions in the power sector. A complete phasing out of quotas for coal-fired power plants, along with the introduction of a market for ancillary services, would encourage greater private investment in renewables and storage capacity and facilitate the shift of coal power plants to peak load. Together with effective carbon pricing through a tightening of the emissions standards under China's emissions trading system (ETS), electricity market reforms would optimize system cost, enhance flexibility, level the playing field for renewable energy, and shift the role of China's large existing coal fleets.
- **Promote demand management measures for electricity use and heating.** Regulatory measures and time-of-use retail tariffs could help drive further improvements in energy efficiency. China could also promote distributed renewable energy and storage to take some load out of the grid, establish demand response programs where consumers are paid for voluntary load control, and develop smart grid and electric vehicle-to-grid applications that further decrease peak demand and increase grid flexibility. In the heating sector, prices remain well below cost recovery and the limited use of consumption-based billing reduces incentives for energy savings, with the resulting subsidies benefiting richer households with larger dwellings disproportionately. Targeted support to the poor may be needed, however, to address affordability concerns if tariffs are adjusted to reflect costs.

Policy Package 2: Decarbonize key energy demand sectors— industry and transport

Decarbonizing transport

Transport sector GHG emissions are growing fastest among all sectors. If unmitigated, transport emissions would peak in 2040 at about 150 percent of the current level, much later than China's target overall peaking year of 2030, before decreasing to the current level by 2060. Decarbonizing the transport sector requires concerted efforts encompassing policies, pricing, regulatory measures, infrastructure investments, and technological innovation, through which motorized trips can be avoided or shifted to lower energy-intensity modes, or their energy efficiency improved.

- **Advance electrification beyond public transport vehicles to include the private and commercial fleet.** Electric vehicles in China take up less than 2 percent of the total fleet and are concentrated mostly in the largest urban areas. Given rapid motorization trends driven by rapidly rising incomes, early action could mitigate risks of costly and emission-intensive lock-in in fossil fuel technologies. During the initial market development, public policies may be needed to ensure price parity (through taxes and incentives), but these interventions should be temporary and need to be carefully designed. Scaling up charging infrastructure by enabling private investment is equally important. Early actions to advance electrification would be critical for advancing emissions peaking in transport, from 2040 or later under the business-as-usual scenario to 2030–35, bringing about an emissions reduction of about 14.0–18.4 Gt from now until 2060. While electrification can achieve some emission reduction even with China's existing power mix, as pointed out above, frontloaded decarbonization of electricity supply is crucial to realize the full abatement potential of electrification in the sector.
- **Combine regulatory measures with pricing instruments to encourage fuel and energy efficiency improvement by the private sector.** China has effectively implemented administrative measures toward stricter fuel economy and energy efficiency standards of vehicles over time. These regulatory tools, combined with higher fuel taxes or carbon pricing, would provide strong incentives to private and commercial fleet operators to reduce fuel consumption, which is estimated to bring about an emissions reduction between 4.3-7.0 Gt from now until 2060.
- **Promote modal shifts from private road transport to public mass transit (for passenger transport) and to railway and waterway (for freight transport), through deeper integration across modes and pricing incentives.** Despite the success in rapidly building an extensive network of high-speed railways and urban metros, the integration between modes has been weak due to the lack of institutional coordination. The current pricing structure results in lower relative prices for carbon-intensive modes (road and air transport) compared to lower-carbon modes (rail and waterway). Meaningful shifts to low-carbon modes, which require both physical and operational integration across modes and relative pricing that reflects externalities, can bring about an emissions reduction between 2.4-3.3 Gt from now until 2060.
- **Promote technology development for alternative low-carbon fuels for harder-to-decarbonize sectors.** Waterborne and air transport systems, which account for about 15 percent of transport emissions and are growing fast, are difficult to electrify with current technologies. Alternative options, including green hydrogen, ammonia, and potentially new generations of batteries, are not yet commercially viable. Continued innovation will be required to achieve full decarbonization of the transport sector by 2060 in line with government targets.

Decarbonizing industry

Industrial energy efficiency in China has improved steadily over the years, but greater progress is possible. Although the growth rate of industrial process emissions has been declining since 2005 thanks to rapid improvements in energy efficiency, decarbonizing China's large heavy industries will be challenging because low-carbon production technologies remain costly (for instance, use of hydrogen and carbon capture in steel production) or do not yet exist (as in cement-production). A structural shift away from heavy industries, a move toward a circular economy, and the development of new technologies, including carbon capture and storage (CCS), will be required to bring industrial emissions down.

- **A shift from traditional investment-led towards more consumption driven growth would reduce trade-offs between the authorities' short-term growth and long-term climate objectives.** China has traditionally relied heavily on investment to drive growth. This investment-driven growth model has stimulated demand for steel, cement, and other carbon-intensive outputs of heavy industries and thereby increased emissions. The economic returns to investments especially in infrastructure and real estate have been declining. Instead of stimulating further accumulation of physical capital, using government policies to support consumption would be consistent with China's objective of economic rebalancing toward services and consumption while simultaneously mitigating the trade-off between short-term growth and ambitious emissions targets.
- **Greater attention to circular economy opportunities would reduce emissions intensity and help overcome material supply bottlenecks.** Promotion of the circular economy can support emissions reductions. Electric Arc Furnace (EAF) production is currently constrained by domestic scrap steel supply. A standardized scrap steel recycling system would facilitate increased use of scrap, important in the context of China's end-of-life steel availability quantities, which are expected to double over the coming decade as existing infrastructure reaches end-of-life. At the same time, tighter design standards for new buildings can be used to mandate more recycled content.
- **In the longer term, there is a need to support direct and indirect drivers of technological advancement.** A range of technologies is available to reduce emissions but requires price incentives to support uptake. Technologies available range from well-established to experimental and can dramatically reduce emissions (Lin et al. 2021). Background analysis of firm-level data in China's major industries, undertaken for this report, demonstrates the correlation between research investment, technological innovation, and industrial efficiency across sectors.[2] It also highlights the role of foreign investment in driving efficiencies by diffusing advanced management experience and cleaner technologies. The planned expansion of the ETS will motivate efficiency measures when it is expanded to cover areas of the economy beyond power generators.
- **Decarbonizing the industrial sector may also induce relocation of industries toward provinces with higher renewable energy potential.** China's industrial capacity, especially its carbon-intensive heavy industries, is spatially concentrated in the northwestern provinces, reflecting historical industrialization patterns that were in part driven by the endowments with carbon-intensive energy sources (such as coal). The low-carbon transition may shift comparative advantages to areas with high renewable energy potential (solar, wind, hydro) and fuels derived from these inputs (hydrogen, ammonia). This will likely reshape the economic geography. Enabling flexible factor markets could ease this relocation where it contributes to most cost-effective low-carbon production.

Policy Package 3: Enhance climate resilience and low-carbon development in rural landscapes and urban areas

Despite progress in setting a national policy framework, there are opportunities to improve adaptation efforts at both the national and sector levels. Fortunately, mitigation and adaptation actions are synergetic in several areas, such as city planning; agricultural, water, and land management practices; the development of green finance; nature-based solutions (NbS); and the creation of an offset market, together with building more resilient social protection systems.

Low-carbon and resilient rural landscapes

Physical risks from climate change will affect the country's agricultural production potential and the availability of ecosystems services such as water yield, erosion control, and carbon sequestration. Changes

2 Background note on determinants of industrial eco-efficiency, prepared by Yutao Wang et al. (Fudan University).

in crop yields and the availability of arable land will affect agricultural output and could increase risks, unless production practices are adapted to climate change. Water resources are already being impacted by climate variability, and climate change will severely affect China's water systems. Meanwhile, agriculture, together with land use, land-use change, and forestry (LULUCF), accounts for 6 percent of emissions, although this has declined over the past decade.

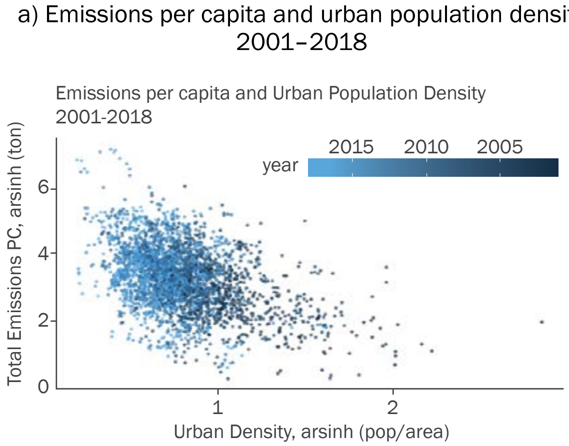
Nature-based solutions, such as afforestation, forest management, nutrient management, improved grazing land management, and wetlands restoration, offer opportunities to contribute to climate change mitigation and resilience. Preliminary estimates suggest the potential to remove at least 768 Mt of CO_2 equivalent annually (CO_2 yr^{-1}) by 2030 through NbS in China. This could offset difficult-to-mitigate emissions, reducing total costs of achieving carbon neutrality. NbS can also deliver potentially large co-benefits, in terms of ecosystems, watershed management, and pollution reduction. Research prepared for the CCDR suggests that land-based carbon sequestration could be improved by 33.9 percent with no net decrease in food production, although some switching of land use is required.

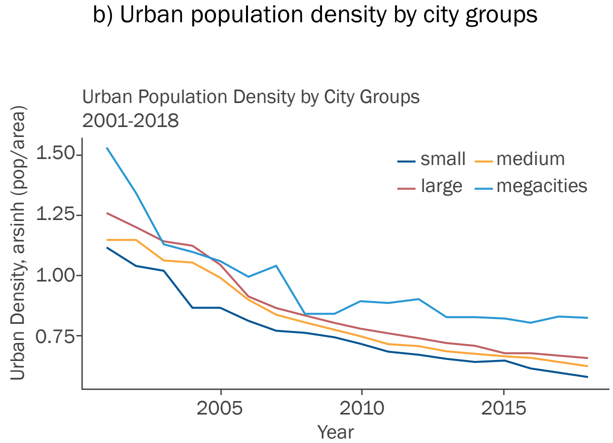
- **Elevate NbS within the national climate change planning process and use carbon credits to leverage new sources of financing.** There is a need to reflect the potential of NbS in high-level planning, and explicit targets should be set toward the 30-60 goals. Unlocking NbS potential will also require new sources of financing; carbon credits in conjunction with the ETS could be harnessed for this purpose. Public funding will continue to be necessary but spending effectiveness could be improved. Public eco-compensation programs (over US$30 billion annually), for example, could be conditioned on ecosystem outcome proxies (for example, plantation diversity) rather than outputs (plantation area) with tighter spatial targeting (that is, prioritizing areas with the highest biodiversity and carbon sequestration potential) and use of reverse auction mechanisms. In addition, the introduction of China's emissions trading scheme (ETS) provides an opportunity to finance NbS through the sale of carbon offsets.
- **Reduce China's food system-related greenhouse gas (GHG) emissions by repurposing agricultural public support, reducing food loss and waste, and recycling.** This would entail decreasing expenditures coupled with production and using the fiscal savings to support the development of green technology in R&D expenditures. R&D expenditures include technologies that mitigate GHG emissions; alleviate soil and water pollution from fertilizer, pesticide, plastic film, and livestock and poultry waste; reinforce climate adaptation and disaster resistance; and increase the efficiency of natural resource use (land and water). Green subsidies should be designed with clear and conditional environmental requirements for potential recipients. Only producers who meet the environmental requirements or set standards should receive subsidies.

Low-carbon and resilient cities

Cities in China play an important role in realizing climate and development goals. The urbanization rate, currently at 60 percent, is projected to reach 80 percent in 2035, with an expected urban population of over 1 billion. Cities are expanding more rapidly in areas exposed to climate risks. Moreover, sea-level rise and storm surge constitute a serious and imminent threat to Chinese coastal cities and infrastructure. At the same time, urban built-up areas currently represent up to 90 percent of total CO_2 emissions in China. While population density has fallen steadily in recent years, our analysis shows that lower urban population density is associated with higher per capita emissions (Figure O.6). Reversing this trend and creating conditions for denser, well-connected, and people-oriented cities would be good for the climate while seizing the full productivity benefits of urban agglomeration. Moreover, urban NbS, such as harnessing wind cooling to deal with urban heat traps, using natural water bodies for flood control, and creating integrated green urban spaces to preserve biodiversity, can enhance climate resilience while making cities more livable.

Figure O.6. Denser Chinese Cities Have Lower Per Capita Emissions, but Density Has Been Declining Over Time





Source: World Bank calculations. Note: Urban density is calculated by urban population (population/built area) and the unit is the inverse hyperbolic sine of 10 thousand people per square kilometer. Emissions are total emissions per capita, and the unit is log of tons. City groups are defined as follows: small cities—less than 1 million (50 cities in 2018), medium cities—between 3 and 5 million (52 cities in 2018), large cities—between 5 and 10 million (62 cities in 2018), and megacities—more than 10 million (11 cities in 2018).

- **Promoting denser, well-connected, and people-oriented urban growth.** Urban planners have a number of tools at their disposal to achieve a low-carbon urban growth path, including: (i) regulatory measures such as floor area ratios to influence the density of development, (ii) land use regulations to discourage urban sprawl and promote compactness, (iii) coordinated urban expansion and public transport investment strategies to encourage transit-oriented development, (iv) area master plans to promote walkable neighborhoods and small-block development, and (v) scaling up of urban re-densification and regeneration programs. The dependence of China's cities on land sales for revenues has encouraged sprawl, and the introduction of property taxes and alternative sources of local revenues could thus greatly encourage densification of urban areas with lower emissions and enhanced productivity.

- **Combine grey and green solutions and engage local planning authorities to protect critical public assets against floods, storm surge, and sea-level rise.** Policy measures could include the enhancement of early warning systems, planning and investing in the restoration of coastal mangroves, and investing in improved drainage. Moreover, to maximize the benefits for communities, city governments should involve local residents in the implementation process to not simply raise awareness, but also to leverage community resources for disaster prevention and response.

- **Strengthening city-level GHG inventories and related analytics would be crucial to help cities identify key emissions reduction potential and monitor progress toward the achievement of carbon goals.** Methodologies for GHG accounting also need further standardization across cities, to facilitate emissions trading and guide private investment.

- **Strengthen fiscal incentives and financial and building regulations to encourage private investment in more energy-efficient buildings.** Aligning domestic building standards with international norms could attract more investment, including from the growing green finance pool. More reliable monitoring and disclosure of building energy efficiency could inform investors, regulators, and homeowners/occupiers. It would also allow a shift of existing fiscal incentives for the building sector to incorporate ex-post performance measures for energy conservation and emissions reduction. Finally, building carbon emissions could be included in the carbon trading market system.

Cross-cutting institutional reforms for adaptation

China's adaptation policy landscape remains fragmented. The current regulatory system provides limited information and incentives for private actors to prepare for and insure against the effects of a warming climate. National policies lack a coherent effectiveness evaluation framework, while the use of quantitative targets and monitoring systems on climate adaption at the local level is limited.

- **Identify, monitor, and fill gaps in the adaptation capacity of people, firms, and local governments.** A first step would be to make existing databases on climate vulnerability more broadly accessible to government and nongovernment actors. Local governments lack the capacity and knowledge to implement more resilient policies and engage residents on the ground. Governments at the subcity district level could benefit from peer learning and collaboration between urban and rural districts to jointly address climate change-related risks. This could be accompanied by the development of an adaptation effectiveness evaluation framework. With improved data availability on disaster risk and adaptation capacity, private insurance markets can set appropriate incentives and help mobilize funding for risk mitigation.
- **Improve the targeting of social transfers to address climate vulnerabilities.** Food price shocks and climate change-induced agricultural production shocks will be key challenges faced by the vulnerable populations in China over the next few decades. Risk mitigation measures include strengthening farmer cooperatives, fostering the adoption of climate-smart agricultural practices, improving access to climate insurance and small agricultural loans, enhancing off-farm income and employment opportunities, and investing in quality education and training services. In addition, targeted transfers will be needed to prevent vulnerable rural households from falling back into poverty.

Policy Package 4: Harness markets to drive cost-effective economy-wide abatement and innovation

The transition to carbon neutrality will require the use of well-designed economy-wide policies. Economy-wide policies are important to deal with market failures and ensure relative prices reflect both the social cost of carbon and the public benefits of low-carbon innovation and technology diffusion. But achieving carbon neutrality will require more than adjustments in relative prices. Broader structural reforms to promote a more decisive role of market forces in guiding the allocation of capital, land, labor, and R&D investment are hence critical to enabling the economy to adapt more efficiently to changing price signals and regulations.

- **Expand the role of carbon pricing with forward guidance.** Simulations show that a more broadly applied and higher carbon price rising to US$50–75 per ton of carbon by the end of this decade could help reduce China's emissions by about 15 to 20 percent. To move in this direction, China could strengthen the ETS design with a total emissions cap with pre-announced annual emissions cap reductions, aligned with China's desired emissions reduction path. This would allow investors to factor future carbon price increases into their investment decisions today. Over time, the ETS should also be expanded to other emitting sectors, as planned, and could be complemented by carbon taxation in sectors in which ETS implementation is not feasible. The efficacy of the ETS or any other form of carbon pricing will also hinge upon the successful implementation of market reforms in the power sector (discussed above).
- **Deepen state-owned enterprise (SOE) reforms to enhance competition, productivity growth, and emissions reduction.** SOEs are estimated to generate about half of China's total greenhouse gas emissions, given their dominant presence in carbon-intensive value chains.[3] State ownership has given the government significant capacity to implement low-carbon policies, including for instance the rapid scale-up of renewable energy in recent years. SOEs will remain protagonists in China's transition to carbon neutrality. Adopting carbon accounting and monitoring systems together with enhanced disclosure, including publication of SOE-specific climate objectives and performance as part of the SOE

3 Clark and Benoit (2022), "Greenhouse Gas Emissions From State-Owned Enterprises: A Preliminary Inventory," Columbia Center on Global Energy Policy. (link)

sector annual reporting, would help inform SOE corporate management and facilitate monitoring and oversight. At the same time, deepening reforms to expose SOEs to market discipline and competition—in line with China's own stated reform objectives—would help ensure emission reduction is achieved in an efficient manner. Competitive and open markets would create powerful incentives to enhance productivity, including in the use of energy and other carbon-intensive inputs while stimulating innovation and adaption of new technologies. Strengthened corporate restructuring and insolvency frameworks would also be important to facilitate market-based exit of nonviable firms and reduce excess capacity, including in high-emitting sectors.

- **Foster market-driven green finance.** While China's green finance markets are growing rapidly, green assets still account for only a fraction of China's financial market, with green loans and bonds making up about 8 percent and 1 percent, respectively, of the total. Green equity markets, especially for early-stage risk capital necessary to spur innovation, remain shallow. At the same time, climate risks are not properly priced in and play a limited role in asset allocation. A robust green financial market infrastructure, including standards and carbon accounting and disclosure requirements, would help catalyze the development of green finance, complemented by steps to integrate climate considerations into financial regulation and supervision. Broader financial sector reforms, particularly phasing out implicit state guarantees in financing that continue to favor the state sector, could accelerate capital reallocation to productive low-carbon investments and support the shift to a more innovation-driven, private sector-led growth.
- **Create an effective innovation ecosystem by correcting market and governance failures in innovation and early-stage technology diffusion.** Public R&D support is necessary to help resolve multiple market failures. But implementation of these policies is delicate, and public resources must be spent well to have the desired impacts. Interventions should be based on a clear understanding of their efficacy and relative cost-effectiveness. China has an extensive system of R&D support, including public guidance funds—state investment vehicles to provide equity and debt financing to enterprises—as well as other forms of demand-side subsidies to encourage shifts in consumer behavior. Enhancing the efficiency and efficacy of public R&D support will require complementary reforms to open the innovation system and encourage market entry and competition on a level playing field between private—domestic and foreign—firms and SOEs.
- **Reforming trade and investment policies to encourage low carbon production and consumption.** Analysis for this report demonstrates that China's Non-Tariff Barriers (NTBs) and import tariffs are on average higher on lower-carbon products, particularly in the case of NTBs. This is estimated to result in an implicit subsidy on imports of high-carbon products equivalent to around $US68 per ton of CO_2. The government has already announced planned tariff reforms to reduce the incentive to import high-carbon goods. NTBs could also be reviewed to identify and rationalize policy distortions that benefit high-carbon product groups or negatively affect low-carbon supply chains.

Policy Package 5: Manage transition risks to ensure a just transition

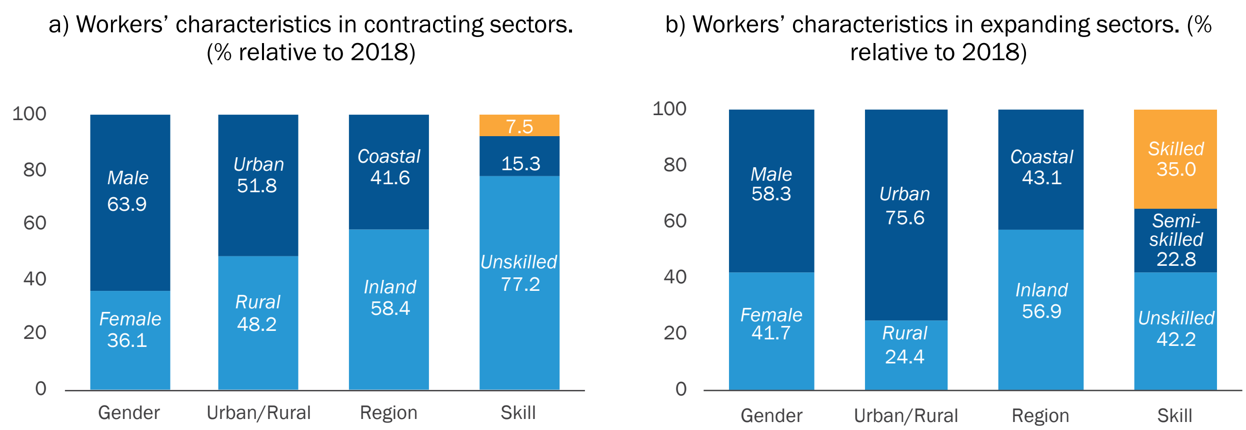
Ensuring a just transition needs to be a central priority in the decarbonization strategy, with policies to facilitate the labor market transition and targeted support to areas with concentrated losses. Impact simulations carried out for this report suggest that job gains are generally predicted to outweigh job losses but are likely to occur in different sectors, occupations, and regions. The results suggest an employment decline of around 1 to 2 million workers by 2030 in the coal industry, which is the most affected. Job losses are in largely male-dominated, lower-skilled occupations and in China's central or western provinces (Figure 0.7). On the other hand, job gains are predicted to be in higher-skilled industries that are more likely to be in China's coastal cities.[4]

4 Della Vigna et al. (2021).

- **Enhance labor market flexibility and social safety nets to enable a more seamless labor market adjustment.** Reducing barriers to labor mobility, reforms to the hukou (household registration) system, and the portability of social benefits could help lower the adjustment costs of the transition. Tailored social safety nets, including temporary income support, could also help cushion negative employment shocks and encourage workers to remain in the labor market. Effective active labor market policies—re-skilling, job matching, and transition support—will also be needed to buffer labor market impacts.
- **Provide more targeted assistance that goes beyond social safety nets, to groups that will experience concentrated losses from the low-carbon transition.** Even though direct coal-related jobs account for a very small share of China's total, they are heavily concentrated. Three provinces alone account for two-thirds of direct coal jobs.[5] The economies of these provinces are also undiversified and highly dependent on coal for fiscal revenues. It will be important to assist workers to move to new opportunities and to provide other forms of growth, employment, and revenues in affected communities, using targeted place-based support and investment focusing on economic growth, diversification, and regeneration in coal regions.

Figure O.7. Job Losses Will Disproportionately Affect Lower-Skilled Men, Working Inland, Whereas Job Gains Are More Likely to Be Urban, Skilled Jobs in Coastal Regions

Distribution of jobs lost and gained, holding job characteristics fixed.



Source and Notes: World Bank calculations based upon CGE modeling results in 2030 relative to 2018, combined with average sector characteristics based on 2018 China Family Panel Survey household survey data. Sector characteristics are held fixed at their 2018 levels.

Policy Package 6: Foster global climate action

Beyond China's direct contribution to meeting global emissions reduction targets, its large domestic market size, industrial prowess, and growing trade and financial linkages, especially with developing countries, create additional opportunities to foster climate action. To maximize its impacts on global climate goals, domestic policy shifts will need to be complemented by consistent external policies to ensure climate-friendly trade and investment links with the rest of the world. The recent announcement to not build new coal fired power plants is an important step in this direction.

- **Create stricter rules for outward foreign finance:** Encourage Chinese lenders, including policy banks (China Development Bank and China Exim) to adopt clean financing principles (the "Equator Principles") and to phase out the financing of coal and other carbon-intensive infrastructure. Climate-related information disclosure and guidance on standards would also be important.

5 He et al. (2020).

- **Assist emerging economies with low-carbon projects:** China could take steps to encourage the emerging economies in which it finances infrastructure to opt for lower-carbon projects. Technical assistance using China's own experience in ramping up renewable energy could help other countries forge a viable lower-carbon path and deepen markets for low-carbon technologies.

From Analysis to Action

To kick-start the transition to more resilient, carbon-neutral development, we conclude with the following priorities for action during the next five years: The proposed policy measures combine economy-wide and sector-specific reforms in the key emitting sectors. Several of them are good for the climate and for development. For example, reforms to ensure the development of more compact and livable cities would make China's cities more resilient and reduce their carbon footprint while boosting productivity gains from agglomeration. Similarly, structural reforms to enhance competition, provide a more decisive role to market forces in resource allocation and rebalance the economy from industry to services would contribute to achieving both climate and growth objectives. Reforms should be sequenced to take advantage first of no-regret steps and lower-hanging fruit—for example, the availability of low-cost renewable technologies in the power sector. Some of the measures, like the accelerated rollout of renewable energy generation capacity, contribute to speedy reductions in emissions. Others—for example, refining China's ETS or investing in low-carbon research and development—may not cause large immediate gains but could establish important foundations for deep decarbonization in the long run. Together, these measures constitute critical first steps that China could take over the next five years. Given the uncertainties involved, policies and their impacts will have to be monitored and adapted over time.

Table O.3. Short-term (next 5 years) priorities

Rationale	Policy Options
1. Define the trajectory to carbon peaking and deliver clear signals to firms	
China has made long-term commitments, but short-term emission targets remain ambiguous.	• Provide clear forward guidance by setting annual mass-based emissions caps over the next decade, supported by a consistent carbon accounting framework for firms, provinces, and cities.
2. Accelerate the power sector transition with market reforms and investments in renewables	
The sector is highly reliant on coal, and it occupies the largest share of total emissions. Green energy technologies are increasingly available and affordable. The demand for electrification in downstream sectors (transport, industry) is rising.	• Increase, by 2030, solar and wind power generation capacity to 1200 GW to 1,700 GW, supported by additional energy storage of 200 GW and more flexible electricity grid. • Adopt international best practice in system planning, reliability regulations, and variable renewable energy (VRE) generation forecast and dispatch to enable phasing down of coal use. • Expedite electricity market reforms, including pricing reforms, development of ancillary service and capacity markets, and interprovincial power trade. • Promote demand management measures, including energy efficiency, distributed renewable energy, and demand response programs.
3. Decarbonize key energy demand sectors— industry and transport	
Emissions from transport and industry are increasing. There is potential to switch to clean energy sources, including electrification, efficiency improvement, and demand management.	• Adopt macroeconomic policies to support rebalancing from industry and investment-led to services and consumption driven growth. • Set clear and ambitious emissions reduction targets and technology standards in the cement and iron and steel industries.

Rationale	Policy Options
	• Accelerate electrification of the private and commercial fleets, moving away from focus on public buses, providing tax incentives toward price parity, nonmonetary incentives, and adequate charging infrastructure (in conjunction with the low carbon energy transition to decarbonize power supply). • Incentivize transport users to improve fuel and operating efficiency through pricing and regulations on vehicle and fuel standards. • Promote modal shifts to public mass transit and low-carbon freight modes (railways and waterways) through modal integration and pricing incentives.
4. Enhance climate resilience and adaptation in rural landscapes and urban areas	
The land-use sector can be harnessed to increase resilience, and it can become a net carbon sink providing opportunities to offset hard-to-abate emissions in other sectors.	• Develop an adaptation policy framework for agriculture, increase the use of nature-based solutions, and use scientific and meteorological information to inform water use and water resources planning. • Increase the profitability of investments in NbS by accelerating forestry sector reform, reorienting eco-compensation, and leveraging carbon offset markets. • Repurpose public sector support to agriculture to support low-carbon land use and promote the reuse of agricultural waste. • Strengthen policy framework on urban land-use and spatial planning, to discourage sprawl. • Strengthen standards and provide fiscal incentives for energy conservation and emissions reduction in the building sector. • Strengthen interinstitutional collaboration and vulnerability data access to households, firms, and local governments, and develop an adaptation effectiveness evaluation framework.
5. Harness markets to drive cost-effective economy-wide abatement and innovation	
Economy-wide climate policies are necessary to internalize both the negative externality of carbon emissions and the positive externalities from innovation.	• Expand the use of carbon pricing mechanisms, including the ETS, with a focus on (i) building market infrastructure, (ii) unifying performance benchmarks, and (iii) introducing permit auctioning as the foundation for a gradual transition toward an effective cap and trade system with an absolute emissions cap. • Enhance competition between SOEs and non-SOEs to allow market forces to drive allocation of capital and R&D resources. • Revise nontariff trade barriers to eliminate incentives to trade in high-carbon products. • Reform R&D support for low-carbon technologies, moving from quantity to quality of research and patenting. • Harness the financial sector by establishing corporate emissions accounting systems, mandating climate-related financial disclosures, and using blended finance to favor innovation.
6. Mitigate the social costs of the transition and prepare the labor force for the low-carbon economy	
The low-carbon transition will have distributional implications. Households will also be affected by rising energy prices and by changes in the labor market.	• Improve labor mobility through hukou reform and active labor market programs. • Provide targeted assistance to communities that will experience concentrated job losses. • Revisit government skills development strategies and systems and work with schools, training institutions, employers, and workers to incorporate green skills into the relevant programs.

Rationale	Policy Options
7. Foster global climate action	
With China being the largest source of infrastructure financing in low-income economies, adopting climate-friendly investment practices would amplify global impact.	• Encourage Chinese lenders, including policy banks—China Development Bank and China Exim—to adopt clean financing principles ("the Equator principles"), and phase out financing of coal and other carbon-intensive infrastructure.

1.

Introduction and structure of the report

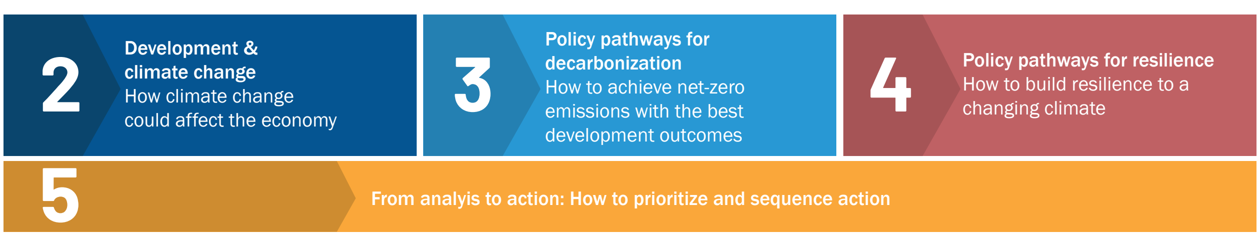
1. Introduction and structure of the report

The China Country Climate and Development Report (CCDR) provides analysis and recommendations on integrating the country's efforts to achieve high-quality development with the pursuit of carbon emission reduction and climate resilience. Without adequate mitigation and adaptation efforts, climate risks will become a growing constraint to China's long-term growth and prosperity, threatening to reverse development gains. Conversely, if efforts to tackle climate risks lead to a significant decline in growth and rising inequality, they would deprive millions of people of development and likely erode support for the reforms necessary to achieve a lasting economic transformation. Hence, China will need to grow and green its economy at the same time. This report offers policy options to achieve these dual objectives by easing inevitable trade-offs and maximizing potential synergies between China's development and climate objectives.

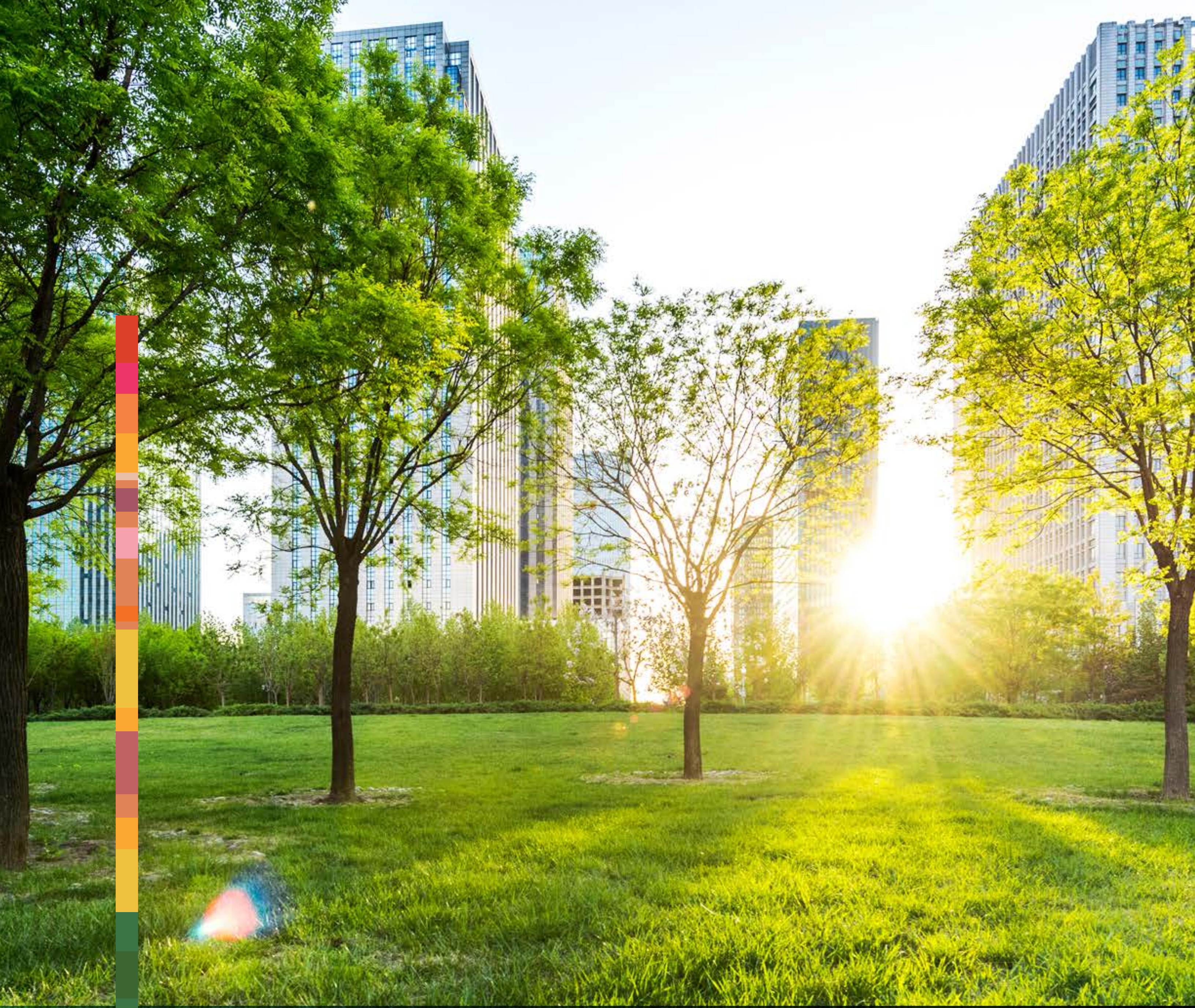
China's development and climate change are deeply intertwined. The country is both a contributor to rising global greenhouse gas (GHG) emissions causing climate change and severely affected by its adverse impacts. Although not the main source of historical cumulative emissions, China today accounts for 27 percent of annual global carbon dioxide and a third of the world's greenhouse gases emissions. Alongside other larger emitters, China's contribution to reducing global climate risks is therefore crucial. China has made ambitious commitments to peak emissions of carbon dioxide before 2030 and achieve carbon neutrality before 2060 (these targets are also known as the "30-60 goals"). Reducing greenhouse gas emission in China's relatively coal-dependent and carbon-intensive industrial economy will involve fundamental structural changes in energy, industrial and transport systems, cities, and land use. This will have inevitable impacts on China's future development trajectory—posing risks but also opening new opportunities. At the same time, large parts of China's population and economic infrastructure are heavily exposed to climate risks, with poorer households particularly vulnerable and less able to protect themselves adequately. Investing in adaptation and greater resilience is thus imperative, at the same time as the country aims to control and reduce its own emissions. Synergies between investments in mitigation and adaptation exist and deserve particular attention.

China's climate and development challenges and opportunities are in many respects unique. First, as China has set its own climate objectives to peak carbon dioxide emissions before 2030 and achieve carbon neutrality before 2060, the report is not about *whether* China should act to achieve these goals but *how* it can do so while safeguarding development gains and ambitions. Second, the size and structure of China's economy create unique risks but also opportunities to seize some of the technological and economic benefits of early climate action. Third, as the world's second largest economy, China's choices will matter not only for economic actors in China but also for economic actors throughout the world. China's climate actions offer the opportunity to exert global leadership and demonstrate viable and development-compatible pathways and could induce other developing countries to follow. These priors have shaped the overall framework, relative focus, and scope of this report.

Figure 1. The CCDR at a glance



The remainder of the report is structured as follows. Chapter 2 focuses on China's development, past and present, and how a warming global climate and China's own decarbonization efforts could affect the economy. Chapter 3 explores policy pathways to achieve carbon neutrality with the best development outcomes, Chapter 4 explores how climate change is affecting China and how to build resilience, and Chapter 5 concludes with key policy recommendations (Figure 1).



2.

Framing the climate challenge in China's development context

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2. Framing the climate challenge in China's development context

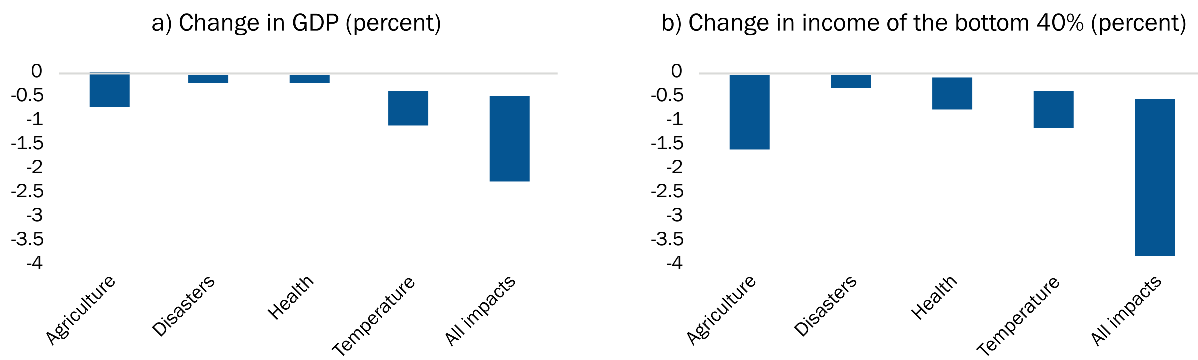
2.1. Prosperity in a changing climate

Unmitigated climate change poses a significant threat to China's long-term growth and prosperity. In comparative terms, China is ranked 61st out of 181 countries for climate vulnerability in the 2020 ND-GAIN (Notre Dame Global Adaptation Initiative) Index. Already today, climate change is affecting China and impacts are expected to intensify in years to come. As average temperatures rise, natural disasters and extreme weather events such as heat waves and floods are projected to grow in frequency and severity. Given China's large territory, specific exposure and drivers of climate risk vary across its different geographies.

The impacts of climate change threaten China's densely populated and economically critical low-elevation coastal cities, which are estimated to account for a fifth of China's population and a third of its gross domestic product (GDP). China already experiences frequent coastal flooding, storm surges, coastal erosion, and saltwater intrusion. Flood damages are likely to grow due to climate change-induced sea-level rise, unless further adaptation measures are taken. The GDP at risk (in 2019 purchasing power parity) in the Shanghai and Guangzhou metropolitan areas, for example, could surpass, respectively, US$1.6 trillion and US$291 billion a year by the end of the century (Bernard and Shepherd 2021).

Whereas the coast is at risk of flooding, arid and semi-arid regions in interior provinces in northern and western China are exposed to more frequent and extreme heat waves and droughts. This will add stress to already overexploited water resources and intensify water security risks, imposing significant and long-lasting impacts on agriculture—a major source of income, especially among China's low-income rural residents. China has made huge investments in transferring water from the water-rich southern provinces to the water-scarce northern ones, but a warming climate is likely to reduce the availability of melting ice water from the headwaters of all of China's major rivers, highlighting the need to shift attention toward improved water resource management. Aside from risks to human livelihoods, the impact of excessive water extraction on ecosystems and biodiversity also needs to be factored in.

Figure 2. Unabated climate change poses a major threat to China's economy, with estimated GDP losses between 0.5 percent and 2.3 percent per annum as early as 2030

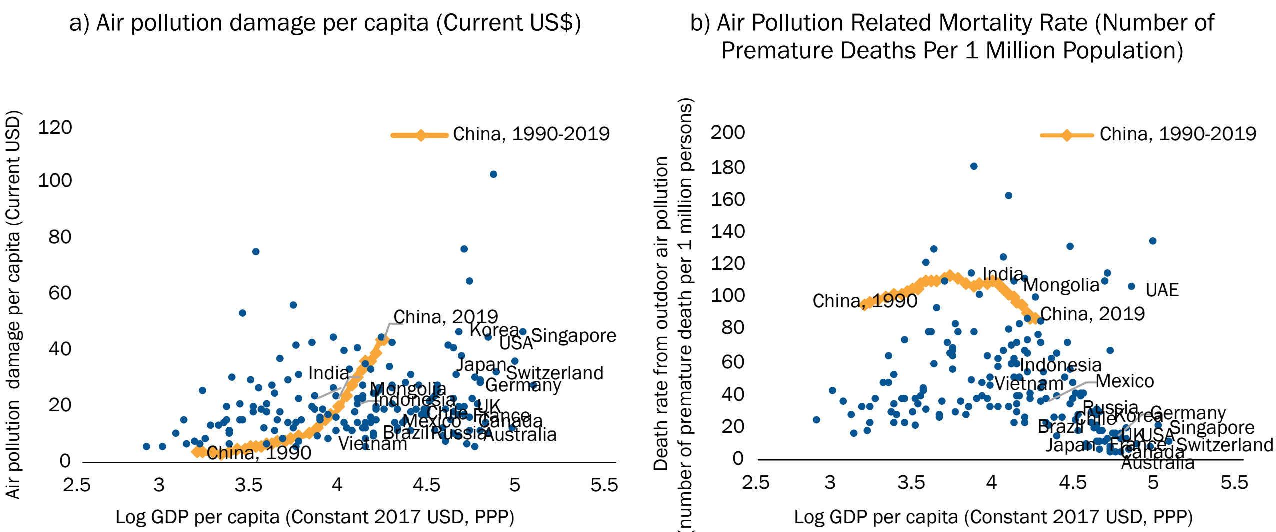


Source: Hallegatte et al. (2017), Shockwaves modeling for China.

Note: the bars in each graph represent ranges that correspond to alternative socio-economic and climate change scenarios.

Climate impacts exert growing economic costs, often disproportionately affecting China's lower-income households. Annual losses due to natural hazards averaged US$76 billion annually over the past five years, with around one-third of China's agricultural land negatively affected. Studies suggest that these effects will intensify in the future. For example, World Bank modeling by Hallegatte et al. (2017) estimates that climate change could result in GDP losses of between 0.5 and 2.3 percent as early as 2030, depending on the climate scenario (Figure 2a). Income losses will disproportionately hit the bottom 40 percent of the income distribution, a bracket that could incur income losses of up to 4.7 percent by 2030 in the most severe climate scenario. Other research has arrived at similar estimates, suggesting GDP losses amounting to around 0.5 percent of GDP in the next decade, 0.5 to 3.5 percent of GDP by midcentury, and 1 to 6 percent of GDP by 2100, depending on the climate scenarios (CMCC 2021; Swiss Re Institute 2021).[6]

Figure 3. Air pollution is causing a significant economic and human toll



Source: Adjusted Net Savings Database, World Development Indicators, World Bank.

In addition, despite significant improvements in recent years, air pollution—closely associated with China's carbon emissions—poses a serious threat to the well-being of millions of Chinese. Despite substantial improvements in air quality in recent years, 42 percent of China's population still lives in areas that do not meet the World Health Organization (WHO) air quality guidelines, and almost all Chinese cities have particulate matter 2.5 (PM2.5) concentrations above the WHO recommended thresholds. Chronic obstructive respiratory disease and other health impacts induced by air pollution are estimated to account for about 1.5 million deaths annually in China (Figure 3a). Direct economic losses are estimated to amount to about 0.5 percent of GDP annually (Figure 3b). Moreover, air pollution has been shown to negatively affect labor productivity (Chang et al. 2019). Accounting for these effects significantly increases the economic returns to climate action as shown in this CCDR.

Mitigating the causes of climate change and enhancing resilience to its consequences are therefore central development challenges for China. China's policy response to climate risks will be shaped by its unique position in the global economy and environment. This includes the balance between mitigation and adaptation measures. China plays a pivotal role in global efforts to contain GHG-induced temperature rises. Without effective mitigation efforts in China and other large emitters, including high-income economies that account for a disproportionate share of historical cumulative emissions, it will be impossible to achieve the goals of the Paris Agreement. This report thus puts a significant emphasis on pathways to achieving China's

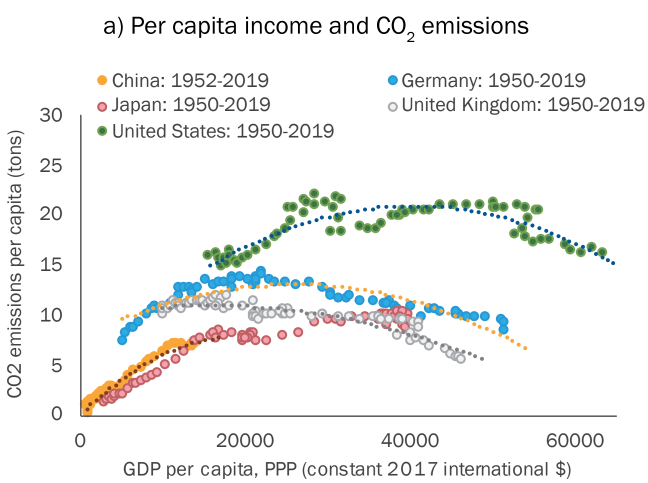
6 Details on these trends and potential sensitivities to climate shocks are further discussed in Chapter 4.

carbon peaking and neutrality goals, thereby limiting its own and the world's exposure to physical climate risks, described above. And although China's efforts to mitigate climate change are important, like other countries, it will have to simultaneously adapt and build resilience to protect human life and avoid economic losses from the effects of residual climate change. Adaptation and mitigation will thus have to be integrated as part of a comprehensive climate and development strategy. This report places particular emphasis on measures that could simultaneously contribute to both objectives.

2.2. Unprecedented economic development but rising environmental strains

Over the past 40 years, China has achieved unprecedented economic growth and development gains but also experienced rising carbon emissions. Like other industrial countries, China's development process has historically exhibited a strong link between growth of per capita incomes and rising per capita emissions (Figure 4). China's rapid economic ascendance since the 1970s has led to a nearly 30-fold increase in per capita income but has also resulted in carbon dioxide (CO_2) emissions growing more than tenfold over the same period (World Bank World Development Indicators [WDI], Climate Analysis Indicators Tool [CAIT]). This correlation between growth and emissions reflects deep interconnections: The very same drivers that propelled China's rapid economic growth and unprecedented development gains—capital deepening, export-led industrialization, and urbanization—have also resulted in rising carbon emissions. The strong reliance on energy-intensive activities in driving economic development led China to become not only the world's second largest economy but also the largest energy consumer, while its reliance on coal as a primary energy source has made it the world's biggest current emitter of energy-related CO_2.

Figure 4. Growth and GHG emissions have historically been closely linked



Source: World Bank World Development Indicators (WDI), Climate Analysis Indicators Tool (CAIT).

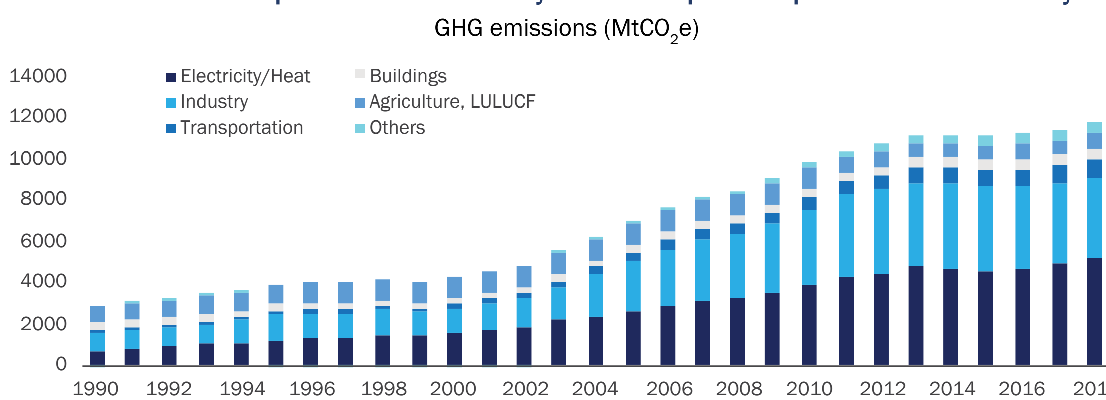
Table 1. Different Measures of China's Carbon Footprint

(Unit)	GHG Emissions per Capita (Tons CO_2e per person)	Emission Intensity (kg CO_2e per PPP $ of GDP)	Total GHG Emissions (Mt CO_2e)
Brazil	5.0	0.13	1057.3
China	9.0	0.46	12705.1
India	2.5	0.26	3394.9
Indonesia	3.7	0.19	1002.4
Philippines	2.2	0.14	234.3
Russia	17.2	0.39	2476.8
United States	18.3	0.23	6001.2
Vietnam	4.7	0.33	450.1
European Union	7.6	0.13	3383.4
OECD	10.7	0.18	14551.2

Source: World Bank World Development Indicators (WDI). Data refers to total GHG emissions (CO_2 equivalent) and the year 2019.

Although contributing a large share of current emissions, China's historical cumulative emissions are lower than those of other major economies. Historical cumulative net anthropogenic carbon emissions in North America, Europe, and Eastern Asia (including China) are 23 percent, 16 percent, and 12 percent, respectively.[7] On a per capita basis, China's emissions in 2019 (9 tonnes CO_2-equivalent [tCO_2e] per year) surpass those of the European Union (7.6 tCO_2e) but remain slightly below the Organisation for Economic Co-operation and Development (OECD) average (10.7 tCO_2e) and well below the United States average (17.6 tCO_2e). However, the carbon intensity of China's GDP—the amount of carbon used to generate a unit of output—remains relatively high (Table 1). Improved industrial energy efficiency and a shift of the energy mix toward renewables has moderated emissions growth since 2016, although China's absolute emissions have continued to rise at 2 percent annually during the past decade. And although China's efforts to mitigate climate change are essential, like other developing countries, it will have to simultaneously adapt and build resilience to protect human life and avoid economic losses from the effects of residual climate change.

Figure 5. China's emissions profile is dominated by the coal-dependent power sector and heavy industry

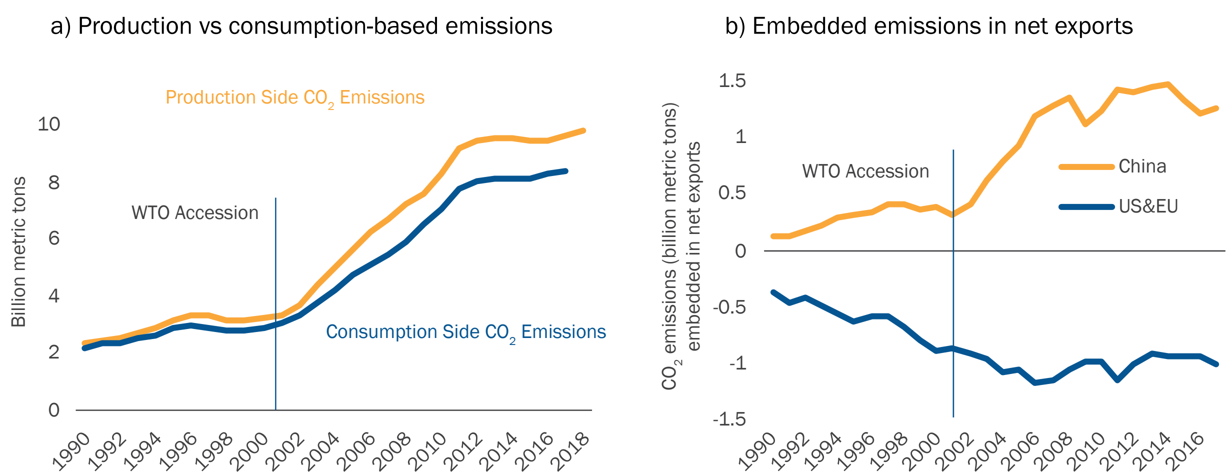


Source: World Bank calculations using data from CAIT, the National Bureau of Statistics of China (NBS), and the International Energy Agency (IEA).

7 2021 IPPC Report.

China's rapid emissions growth has been driven primarily by the coal-dependent power sector and heavy industry. China's coal-dependent power sector accounts for the largest share of emissions, with electricity and heat generation accounting for 45 percent of all GHG emissions, but thanks to a gradual shift in the energy mix, emissions from the power sector have started to moderate in recent years (see Figure 5). China's industrial emissions also remain exceptionally large, at 33 percent of CO_2 emissions in 2018, which compares to shares of 9 percent in the US and 12 percent in the EU. This reflects China's position as a global manufacturing hub, and, more importantly, its outsized and carbon-intensive construction and heavy industries—steel, cement, and other construction materials. Heavy industry accounts for 96 percent of industry CO_2 emissions, with 85 percent of those from the cement, steel, and iron sectors alone. The transport sector's emissions account for about 8 percent of total GHG emissions and continue to rise unabatedly as higher incomes drive motorization and mobility demand. Finally, buildings account for about 5 percent of total GHG emissions, driven by both low energy-efficiency building stock and expansion of floor space, as incomes and urbanization rates have risen.

Figure 6. Export-led growth has resulted in a wide gap between China's production and consumption emissions



Source: World Bank staff estimates based on data from Our World in Data.

China's large export sector also contributes to emissions. China is a net exporter of embedded emissions, with an estimated 13 percent of China's domestic, or "production side" emissions embedded in exports to other countries in 2018 (Figure 6).[8] In the wake of China's accession to the World Trade Organization (WTO) in 2001, emissions initially rose fast, propelled by rapid export and foreign direct investment (FDI) growth. During the first decade of the 2000s, production emissions growth outstripped consumption emissions, whereas production emissions in the US and the EU, China's main trading partners, declined. More recently, China's carbon emissions embodied in gross exports started to taper, in line with external rebalancing of the economy after the global financial crisis and a declining export share in GDP. Reflecting China's comparative advantage in manufacturing, 88 percent of embedded carbon emissions come from the manufacturing sector, with chemical products (17 percent) and metal products (17 percent) the two largest contributors.[9]

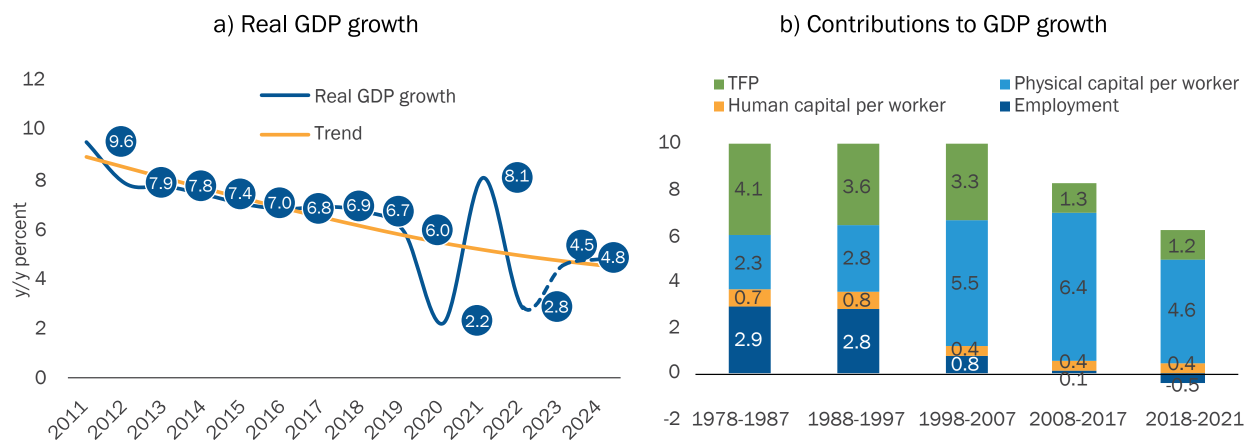
8 Embedded emissions refer to the carbon content exported goods. In other words, emissions that are generated in China by producing goods that exported to other markets. The calculation is based on domestic value added, using OECD data.

9 World Bank staff data, based on data from the OECD and COMTRADE (common format for transient data exchange for power systems).

State-owned enterprises (SOEs) continue to play a dominant role in China's economy, especially in carbon-intensive sectors. SOEs are estimated to account for around 25 to 40 percent of GDP and around 40 percent of employment.[10] SOEs control value chains for sectors responsible, directly or indirectly, for the majority of China's emissions: coal, electricity, oil, gas, steel, and cement. It is estimated that SOEs generate about half of the country's total GHG emissions (Clark and Benoit 2022). Addressing emissions generated by SOEs will therefore form a key component of reaching China's goal of carbon neutrality before 2060.

China's climate goals are not the only reason its economy needs to adjust. Reflecting looming demographic headwinds and a sharp decline in productivity growth, China's potential growth has gradually slowed over the past decade (Figure 7). The overreliance on state-led investment, especially in carbon-intensive infrastructure and real estate, has led to rapidly diminishing economic returns. China's medium- and long-term growth prospects are increasingly dependent on its ability to reinvigorate productivity growth and rebalance the economy: from traditional infrastructure investment to innovation, from exports to domestic consumption, from industry to high-value services, and from state-led to more market-driven allocation of resources. We show in this report that the reforms China needs to sustain growth would also significantly lower the cost of climate action.

Figure 7. China's increasingly factor-driven growth model is facing constraints



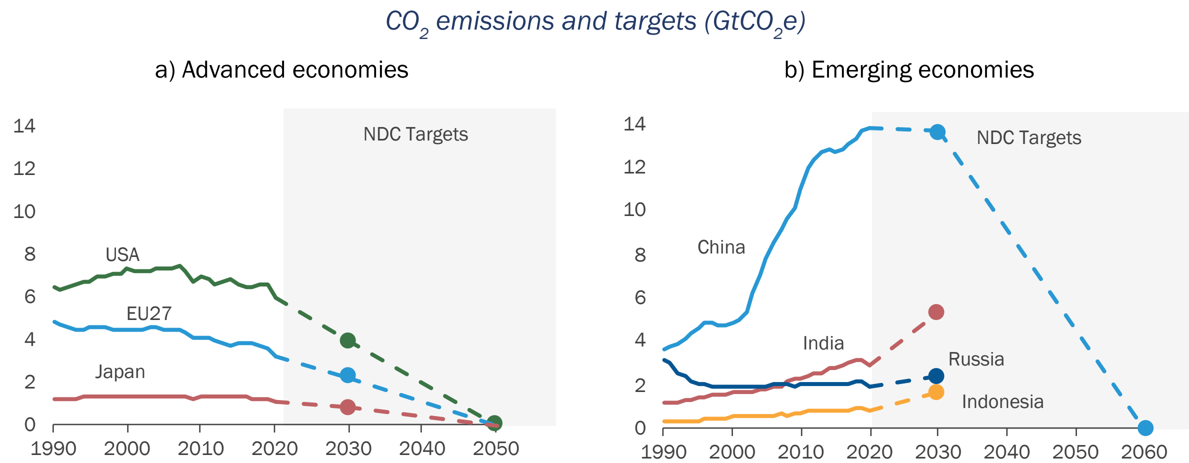
Source: World Bank analysis based on Penn World Tables (PWT) and National Bureau of Statistics (NBS) data.

2.3. Rebalancing from high-speed to high-quality growth

China has high ambitions, both for development and climate action. China aims to achieve sufficient economic growth to double annual per capita income between 2020 and 2035 to around US$21,000. At the same time, China's policy objective function has increasingly shifted to wider policy objectives such as tackling income inequality and reducing environmental degradation. The vision of creating an "ecological civilization" that integrates sustainability into development has been enshrined in China's constitution and is seen as a central element of China's long-term growth and development path. China's own policy and development planning documents, including the 14th Five Year Plan, have highlighted this, emphasizing growth alongside a range of environmental and social targets. It is within this broader context that China made its ambitious long-term climate commitment, pledging to peak emissions before 2030 and achieve carbon neutrality before 2060. The scale of this carbon neutrality challenge should not be underestimated: achieving this goal will require a transition from peak emissions to carbon neutrality in a faster timeframe and an emissions peak at a lower income level than the one experienced by advanced economies (Figure 8).

10 Estimating the share of SOEs is challenging because statistics are not released by ownership status. See Zhang (2019) (link) or Lin et al. (2020) (link) for estimates and discussion.

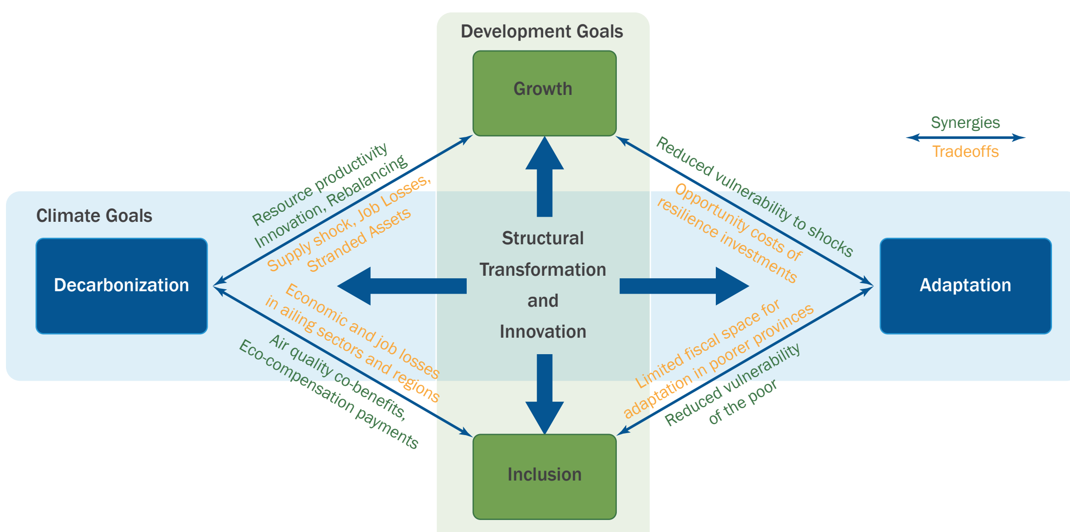
Figure 8. China's transition from peak carbon to carbon-neutrality will be faster than advanced economies



Source: Climate Action Tracker.

There are both complementarities and tensions between China's climate and development goals. While addressing climate risks is imperative to securing long term development, decarbonizing China's coal-dependent and carbon-intensive industrial economy will not be easy. It will involve fundamental structural change of the economy, energy and transport systems, cities, and land use. This requires a combination of accelerated structural transformation with resources—labor, capital, and land—moving from high-carbon to low-carbon activities, as well as innovation and diffusion of new technologies to enhance energy efficiency and resource productivity within all emitting sectors. The implied deep and accelerated structural change carries important economic and social risks. However, because of China's technological capabilities, the pathway to carbon neutrality also opens new opportunities for development, and because of China's size, substantially increases the probability that the world as a whole avoids catastrophic climate change. Greater adaptation efforts will be needed under any circumstances to mitigate economic damages and protect the most vulnerable, but these efforts, too, open new opportunities for greener and more resilient growth; for example, in agriculture or in the development of China's cities and infrastructure (Figure 9).

Figure 9. An Integrated Climate and Development Framework for China



Source: Report authors.

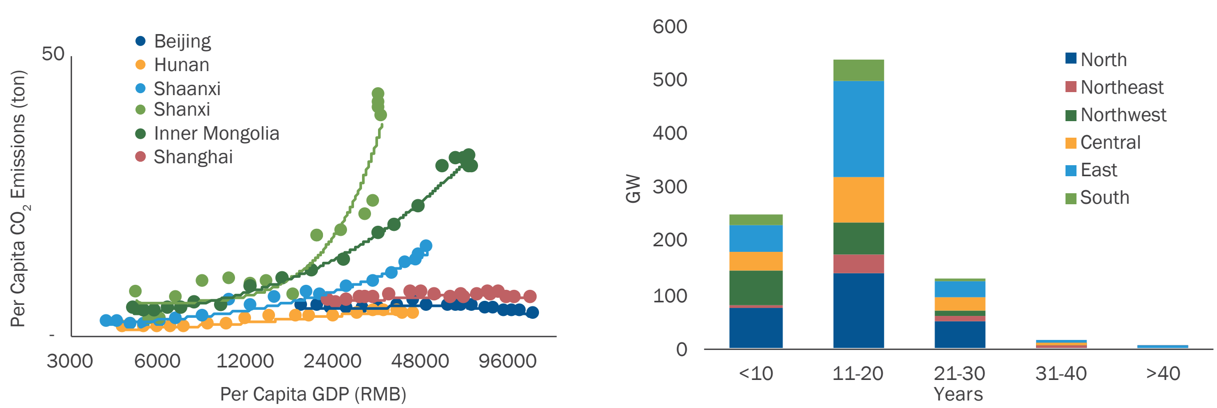
The disruptions and dislocations stemming from the accelerated structural transformation and creative destruction necessary for achieving carbon neutrality need careful attention. Energy prices will likely have to increase—at least in the short run—with detrimental impacts on consumers and firms. A large part of China's existing carbon-intensive capital stock, including a relatively young fleet of coal-fired power plants, may become obsolete, and job losses will occur in high-carbon industries, with impacts on potential growth and inclusion. Our estimates based on census data suggest that around 10 to 15 percent of China's jobs are in relatively high-carbon industries that may be affected by the low-carbon transition. This of course does not mean all these jobs will be lost, but skill content and requirements may change. On the capital side, stranded assets could also be significant. Reflecting China's rapid and relatively recent capital accumulation, its existing fleet of coal plants, steel mills, and cement factories is not only carbon intensive but also relatively young. For example, 40 percent of China's coal plants have been built in the last 10 years, meaning that early retirement of a significant amount of existing capacity in coal-fired power generation will be required to meet the decarbonization goals (Figure 10b).

Because industrial structures, and hence carbon intensity, vary starkly across China's provinces, these impacts will be felt unevenly across China's regions and could widen spatial imbalances in income and welfare. Some of the poorer northern and western provinces that are more heavily reliant on coal and heavy industries than the richer coastal cities in the southeast are particularly exposed to these transition risks and, without countervailing support measures, China's already large spatial income and welfare gaps could widen because of the low-carbon transition. In 2019, the carbon intensity of GDP was over 20 times higher in the most carbon-intensive province (Ningxia) compared to the least carbon-intensive province (Beijing). Beijing has already passed peak emissions and many other coastal provinces are also approaching peak emissions, reflecting the relocation of carbon-intensive industries to other provinces and the emergence of modern service economies (Figure 10a) (Du et al. 2017). By contrast, emissions continue to grow in many poorer and more resource-dependent provinces like Ningxia, Xinjiang, Shanxi, and Inner Mongolia. Reliance of these provincial economies on coal and coal-related heavy industries imply significant transition costs.

Figure 10. Transition risks vary significantly across provinces

a) Per Capita Output and emissions by province

b) Stranded assets—Age distribution of existing coal-fired power plants in China by region



Source: World Bank calculations using data from Carbon Emission Accounts and Datasets (CEADs) and NBS.

Yet, arguably China is also well positioned to turn the climate challenge into an opportunity. Like previous transformations of similar scale, the accelerated transition to reduced carbon intensity in China and the rest of the world will unlock new sources of economic growth, innovation, and job creation. There are five key reasons why the low-carbon transition offers economic opportunities for China and why the country may be uniquely positioned to take advantage of these shifts:

1. **Increasing returns to scale, large domestic market, and manufacturing capabilities:** Many low-carbon technologies, including wind and battery storage, have been shown to have increasing returns to scale in innovation, manufacturing, and operation. This opens opportunities particularly for large countries like China. It implies that progressive deployment of low-carbon technologies in China can push down prices, reducing abatement costs. China's scale-up of renewable energy—wind and solar—with accelerating uptake driving down costs is an instructive example (Figure 11c). At the same time, China's manufacturing capabilities enable the economy to respond to rising demand and build comparative advantages in emerging low-carbon technologies. Finally, it also means that early-stage investments in research can be catalytic with returns accumulating over time, resulting in amplified effects. Indeed, China is rapidly accumulating innovation capacity, as evidenced by low-carbon patenting activity that has accelerated over the past decade (see Figure 11a) (Crubb et al. 2021).

2. **Expanding export markets:** Beyond China's domestic market, there is a sizable global market opportunity. With 85 percent of the world's population and 90 percent of global GDP now in countries that have net-zero pledges, there will be growing demand for low-carbon products and export markets that expand dynamically over time as prices fall. Indeed, the country is already displaying a comparative advantage in several renewable exports.

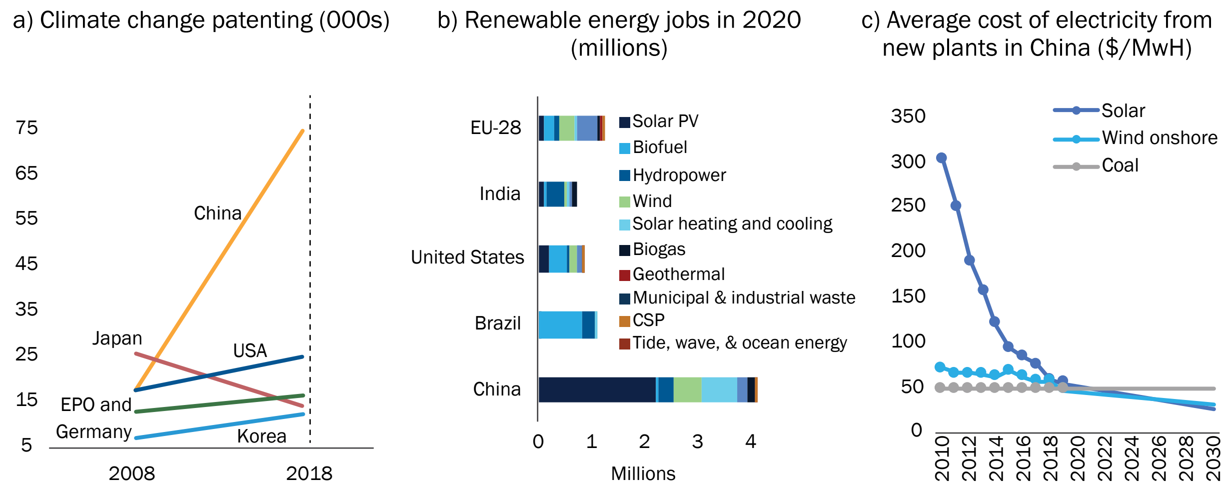
3. **High domestic savings rates:** At 47 percent of GDP, China has one of highest domestic savings rates in the world, providing ample liquidity that can be mobilized to fund the expansion in green investments. China is already becoming a leader in green finance, with the biggest green bond and credit markets in the world. Low domestic interest rates mean that relatively more capital-intensive green technologies can still be competitive. Given falling returns in traditional infrastructure and real estate sectors, and in contrast to many other developing countries, the challenge for China is not to scale up investment but rather to shift its allocation in the direction of low-carbon activities and technologies.

4. **High-skilled job creation:** China already has an estimated 54 million "green jobs" and over 4 million jobs in renewable energy (see Figure 11b). Various projections all suggest that the transition to carbon neutrality in China will result in more job gains than losses, and the job gains will be in higher skilled, higher-productivity industries than job losses, forming an important avenue for economic transformation, as resources move to higher productivity sectors.

5. **Reduced dependence on imported fossil fuels:** Accelerating the energy transition would strengthen China's resilience to the volatility of global fossil fuel prices by reducing its dependence on oil and gas imports. China is a net importer of fossil fuels – oil, gas, and coal – with imports averaging about two percent of the country's gross domestic product (GDP). This dependence on fuel imports is exposing the economy to global commodity price fluctuations, as evidenced by the recent price shock due to the war in Ukraine. In contrast, renewable energy is essentially a domestic resource, especially for China, which is a major producer of key renewable energy technologies from wind turbines to battery storage

6. **"Co-benefits," such as improved health outcomes from lower pollution.** Many policies targeting CO_2 emissions can help to simultaneously reduce emissions of air pollutants and mitigate associated health impacts and economic losses. In the same vein, policies to reduce emissions in agriculture from excessive use of fertilizer could have significant co-benefits on food and water quality. Improved urban planning could reduce per capita emissions by creating denser cities, while also enhancing productivity. Measures to make cities more resilient through nature-based solutions could help make China's cities more livable. In the concluding section, this report highlights these potential synergies in deriving priorities for policy action.

Figure 11. China's low-carbon opportunity: rapid growth in patenting and renewable energy jobs, and declining renewables prices



Source: A. Engineering and technology (E&T) analysis using IFI CLAIMS data (link), B. World Bank analysis using IEA and International Renewable Energy Agency (IRENA) data, C. IRENA, Carbon Tracker Initiative, Wood McKenzie. Note: "Solar" refers to utility-scale photovoltaic power and "wind" to the onshore type (not offshore). Data are capacity-weighted average levelized cost of electricity from new power plants in China in constant 2019 yuan and dollars per megawatt-hour. Levelized cost of electricity is calculated as the sum of construction and operating costs over expected power generation.

Rebalancing China's economy and developing new drivers of growth could make future growth less carbon intensive. China's structural development and its climate agendas are mutually reinforcing. Reforms that support rebalancing—for example, liberalization of service sectors or steps to boost private consumption and lower excessive public investment—could contribute to reducing emissions intensity. At the same time, the opportunities in developing green technologies could also unleash a new round of innovation and diffusion of new technologies that could contribute to future productivity growth.

Given the scale and complexity of transforming China's economy, the public and private sectors must work together. A robust private sector can play a central role in delivering market solutions, improving productivity, reducing costs, stimulating technological innovation, filling the financial gap, and eventually transforming the economy to become more resilient and achieve carbon neutrality. For this to happen, private sector firms will need a predictable regulatory environment and a level playing field with access to markets and finance, especially long-term funds required for climate change mitigation investment and innovation. Complementary public sector investments and fiscal incentives can increase the attractiveness of green private sector investments and cover critical gaps, where private markets fail.

For China to achieve a growth-friendly and inclusive path to a low-carbon and resilient economy, the country will need a package of structural and market reforms to complement climate policy instruments. Although China's economy has some market-driven features, there are key distortions in both factor markets and key product markets (for example, energy). These distortions have contributed to misallocation of resources and stifled competition, weighing on productivity growth but also contributing to relatively high carbon intensity. Unless addressed, they could become impediments for an efficient decarbonization process. Structural reforms to promote a market-based allocation of capital, labor, and land and to facilitate the smooth entry and exit of companies would enable the economy to adapt more efficiently to changing price signals and regulations, thereby lowering adjustment costs.

3.

Policy pathways for a growth-friendly and inclusive decarbonization

3. Policy pathways for a growth-friendly and inclusive decarbonization

3.1. China's existing climate policy mix

China's 30-60 targets, along with its updated Nationally Determined Contribution (NDC), set the goalposts for China's long-term climate ambition. In addition to the 30-60 targets, in October 2021, just before COP-26 (the 26th United Nations Climate Change Conference in 2021), China submitted its updated NDC to the United Nations Framework Convention on Climate Change (UNFCCC). The NDC confirmed the broad targets announced in 2020, committing for 2030 to cut CO_2 intensity by over 65 percent from the 2005 level, increase the share of nonfossil fuels in primary energy consumption to 25 percent, increase the forest stock volume by 6 billion cubic meters (m^3) from the 2005 level, and reach 1200 gigawatts (GW) of solar and wind power generating capacity.

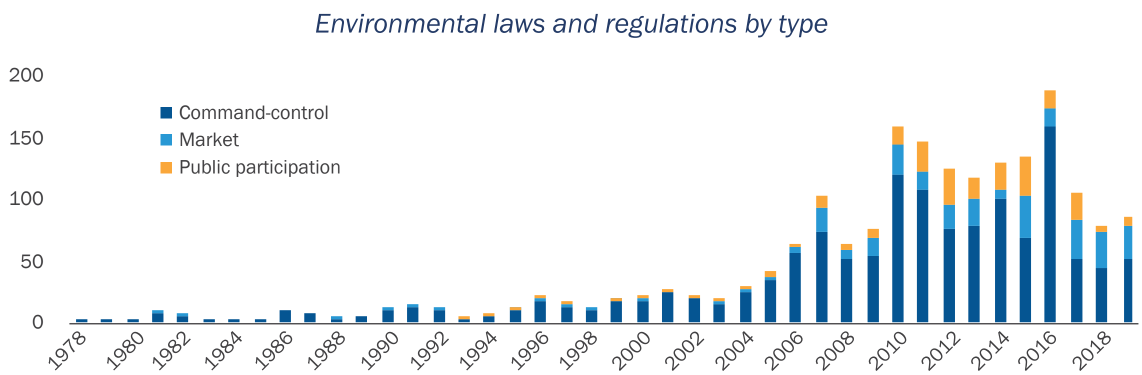
Following the NDC, China ramped up efforts to integrate climate action in economy-wide development efforts, while many of the details on how climate goals will be achieved, including key emissions targets, are still being formulated. The country recently issued the *1+N climate policy framework*, providing further details on China's 30-60 goals. The "1" in the policy framework's title stands for the overarching "Working Guidance,"[11] which identifies core strategic priorities. The "N" in the policy framework indicates both the published and upcoming action plans in key sectors and industries for achieving carbon peaking and neutrality. The action plan published by the State Council in October 2021 specifies what is required to ensure the achievements of the 2025 and 2030 targets as laid out in the overarching Working Guidance. In 2022, the country issued the National Climate Change Adaptation Strategy 2035. Taken together, these documents and targets emphasize that endeavors to peak carbon dioxide emissions and achieve carbon neutrality must be incorporated into the overall economic and social development framework, under the country's guidelines for exercising nationwide planning, prioritizing conservation, and leveraging the strength of the government and markets both on the domestic and international fronts, while guarding against risks. These efforts suggest significant but relatively gradual progress in the next decade, followed by an acceleration afterwards. The short-term focus remains on reducing the *carbon emissions intensity* of domestic production rather than capping and reducing *absolute emissions*.

China's climate policy mix has so far relied more on regulatory and command-and-control measures than on market-based instruments, with a central role for targets and quotas. A classification by Zhang et al. (2022) of nearly 2000 environmental policies from the National People's Congress or the State Council from 1978 to 2019 has shown that nearly three-quarters were command-and-control policies, referring to policies that are mandatory and achieved through administrative instruments (Figure 12). Market-based instruments, such as fiscal policies related to environmental governance, emissions fees, or emissions trading need to be further strengthened. Administrative targets for energy consumption, energy intensity, and air pollution have been key instruments since the 11th Five-Year Plan (FYP). These targets trickle down from the top to the lowest administrative levels, including townships and individual enterprises, and their fulfillment is an important criterion in evaluating the performance of both local government officials and state-owned enterprise managers. These targets are in turn mostly achieved through administrative measures, ranging from mandated technology upgrading to forced plant closures. During the 12th FYP (2011–2015), for instance, thousands of inefficient power plants were forcibly closed, resulting in a cumulative reduction representing nearly 5 percent of total global emissions (Liu et al. 2021).

11 The full name is Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy.

Administrative measures have been complemented by significant public investment and support programs to encourage development and adoption of low-carbon technologies. Direct subsidies, feed-in-tariffs for renewable energy, and fiscal incentives such as value-added tax (VAT) exemptions have played a particularly important role in the development of renewables and low-carbon technologies. In the 13th FYP period (2016–2020), research and innovation on energy technology were priorities in China's "National Innovation-Driven Development Strategy," accompanied by the development of a network of national laboratories and energy R&D centers. China has been the biggest investor in renewable energy over the last decade, spending nearly US$760 billion between 2010 and 2019, with a significant amount coming from the private sector (UNEP 2019). China has also invested heavily in low-carbon public infrastructure, including the expansive high-speed rail network, intracity public transport networks, public transport electric vehicles (EVs) and EV infrastructure.

Figure 12. China's policy mix has relied more heavily on command-and-control policies than market instruments



Source: World Bank staff, based on Zhang et al. (2022).

Even though China has recently established a national emissions trading scheme (ETS), market instruments have so far played a limited role in reducing emissions. China first embarked on efforts to test emissions trading with pilot programs launched in seven provinces and cities starting in 2013. Just under a decade later, trading on the national ETS began in July 2021. However, at present there remain various limitations to the ETS, both in relation to its design, coverage, and the wider role of price signals in influencing resource allocation in China's power sector, which will be discussed in more detail in Chapters 3.2 and 3.3.

China's reliance on target-driven command-and-control measures has achieved a significant reduction in emissions, but sometimes with unnecessarily high economic costs. There is evidence that an overreliance on command and control could lead to inefficient outcomes. For example, Fan et al. (2022) have shown that mandated technology investments to achieve dual-energy targets during the 11th FYP were chosen administratively and did not actually have a discernible impact on emissions. For air pollution control targets, Stoerck (2020) finds that administrative measures were associated with a wide variation in the marginal abatement costs, suggesting emissions reduction was often achieved in unnecessarily costly ways. Si et al. (2020), focusing on the period from 2002 to 2013, found that environmental policies involving financial incentives or monetary awards had more favorable impacts on output and firm profits than command and control policies. Timilsina, Pang, and Chang (forthcoming) find that the GDP cost of achieving China's NDC emissions targets by 2030 through quantitative emissions quotas could amount to 0.95 percent of GDP, whereas the use of a carbon tax with revenue recycling to lower corporate taxes could lower such costs to 0.11 percent of GDP in the best case.

3.2. Augmenting the policy mix—five fundamental shifts

To achieve a growth-friendly and inclusive decarbonization pathway, China's policy framework will need to evolve, taking advantage of different, complementary policy levers. There is no silver bullet to achieve decarbonization. The policy mix should deploy different instruments in a complementary and mutually reinforcing way. This is important because policy instruments differ not only in their abatement efficacy and cost effectiveness but also in their impacts on growth and inclusion. The following five shifts could anchor overall policy priorities:

1. **Translating long-term climate goals into clear forward guidance to anchor expectation and allow a smoother adjustment.** China's long-term targets still lack clear milestones for emissions reductions, causing policy uncertainty and reducing the incentive for low-carbon investments. It is well established that policy uncertainty is bad for both growth and decarbonization, being a major impediment to private sector investment, green or otherwise. Establishing absolute mass-based emissions caps as part of the "1" decarbonization guidance or China's five-year plans could anchor expectations of citizens, public institutions, and the market about the intended emissions reduction pathway. It would also allow the government to ensure consistency between policy measures and ambition and assess progress over time.
2. **Avoiding backloaded policy action to ensure a smooth transition.** The emissions trajectory between now and 2060 will determine both whether emissions are reduced gradually or abruptly, and China's stage of economic development when emissions are cut. There are reasons in favor of backloading the emissions trajectory, including allowing abatement costs to fall over time with the discovery of new technologies. Additionally, the impact of the war in Ukraine on global energy prices has led to a reconsideration of short-term decarbonization plans in many countries, including China, as policy makers emphasize energy security above all else. A tactical pause in the short run may be advisable to maintain political support for the long-term goal. But backloading climate action risks creating higher adjustment costs from more abrupt action in later years, and increased stranded assets, along with missed economic opportunities to develop first-mover advantages in low-carbon technologies and industries.[12]
3. **Complementing command-and-control with more market-based incentives to enhance efficiency and lower adjustment costs.** As discussed above, administrative targets, regulations, and quotas can have high efficacy at lowering emissions, especially in the context of China's strong administrative capacity, but can also create inconsistencies and result in low economic efficiency. Together with forward guidance, price signals and market incentives could guide a more efficient and dynamic resource reallocation process, spur innovation, and induce behavioral changes. For these price signals to work, however, factor and product markets need to operate efficiently without distortions, underscoring the importance of complementary structural reforms. Detailed policy options are discussed in section 3.5.1.
4. **Rebalancing from state-led to more private sector-driven investment and innovation to foster faster diffusion and discovery of low-carbon technologies.** Low-carbon supply-side policies, including investment in low-carbon infrastructure and technologies, have generally been found to be an important complement to pricing and regulatory instruments. By addressing market failures in the development and diffusion of low-carbon technologies, they can help lower transition cost with positive outcomes for growth and inclusion (IMF 2020). But implementation of these policies is delicate, and public resources must be spent well to have the desired impacts. China has an extensive system of R&D support. Enhancing its efficiency and efficacy will require complementary reforms to open the innovation system

12 The International Monetary Fund (IMF) (2022) shows that the output costs of achieving China's carbon neutrality target with the same cumulative emissions would be far higher if climate action (represented in their study by a carbon tax) is delayed, because of the higher cost of abrupt adjustment.

and encourage market entry and competition, including by the private sector. Specific policies in this regard are discussed in section 3.5.1.

5. **Explicitly incorporating policy measures to soften the distributional implications of the low-carbon transition.** Low-carbon policies are expected to have wide-ranging distributional implications through both consumption and income channels. China has developed some policies to mitigate social impacts—for example, from the reduction of coal capacity. The policy approach now needs to evolve to match the raised ambition, scale, and pace of the envisaged future transition. Complementary policies to mitigate impacts on the most affected provinces, communities, and people will be crucial to making the transition inclusive and ensuring sustained support. Specific policies are discussed in section 3.5.3.

These five shifts underpin the specific policy options and recommendations discussed in the next sections, which focus on the main emitting sectors, and the sectoral and economy-wide reforms that would achieve decarbonization while minimizing the costs and maximizing development impacts.

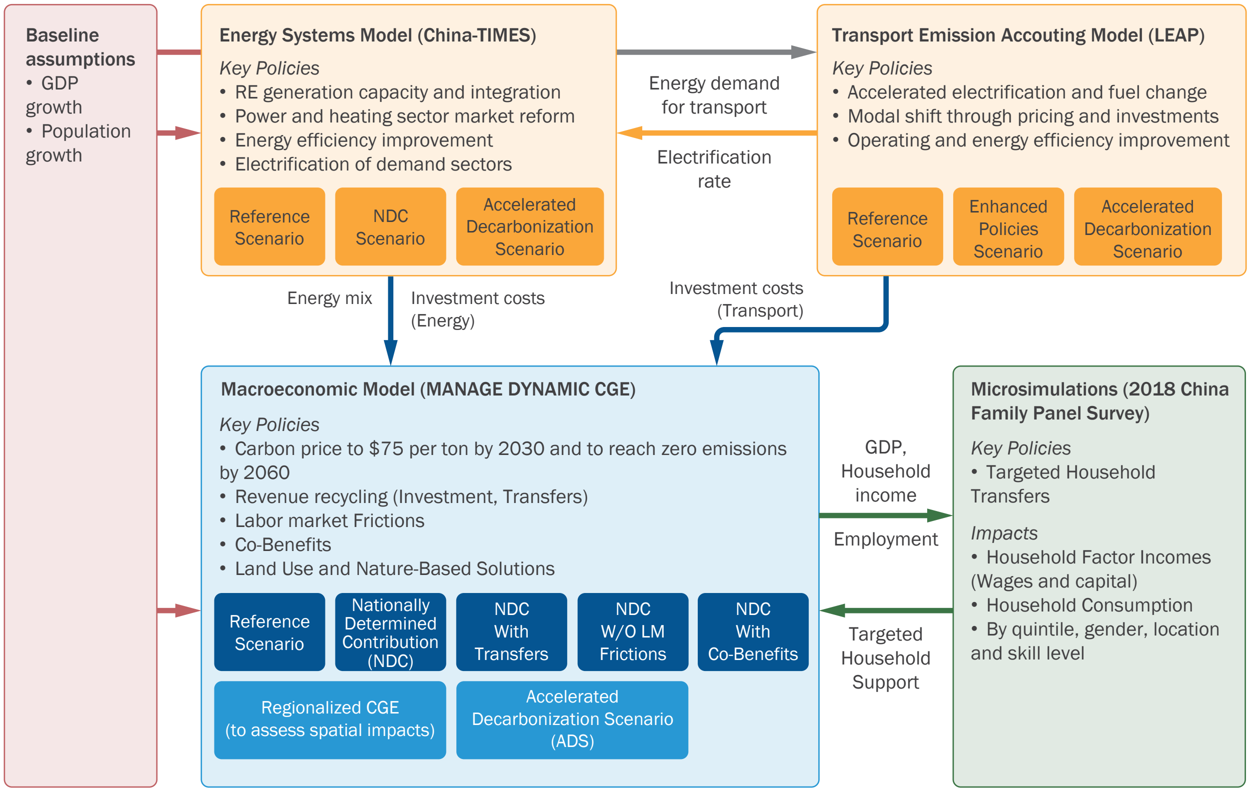
3.3. Gauging the economic and distributional impacts of decarbonization

This section will provide a model-based assessment of decarbonization pathways, seeking to quantify macroeconomic and distributional impacts of different decarbonization policies. At the outset it is important to recognize the significant uncertainty involved in predicting the complex and dynamic long-term change process underpinning decarbonization. Key aspects of the transition—for example, the speed of technological progress in low-carbon technologies—are "known unknowns." Moreover, policy options to drive decarbonization involve an array of pricing instruments, regulations, structural measures, government expenditures, and taxes. Not all of these lend themselves readily to quantification in economy-wide models. Nevertheless, economic models can provide important information regarding the broad magnitude of potential impacts associated with certain policy options and thus inform choices that lead to better outcomes. Rather than attempting to provide specific point estimates, the approach chosen in this study aims to gauge ranges of possible outcomes, drawing on the results from multiple models.

Existing model-based estimates of the impact of the carbon neutrality transition on China's GDP tend to lie in the range of -4 percent to +7.5 percent. The estimates vary so widely not only because they simulate different policy sets, but also because of differences in underlying parameters driving model behavior and hence results. Even GDP impact estimates of the same carbon policy scenario can range from -1.9 to +0.4 percent relative to the baseline by 2030. These insights point directly to the uncertainty that exists in quantifying the economic impacts of decarbonization pathways, but taken together they establish a broad range of possible outcomes.

Using an integrated modeling framework with bottom-up sector models and an economy-wide CGE model, we simulate the impacts of different policy sets to achieve China's carbon neutrality commitments. The principal model architecture, key scenarios, and data flows are depicted in Figure 13. The simulations use the World Bank's Mitigation Adaptation and New Technologies Applied General Equilibrium (MANAGE) model, with integrated bottom-up sector models in transport and energy as well as microsimulations, to assess impacts on households. The results of these microsimulations then recursively inform the design of a stylized household transfer policy in MANAGE. Because decarbonization represents an asymmetric shock that will affect different regions differently, the MANAGE model has been regionalized to simulate impacts at the subnational level. In addition, the assessment also presents the results of an alternative macroeconomic model—E3ME—that allows for stimulus effects and induced technological change (Box 2).

Figure 13. Model architecture and Scenarios for the CCDR



Source: Report authors.

Four different policy scenarios are estimated. We model four stylized scenarios with a combination of core economy-wide carbon pricing, low-carbon supply policies, and innovation subsidies. These scenarios are aligned with China's 30/60 goals and its updated NDC. Scenario 1 combines broad-based carbon pricing with revenue recycling into private investment alongside the policies captured in the sectoral energy and transport models. The scenario also reflects labor market frictions and incorporates increased carbon sequestration from land use change. Scenario 2 combines reforms of scenario 1 but instead of revenue recycling into investment, carbon revenues are used to provide targeted compensation to households. Scenario 3 is similar to scenario 2 but incorporates a more flexible labor market, allowing for a faster reallocation of labor. Scenario 4 is similar to scenario 2 but considers the co-benefits from air quality improvements on labor productivity. Across all scenarios, we model the required efforts to achieve peak carbon dioxide emissions before 2030 and carbon neutrality before 2060. The results are compared to a baseline case of current climate policies already under implementation. The results are summarized in Table 3 and discussed in more detail below.

Decarbonization will require significant investments for a massive green infrastructure and technology scale-up. Specifically, our sectoral models suggest that China would need a total of about US$14 trillion in additional investments in the power and transport sectors alone —in addition to the baseline investments to keep up with demand growth and maintain existing assets—from now until 2060 (see Table 2), equivalent to 0.97 percent of GDP during that period.[13] Much of these investments would need to be frontloaded to meet the target of peaking carbon dioxide emissions before 2030, requiring about US$2.1 trillion (equivalent to roughly 1.1 percent of GDP) in the next decade alone. Some of these investments—such as

13 Other estimates which include other sectors (building, agriculture, industry) estimate total investment needs at US$22 trillion. CICC Research, CICC Global Institute. (2022). Guidebook to Carbon Neutrality in China: Macro and Industry Trends under New Constraints (1st ed. 2022 ed.). Springer.

electrification and fuel switch—are expected to be made by private sector firms and individuals and bring about significant energy efficiency gain that would make these investments not only economically viable but financially attractive. For other areas, public investments will be necessary but not sufficient to meet these needs. They will need to be complemented by good sector policies, broad-based regulatory reform, and new standards to fully tap the potential and incentivize private sector investment and innovation in these sectors. Over time, technological progress may lower some of the costs, and individual investments and the policies to encourage them may be prioritized (or de-prioritized) taking also into account specific cost-benefit considerations.

Table 2. Investment needs to achieve China's NDCs

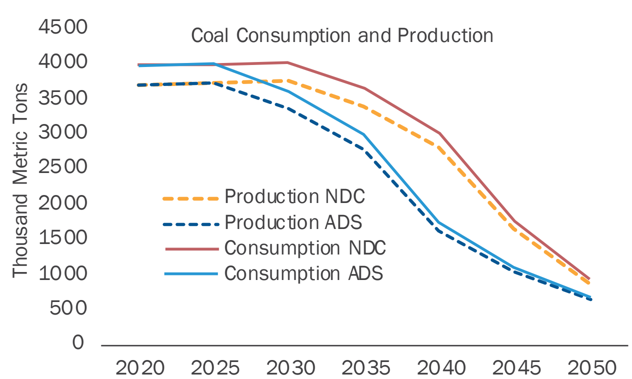
Incremental investment over reference case

(in US$ billion)		2021-25	2026-30	2031-40	2041-50	2051-60	Total	NPV (6%)	NPV (Risk-free)
Electricity (Generation and Grid)		336	368	1,386	1,992	200	4,282	1,757	2,588
Transport	Low-carbon mode Infrastructure	9	49	77	33	18	187	90	124
	Fuel and operating efficiency	-224	413	1,471	370	-102	1,928	843	1,263
	Electrification and fuel switch*	282	897	3,029	1,951	1,242	7,403	2,979	4,419
Total		403	1,727	5,964	4,347	1,359	13,800	5,668	8,394
Percent of GDP		0.55%	1.52%	1.95%	1.04%	0.27%	0.97%	n.a.	n.a.

Source: Bank internal analysis. GDP projections are the same as in the baseline CGE scenario.

*Note: NPV (Risk-Free) is calculated based on the yield curve of China's treasury bonds, ranging from 2.0 percent for the 1-year bond to 3.4 percent for the 50-year bond. *Transport investment includes infrastructure investment (e.g., mass transportation systems, EV charging stations), as well as replacement of rolling stock (private, public, and commercial vehicle fleets).*

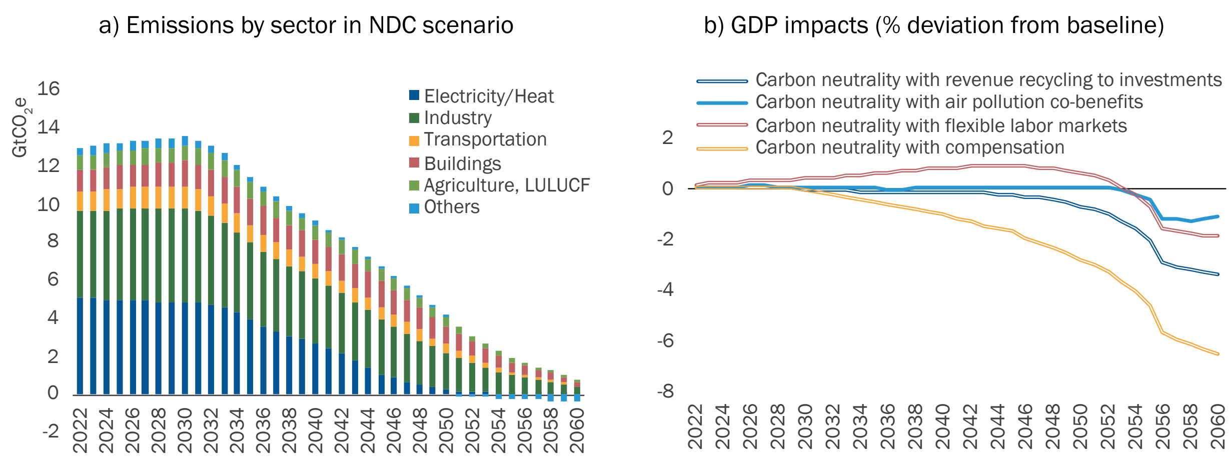
Figure 14. Exiting Coal



Source: World Bank staff estimate based on MANAGE

- **Emissions**: The emissions reduction path reflects the different pace of decarbonization across sectors (Figure 15a). The low-carbon transition of the power sector—the largest source of emissions—is accelerated to achieve a rapid decline in emissions over the next two decades. Coal use would be steadily reduced through investments in available least-cost options in domestic solar and wind, supported by expanded battery and pumped storage as well as reforms to achieve more competitive, nationally integrated power markets that would facilitate the efficient integration of a high share of variable renewable energy.[14] This would enable China to meet its growing electricity demand, which is expected to double by 2060, in part because of increased electrification in end-use sectors, such as buildings, industry, and transport. Although industrial emissions could initially be reduced through further efficiency improvements, capacity reductions, and electrification, deep decarbonization of the industrial sector will require technologies such as green hydrogen and carbon capture, usage, and storage (CCUS).[15] These technologies are not presently commercially viable, and it should be noted that the achievement of China's dual carbon goals, but more broadly the achievement of the Paris climate targets, requires technological progress that reduces the costs of these technologies to a point where they become competitive. In this report, this is assumed to occur by around 2040. By the same token, in addition to continued investments in public mass transport systems in cities, and the expansion of passenger and freight rail networks between cities, innovations in low-carbon fuels for hard-to-electrify modes are required to sharply reduce transport sector emissions. Direct CO_2 emissions from buildings would be mitigated through electrification, clean district heating, and energy efficiency. Finally, carbon sequestration—negative emissions—from nature-based solutions, including expanded forest coverage, also play a key role, enabling carbon neutrality with significant residual emissions in hard-to-abate sectors.

Figure 15. Aggregate Impacts of Decarbonization



Source: World Bank staff estimates based on CGE MANAGE

14 The rapid expansion of renewable energy and storage capacity will require a strong global supply response to avoid increased demand pressure to push up prices for key technologies.

15 This is in line with previous findings by IEA 2021 and ERF 2021.

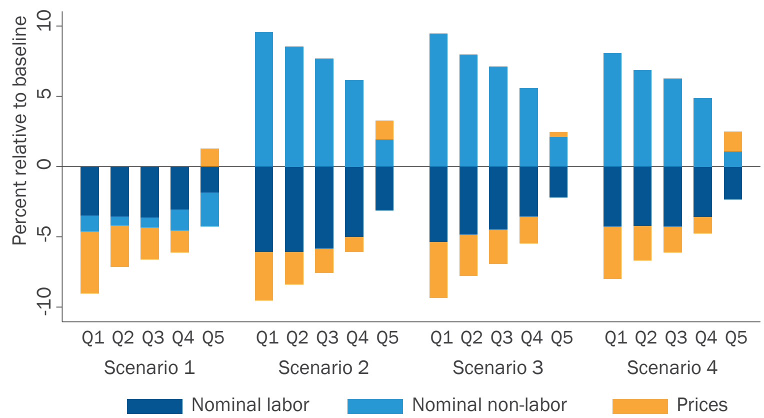
- **Output:** Overall, the results of the CGE modeling imply marginal losses or modest gains in output by 2030 depending on scenarios, but steadily increasing losses as climate ambition is stepped up over time. By 2060, output losses range from 1.1 to 6.6 percent (Table 3 and Figure 15b). Cumulative output deviations over the entire period range from -2.0 to 0.3 percent from the baseline. These estimates are well within the range of existing models. It is noteworthy that in the short run—over the next decade—impacts on output could be marginally positive, reflecting the availability of relatively low hanging fruit, including cost-effective means to increase energy efficiency and shift the energy mix toward renewable energy sources. Long-term output losses mainly result from the supply shock driven by rising energy prices associated with carbon pricing and the accelerated renewal of equipment, which can be partially offset by the growth-positive impacts of an increase in investment thanks to recycling of carbon pricing revenues to private investment (Scenario 1). In contrast, if carbon revenues are channeled into compensating households, this mitigates adverse welfare impacts but tends to exacerbate negative impacts on growth, as incremental mitigation investments crowd out other investment (Scenario 2). Results also indicate that the GDP impact of similar emissions reductions could be reduced if labor market frictions are addressed; for example, through reforms to lower barriers to labor mobility (Hukou reforms) and active labor market policy and re-skilling support, reinforcing the importance of complementary structural reforms (Scenario 3). Accounting for the potential positive impacts of air quality improvements on labor productivity also improves outcomes, partially offsetting negative impacts of energy price shocks (Scenario 4).
- **Jobs**: Aggregate employment effects in the CGE mirror aggregate output effects with broad-based reductions in employment similar in magnitude to the output losses. Disaggregated employment impacts across all scenarios suggest reallocation with the greatest job losses in emissions-intensive sectors and largest job gains in the short run in high-skilled services. Major negative employment effects are felt by the coal sector (coal mining experiences a 700 thousand to 1.3 million decline in employed individuals relative to the baseline in 2030, and a 2.6 to 2.9 million decline in 2060). Further details of the expected employment impacts are discussed in Chapter 3.5.3.
- **Welfare**: Without compensation, household welfare could be negatively affected by both price increases and losses in labor earnings (see Figure 16).[16] At the macroeconomic level, this is reflected in a compositional shift of GDP from consumption toward investment expenditures (Scenario 1). Moreover, climate action without compensating measures also tends to be regressive: higher prices are expected to lead to a substantial (and regressive) loss in households' purchasing power across the distribution, except for the rich, who spent a relatively lower share of their budget on energy-intensive goods.[17] Even though welfare losses are higher among the poorest income groups relative to their income, the brunt of the burden is borne by richer households (60 percent under Scenario 1), because the decline in their labor and nonlabor incomes is significantly larger in absolute terms. Meanwhile, lower employment and earnings among agricultural workers will affect low-income households, while job transitions out of mining, and lower earnings across most sectors for skilled workers, will impact households in the richer quintiles. The lifting of labor market frictions can support the transition to a low-carbon economy, as it will speed the reallocation of workers to better-paid employment opportunities in services and utilities. Finally, incorporating labor income gains from improved labor productivity induced by air quality co-benefits dampens the negative shock to households across the distribution, with the lowest quintiles gaining most (Scenario 4).

16 Alvarez 2019, Garcia-Muros et al. 2022.

17 In line with Wang et al. (2019), utilities contribute most to the loss in households' purchasing power. In China, electricity and fuel represent on average 2.0 and 1.6 percent of household expenditure, respectively. The bottom decile spends 3.1 percent on electricity, and the same budget share is allocated to fuel. Instead, these budget shares are 1.3 and 0.6 percent, respectively, for households in the richest decile.

Figure 16. Distributional Impacts of Decarbonization

Welfare impacts by income groups, 2060 (% relative to baseline). Decomposition by income source.



Source: World Bank staff estimates based on CGE MANAGE.

- **Spatial impacts.** The gap between rural and urban households under the carbon neutrality scenario is expected to increase, as poorer households, often in rural areas, would lose more in relative terms compared to their richer, typically urban counterparts.[18] Yet, the urban-rural gap could narrow, if labor market frictions are reduced. In addition, initial results from the regionalized model suggest that impacts will vary significantly across provinces. Some of the north and northwestern provinces of Xinjiang, Inner Mongolia, Shanxi, Shaanxi, Ningxia, and Liaoning would experience the greatest emissions declines, negative employment, and output effects in 2030. These provinces would experience output declines of close to 4 percent relative to the baseline in the NDC scenario. By contrast, the low-emissions provinces of Tianjin, Guangdong, Jiangsu, and Zhejiang face the best outcomes, with only a 0.9 percent decline, closely followed by Beijing and Shanghai, which would experience declines of 1.2 percent on average. As poorer provinces are more likely to experience sharper declines, decarbonization may worsen already high levels of spatial inequality, unless these effects are mitigated through interregional fiscal transfers.

18 This result is consistent with previous analysis from Liang et al. (2013).

Table 3. Macroeconomic Modeling Results for Reference and NDC Scenarios

SCENARIO AND POLICY SETUP	Emissions 2030	Output 2030	Emissions 2060	Output 2060	Cumulative Emissions 2022–2060	Cumulative Output 2022–2060
Reference scenario (current climate policies; mtCO_2e or billion USD)	13,137	24,849	7,239	54,161	405,180	1,421,448
Scenario 1: Carbon neutrality with revenue recycling to investment (% change from baseline) • Carbon price to $75 per ton by 2030 and to reach zero emissions before 2060 • Revenue recycling into private investment • Labor market frictions • No co-benefits	-3.0	-0.02	-95.4	-3.37	-28.13	-0.66
Scenario 2: Carbon Neutrality with compensation (% change from baseline) • Scenario 1 + • Revenue recycling into full compensation to household	-3.0	-0.02	-95.4	-6.59	-28.13	-2.00
Scenario 3: Carbon Neutrality with flexible labor markets (% change from baseline) • Scenario 2 + • Structural reforms—Flexible labor markets	-3.0	0.40	-95.4	-1.87	-28.13	0.31
Scenario 4: Carbon Neutrality with air pollution co-benefits (% change from baseline) • Scenario 2 + • Co-benefits	-3.0	0.04	-95.4	-1.08	-28.13	-0.11

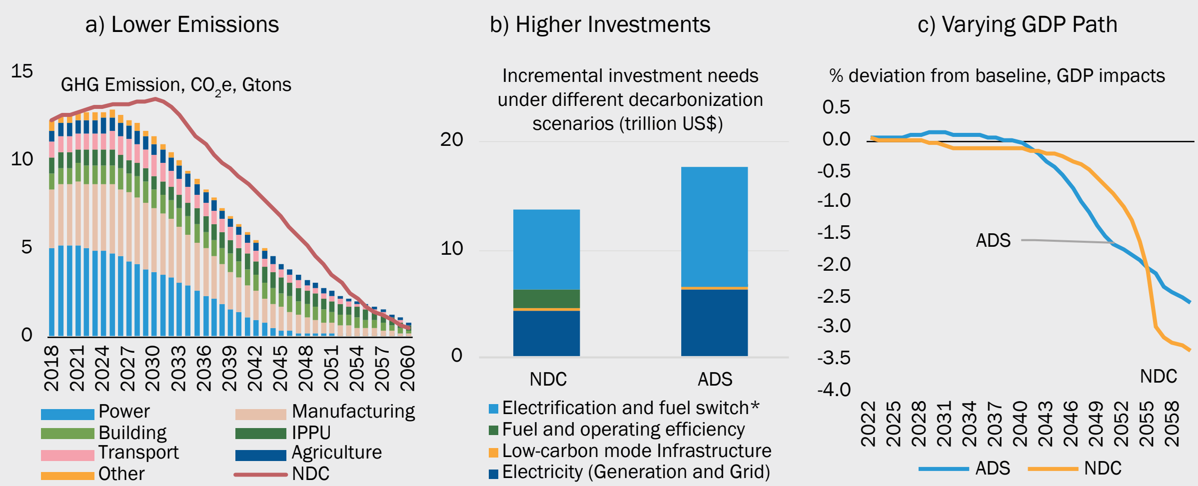
Source: World Bank staff estimate based on MANAGE.
Note: More detailed simulation results are presented in appendix 1.

The results suggest that China's transition to carbon neutrality would be challenging, but its long-run economic costs under reasonable assumptions would remain manageable. The lower bound of the range represents an estimate of adjustment costs without co-benefits under relatively conservative assumptions regarding the development of technology. Beyond 2040, the results of the modeling should be interpreted with additional caution, given uncertainty around key assumptions, including the emergence of cost-effective technologies in key emitting sectors, such as steel and cement. Yet, past experience with sharp cost reductions in renewables has demonstrated that breakthroughs are possible and would indeed become more likely as a result of clear market and policy signals. The results also point to the importance of complementary policies to reduce labor market frictions, which would lower adjustment costs under the standard CGE model by around half. Accounting for the potential co-benefits from reduced air pollution also reduces adjustment costs. Finally, an alternative macroeconomic model suggests that, in a best-case scenario assuming stimulus effects and induced technological change, the zero-carbon transition could even result in small output gains. Overall, these results suggest that with the right policy mix, China could achieve its climate goals at an economic and social cost that is small relative to the potentially catastrophic damages and economic and social consequences that could result from unmitigated climate change (as discussed at the outset of this report and in more detail in Chapter 4, climate-induced economic losses could rise to up to 6 percent of GDP, annually, by the end of the century).

Box 1. Accelerated Decarbonization Scenario (ADS)

While China's NDC envisages a rapid scale up of renewable energy capacity and low carbon technologies, the modelling framework was used to illustrate the potential benefits and costs of an accelerated emission reduction pathway. Under this scenario renewable capacity is expanded to 1700GW by 2030, instead of 1200GW under the NDC. Similarly, in the transport sector modal shifts and EV market penetration are stepped up, compared to the NDC/2030 peak scenario. Such a pathway would allow emissions to peak earlier than 2030, leading to a significant reduction in cumulative emissions of almost 55 billion tons. However, investment needs in the transport and energy sectors would increase significantly by about US$3 trillion (to a total of about US$17 trillion) required over the entire period with most of the additional investment being frontloaded. Meanwhile, changes in GDP would also be smoother as frontloading avoids a sharper and hence more painful adjustment later on.

Figure 17. Impact and Cost of ADS



Source: World Bank staff estimates based on MANAGE

The relatively benign long-run aggregate effects, however, do not imply that the transition to carbon neutrality would be easy. The simulation results across models and scenarios illustrate significant adverse impacts with job and income losses that are sectorally and spatially concentrated. The disruptions and dislocations stemming from the accelerated structural transformation and creative destruction necessary to achieve carbon neutrality need careful policy attention. Structural reforms to enhance the functioning of China's factor (labor, land, and capital) and key product (energy) markets could enable a more efficient reallocation of resources and stimulate competition and technology diffusion, thereby dampening adjustment costs and harmful impacts on growth and welfare (Zhang 2022). Social support to workers and communities negatively affected by the transition is equally important in stemming rising inequality. These policy options will be spelled out in more detail in the next section of this report.

Box 2. An alternative modeling approach using E3ME

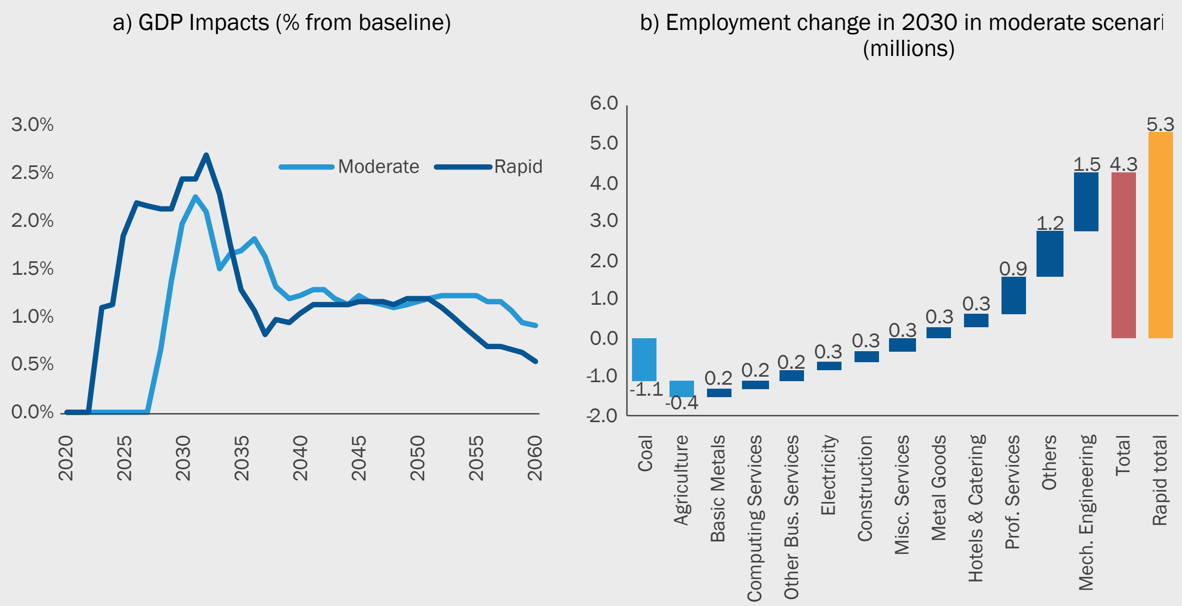
This box presents simulation results, employing an alternative macroeconomic model. The simulations are based on the Cambridge Econometrics' E3ME macro-econometric model, a dynamic model widely used for climate policy assessments. Similar policy scenarios are modeled to reach carbon neutrality, in both a "moderate" and "rapid" transition scenario. This model has several features that differ from CGE models, like the MANAGE model used above, including:

- **Keynesian stimulus effects**: Unlike CGE models, the E3ME is a nonequilibrium model. It is more demand-driven and does not assume that prices always adjust to market clearing levels, allowing for output gaps and endogenous expansion in money supply. Under these conditions, regulations and other policies may lead to increases in output and employment if they trigger adjustments that use spare economic capacity.
- **Induced technological change**: In addition, the model also incorporates endogenous technological change relying on a dynamic (micro-agent) module to simulate technology adoption. The bottom-up technology diffusion modules result in 'S-shaped' paths of technology diffusion, consistent with the innovation literature, and policies to adjust prices and induce initial take-up may thus change the rate of technology diffusion.

E3ME results illustrate the potential upside of climate action with decarbonization boosting growth and job creation. Relative to the reference scenario with current policies, output in the moderate scenario increases by about 2 percent by 2030 or 0.9 percent by 2060 in these simulations (which contrasts with the more pessimistic results of the MANAGE model). Tracking output gains, net employment also improves, although the scale of aggregate employment impacts is smaller than the scale of the GDP impacts because some additional production is enabled through higher productivity. These contrasting outcomes reflect core differences in the economic assumptions underpinning the two models: whereas the CGE assumes that the economy operates in equilibrium without any spare capacity, E3ME assumes that the economy has underused resources (labor and capital) and that debt can fund additional expenditure without crowding out other investment. Within E3ME, climate action also induces accelerated endogenous technology diffusion, as investors learn about new technologies. This endogenously lowers the costs as deployment of low-carbon technology expands and therefore lowers transition costs.

Despite more favorable aggregate output and employment effects, disaggregated sectoral impacts mirror those found in the CGE results. Major job losses are seen in the mining sector, which experiences a 1.1 million decline in employed individuals relative to the baseline in the moderate scenario by 2030. The agriculture sector also experiences a slight decline. But these employment losses are more than offset by employment gains in industries like mechanical engineering, which experiences an employment rise of 1.5 million, and professional services, with a 0.9 million employment rise.

Figure 18. E3ME modeling of the transition to carbon neutrality shows positive GDP impacts, with similar sectoral employment shifts



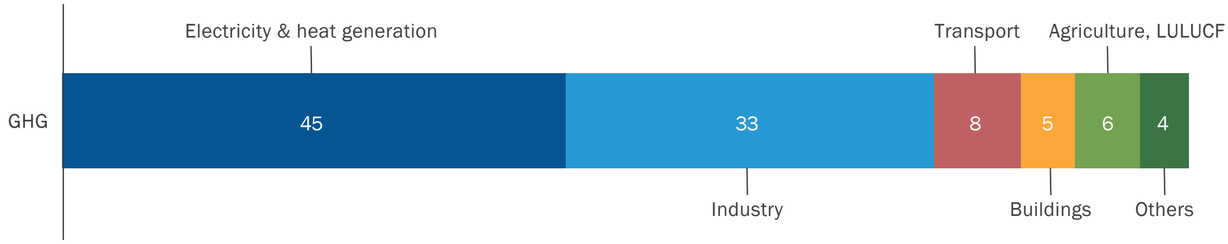
Source and Notes: World Bank calculations using Cambridge Econometrics modeling work.

3.4. Sector policies for carbon neutrality

Achieving China's climate commitment would require major policy reforms and significant investments in the key emitting sectors. In China, energy-related emissions, including from electricity and heat generation, industry, transport, and buildings, account for 90 percent, of total GHG emitted, whereas agriculture and land-use-related emissions, including from forestry and ecosystem services, account for 6 percent (Figure 20). This section provides sector-specific policy recommendations and critical investment needs in each of these sectors.

Figure 19. Five sectors account for 96 percent of China's GHG emissions

GHG emissions breakdown in 2018 (%)



Source and Notes: World Bank calculations using CAIT emissions data. Note: Industry is the sum of manufacturing, construction, and industrial process emissions.

3.4.1. Electricity and heat (45 percent of emissions, growing at 4 percent annually[19])

China's rapid economic growth and associated sharp increase in energy consumption has been fueled primarily by coal. Over the past 20 years, China's total primary energy consumption has more than tripled and total installed electricity generation capacity has increased sevenfold to 2,370 GW in 2021. Although significant improvements in energy efficiency over the same period have led to weak decoupling, with energy intensity of GDP declining by two-thirds, energy demand continued to rise. In the last decade alone, China's electricity consumption rose to 7,520 terrawatt-hours (TWh) in 2020. Peak power demand grew faster than GDP or electricity consumption over the last five years and reached 1,183 GW in 2020.

The energy transition away from coal will be important, for both China and the world to meet the global midcentury climate goals. This is also a key determinant for China to achieve its own climate goals. As the world's largest coal producer and consumer, China relied on coal for 57 percent of total energy consumption in 2020, most of which was met by domestic production (4.07 billion tons in 2020). Three-fifths of coal consumption is for power and heat, and 60 percent of total electricity is generated from coal. Although the share of coal-based electricity has been declining, coal power capacity and generation have continuously grown over the past two decades. Coal-based generation capacity reached 1,109 GW in 2021, which is larger than the total coal power capacity of all other countries in the world. Most coal power plants are relatively young: 45 percent of the existing coal power plants are less than 10 years old, 82 percent less than 20 years, and the average capacity-weighted age is 12.7 years. As China seeks to achieve carbon neutrality before 2060, many of these assets risk being stranded. The average use of coal power plants in China dropped from 61 percent in 2011 to about 50 percent in 2021.

Accelerating the energy transition requires economic pricing and operational reforms in the electricity and heat supply markets. Despite China's efforts to advance power market reforms, incentives remain inadequate for interprovincial cooperation and efficient use and phase-down of coal (Box 3). Limitations on cost passthrough and market contract modality make it difficult for renewable energy to integrate and be used efficiently in the power market. Insufficient cost recovery in the heating sector hampers investment in greater efficiency and renewable energy solutions.

Significant investments and technology advancements are needed to complement policy reforms and achieve decarbonization goals. To evaluate policies and understand their influence on power market decarbonization, three scenarios were considered: (a) Reference Scenario (REF), which is based on current sectoral policies but does not consider climate commitments; (b) NDC Baseline Scenario (NDC), which assumes carbon emissions peaking in 2030, 2.5 gigatonnes of equivalent carbon dioxide ($GtCO_2e$) of residual emissions in 2050, and carbon neutrality in 2060; and (c) Accelerated Decarbonization Scenario (ADS), which shows a pathway of peaking emissions earlier than 2030, reaching 1 $GtCO_2e$ of emissions in 2050 and carbon neutrality in 2060.[20] The summary results are depicted in Figure 20.

19 Data from CAIT, with current GHG emissions breakdown for 2018 and compound annual growth rate (CAGR) from 2010–18.

20 TIMES is used to build an optimization model based on bottom-up energy system linear programming for China's energy system, in partnership with Tsinghua University.

Box 3. China's power market and why reforms will be critical for the transition to carbon neutrality

In China, electricity prices and use/dispatch of power plants are largely determined by provincial governments based on central government guidelines and continue to favor coal-based power generation. Provincial governments responsible for annual generation plans and allocation of operational quotas for coal power plants have an incentive to provide a roughly equitable number of operating hours to each power plant. This process results in system planning to balance supply and demand largely at the provincial level, uneconomic dispatch of the power plants, and limited incentives to absorb renewable energy generation and to cooperate across provincial grids. The system has been reformed since 2015, with generation quotas for coal power plants gradually reduced.

The power crunch in 2021 led to several important changes in power sector regulations. China's energy prices were regulated within a narrow price band until October 2021. As a consequence, when global coal prices increased in 2021, coal generators had no incentive to produce more electricity, as they could not pass through coal price increases. This led to large power shortages across several provinces. In October 2021, the price band was expanded from 10 to 20 percent, and the prices for high energy-consuming enterprises and spot market trading (electricity trading in short time periods like daily, hourly, or real time) were fully liberalized, although trading remains largely interprovincial. Moreover, industrial and commercial consumers were required to purchase additional electricity from the market, with generation quotas to be gradually phased out for these sectors. These changes helped coal generators recover increasing cost to some extent, although because coal prices were simultaneously subject to domestic controls, it did little to encourage greater renewable energy integration.

The integration of national power markets will be critical to move to a system of economic dispatch and facilitate greater use of renewable energy. The current power market has not created adequate incentives for China's grid companies to construct new grid networks to connect large renewable energy-producing regions to the populous coastal regions. Interprovincial power trading is still limited in scale as provinces tend to protect their own producers. Expanding spot market and interprovincial trading has the potential to improve renewable energy integration and would allow the power system to operate with a lower reserve capacity, thus limiting the need for capacity expansion. Reforms were proposed in November 2021 for a cross-provincial spot market, which will begin with a few pilot provinces. This was further prioritized with a set of directives on "fast-tracking the construction of a unified national power market" in January 2022.

Achieving carbon dioxide emissions peaking before 2030 and carbon neutrality before 2060, in line with the Nationally Determined Contribution (NDC) commitments, would result in a significant reduction in carbon emissions, not just for China but on a global scale. Under the NDC Scenario, energy-related carbon emissions would be 120 $GtCO_2e$ lower than under the REF Scenario, significant amounts considering the remaining global carbon budget of 900 $GtCO_2$ that would keep global warming to 2.0°C (IPCC 2021). Such reductions are derived from substantial declines in total primary energy consumption, rapid scale-up of renewable energy, and extensive electrification of energy demand. China's total primary energy consumption in 2050 under the NDC is projected to be lower by 25 percent than under the REF, mainly due to demand side measures and enhanced energy efficiency. The installed capacity of solar PV and wind would reach over 5,000 GW in 2050 under the NDC, whereas it would be only 2,000 GW under the REF. By 2050, renewable energy would need to be the major source of power generation, accounting for about 85 percent of total installed capacity and 80 percent of total electricity generation under the NDC. The share of electricity in total final energy consumption in 2050 would increase from 32 percent under the REF to 46 percent under the NDC, primarily due to fuel switching for heat generation for industry and buildings and electrification in transport.

Box 4. How China can meet energy demand without building new coal-fired power plants

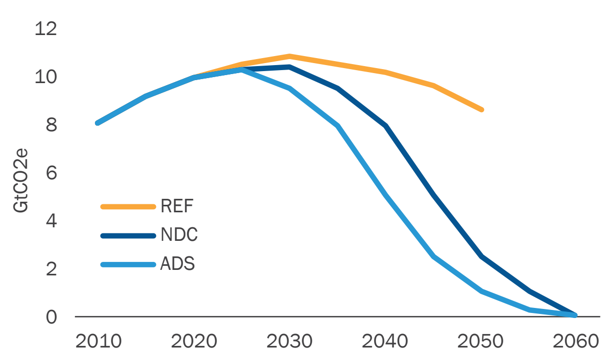
China's energy plan foresees a continuing growth of power demand. Given recent power shortages and the intermittency of renewable energy sources, the authorities have argued that meeting growing demand requires the installment of some 120 GW of additional coal-fired capacity. China's energy plans consider using this capacity predominantly to meet peak demand, while allowing average load factors to decline further. Such a strategy could be costly, as power generators would need to be compensated for providing such ancillary services for system stability.

However, a careful examination of the parameters driving power system planning shows that an alternative scenario without new coal capacity is feasible and may be more cost-effective. Specifically, by allowing greater interprovincial trade, China could exploit the complementarity of peak loads across provinces and thus lower reserve capacity needs. If provincial grids are integrated, with supply and demand balanced at the regional level, the national peak load would be lower than the total of provincial peak loads by 5 to 6 percent. Further lowering reserve capacity requirements to international standards for both coal-fired and renewable power could also keep capacity growth in check. In addition, there remains considerable potential to improve economic dispatch and usage of hydropower and energy storage to meet peak demand following international best practices. In parallel, the potential of demand-side management, including demand response, can be further harnessed to slow down peak load growth and support integration of variable renewable energy.

Following a peak in 2030, coal power generation capacity and its use would need to decline substantially over time under the NDC scenario. The challenges in phasing down the current level of coal generation to achieve carbon neutrality are substantial. The analysis shows that China would need to reduce coal power capacity to about 380 GW by 2050 (about 65 percent reduction from 2021). In the process, the average coal capacity use rate would fall from 48 percent in 2020 to about 10 percent by 2050, shifting the role of coal-fired power plants from base load to serving peak demand. Given the relatively young age of China's coal, this transition implies significant stranded-asset risks, although neither the ADS nor the NDC scenario involve early retirement of coal plants, instead factoring in substantial pricing reforms to compensate generators for low load factors. About 10 percent of the remaining coal fleet is expected to be abated with carbon capture, usage, and storage (CCUS) by 2050—a technology that is not yet commercially viable or available at scale. Such technological innovations will play a critical role in addressing residual abatement needs, not only in the power sector but also in the industrial sectors.

Figure 20. The NDC Baseline Scenario could push energy-related emissions to carbon neutrality before 2060

Projected carbon emissions from energy use



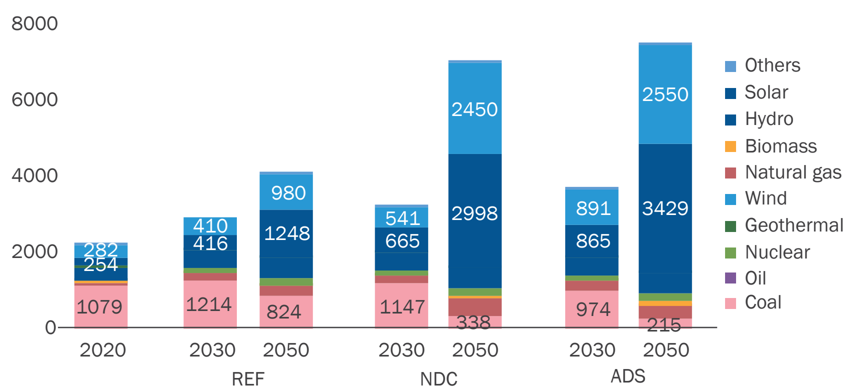
Source: World Bank and Tsinghua University analysis.

Scaling up investment in energy storage to improve grid flexibility is essential for accelerating renewable energy development and integration, while ensuring the reliability of power supply. The share of variable renewable energy, namely solar and wind, is expected to reach about 17 percent of total electricity generation and 37 percent of total installed capacity in 2030 under the NDC. Accelerating renewable energy development may pose challenges in integrating variable renewable energy into the grid and reliability of power supply. Recognizing this, the government announced plans to increase pumped hydro storage to 120 GW by 2030 and battery storage to 30 GW by 2025. Under the NDC, the required storage capacity is estimated at 200 GW by 2030 and 1,300 GW by 2050. Achieving this massive scale up will need to induce a strong global supply response and expansion of production capacity for key technologies (current total global installed battery storage capacity is 17 GW in 2020).

Achieving the NDC commitments requires about US$4 trillion of incremental investment in the power sector cumulatively between 2020 and 2060. In the power sector alone, the investment needs in generation, transmission, distribution, and energy storage by 2060 are estimated to be about US$8 trillion under the REF and US$12 trillion under the NDC.

Figure 21. By 2050, renewable energy will need to account for about 85 percent of total installed capacity in the NDC

Projected Installed Capacity for Electricity Generation



Note: Renewable energy capacity assumptions refer to notional capacity and do not point at any specific project, which will require looking at the technical, environmental, and social considerations associated with project due diligence. Detailed capacity projection end in 2050 due to technical data limits of the existing TIMES model.

Source: World Bank and Tsinghua University analysis.

Private sector participation can help meet these investment needs and accelerate the energy transition, but this requires further reforms. China added 101 GW of renewable energy capacity and made US$266 billion of investment in the energy transition in 2021, the largest in the world. However, the private sector's market share has been shrinking, largely due to the lack of supporting policies and challenges in accessing capital. For instance, the share of solar power plants invested in and held by the private sector plummeted from over 70 percent of total capacity in 2018 to less than 40 percent by the end of 2019, as a result of the so-called 531 Policy, which was announced on May 31, 2018, to accelerate phasing out subsidies for solar PV and ease the financial burden of the government. The changes in government subsidy policies led to reluctance by the banking sector to lend to private companies, which tend to have fewer and less diverse revenue sources than their SOE counterparts. This is compounded by additional conditions imposed by local governments in renewable energy auctions, such as the creation of associated local industries—conditions that specialized renewable energy investors find hard to meet. Delays in subsidy payments, with the outstanding amount estimated to exceed US$60 billion, have added to the challenges for private investors.

China could increase its contribution to the global climate change mitigation by accelerating energy transition beyond the NDC, as illustrated under the ADS. The analysis demonstrates that achieving peak emissions earlier than 2030 can further lower China's cumulative energy-related carbon emissions until 2060 by 50 $GtCO_2e$. In the power sector, this acceleration entails increasing clean energy targets by 2030 compared to what would have been achieved under the NDC Scenario, including (i) increasing solar PV and wind generation capacity from 1,200 GW to 1,700 GW by 2030, (ii) increasing the share of variable renewable energy in electricity generation from 17 percent to 25 percent by 2030, and (iii) increasing energy storage capacity from 200 GW to 300 GW by 2030. Combining the expansion of renewable capacity under the ADS Scenario, with better system planning and power market reforms, allows projected energy demand to be met without the need for additional coal-fired power plants (Box 4). Consequently, following the ADS will increase the investment needs in the power sector. The ADS is estimated to require about US$14 trillion between 2020 and 2060 cumulatively, about US$2 trillion more than under the NDC.

What we recommend

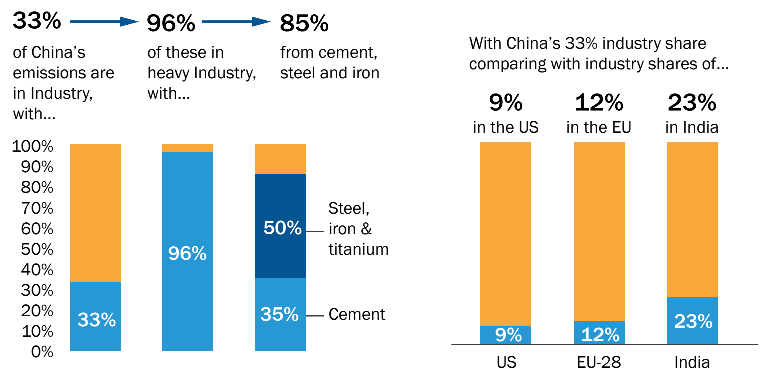
- **Enhance grid operation and dispatch practices and move from provincial level toward regional and national level planning.** Load profiles of provincial grids are complementary to each other, and integrating provincial grids would thus allow one province to take advantage of reserve capacity in other provinces. To take advantage of these complementarities requires the rapid expansion of interprovincial transmission capacity and reforms to optimize dispatch. To accelerate the construction of a national power market—currently envisaged by 2030—China should accelerate regional spot market pilots among neighboring provinces, which would require less upfront investment in transmission capacity.
- **Adopt international best practices in system planning, reliability regulations, and variable renewable energy (VRE) generation forecast and dispatch to reduce the need for additional coal-fired generation capacity.** Increasing the capacity value for VRE in line with standards used internationally would result in less need for additional new coal capacity. Moreover, VRE dispatch can be further optimized by adopting advanced short-term weather forecasting and digitalization at the provincial grid level. Currently grid operators take a conservative approach in estimating VRE generation on day-to-day operation, which may cause a larger coal power capacity than is required to meet system reliability standards.
- **Implement scale up of solar and wind power generation capacity to 1,200 GW by 2030, in line with China's Nationally Determined Contribution (NDC).** While this envisaged scale up is ambitious, analysis undertaken for the CCDR shows that adding more renewable energy capacity, up to 1,700 gigawatts (GW), could advance emissions peaking to earlier than 2030 and result in significant reduction in cumulative emissions. To do so, China would need to add up to 120 GW of solar and wind capacity every year by 2030, 1.5 times the annual average during 2016–20 and 20 percent more than the capacity addition in 2021. This is an ambitious target. Achieving it would require a strong global supply response and increased production capacity for battery and solar/wind components to reduce pressure prices for these technologies.
- **Enhance renewable energy integration capacity by investing in additional storage. Scaling up energy storage is instrumental for avoiding renewable power curtailment and for peak shaving, and thus eliminating the need for additional coal power capacity.** The required storage capacity is estimated at 200 GW by 2030, roughly a tenfold increase from current levels, and 1,300 GW by 2050 under the NDC. To advance peak emissions to earlier than 2030, up to 300 GW of energy storage capacity is needed by 2030 and 1,700 GW by 2050. Competitive auctions for storage capacity could incentivize investments and reduce costs through on-grid battery applications or renewable energy combined with battery storage, alongside the introduction of a market for ancillary services. Achieving this massive scale up in storage capacity will require expansion of global production capacity for key technologies (current total global installed battery storage capacity is 17 GW in 2020).

- **Expedite electricity market reforms.** First, electricity pricing needs to be more cost-reflective, convergent across the provinces, and reflective of market conditions. China should consider fully liberalizing market transactions between power generators and industrial and commercial consumers and eliminating remaining coal power quotas. Second, an ancillary services market and potentially a capacity market should be developed to enable private sector investment in energy storage and compensate power plants to shift from base to peak load serving. Together with effective carbon pricing, such as through a tightening of power emissions quotas under the ETS, these measures would incentivize innovation and significantly reduce the costs of the energy transition. The resulting increase in end-user prices of energy would raise affordability concerns, but these are better addressed through lifeline tariffs or targeted subsidies than through price regulations that discourage market efficiency.
- **Promote demand management measures for electricity use.** Demand management would decrease peak demand and increase system flexibility, lowering additional capacity needs. Measures could include allowing greater variability of time-of-use (TOU) retail tariffs, the promotion of distributed renewable energy and storage, demand response programs where consumers are paid for voluntary load control, and the development of smart grid and electric vehicle-to-grid applications.
- **Strengthen incentive mechanisms for fuel switching, electrification, and demand management for heating.** The majority, about 85 percent, of heating demand in China is presently supplied by coal, followed by other fuels including gas and electricity, through district-level, state-owned combined district heating plants (CHPs) or building-level boilers. Switching from coal to gas can significantly reduce emissions during the transition but would significantly increase costs. Nonfossil fuel solutions exist for heat supply, including heat recovery, geothermal, biomass, and solar. However, highly subsidized heating tariffs imply low profitability and discourage fresh investments in the sector. Furthermore, the lack of metered consumption-based billing means there is little incentive for households to conserve heat. Reforms to pricing and metering policies are politically enormously challenging, and previous pilots have remained largely localized. Nonetheless, such reforms—complemented with targeted subsidies or lifeline tariffs to poorer households—would be vital if the energy transition is to include the heating sector. Promoting low-carbon green buildings, as discussed in the subsequent building section, will further enhance demand-side efficiency.
- **Build a conducive investment climate to encourage private sector participation.** To meet the scale of the investment needs for power sector decarbonization, crowding in private sector investment is critical, especially for renewable energy and energy storage. Enhancing the predictability of the policy framework could help encourage stronger private investment. Avoiding nonsector specific investment conditionalities would also enhance the conditions for private sector participation and attract the technologically most advanced players, reducing costs of the transition. Expanding the green electricity certificate (GEC) market, allowing larger participation from renewable energy generators and voluntary purchasers, and expanding the national ETS to cover renewable energy generation facilities may also enhance cash flow to private sector investors.

3.4.2. Industry (33 percent of emissions, no longer growing)

A major driver of China's economic growth, the industrial sector produces large emissions, both in absolute and relative terms. Industrial process emissions account for one third of China's total emissions (Figure 22). China's industry is relatively emissions intensive, at 1.49 tCO_2e per US$ 2015 gross value added, more than double the G20 average. This is mainly due to the high share of heavy industries in China's economy and to the relatively high emission intensity of the key industries compared to global leaders. Heavy industries—iron and steel, cement, and other construction materials—account for 39 percent of total GDP (relative to 18.5 percent in the US and 22.3 percent in the EU.

Figure 22. Industrial emissions growth has started to decouple from output



Source: World Bank staff, based on NBS data.

China has achieved substantial increases in energy efficiency over the past two decades and an absolute decline in emissions from manufacturing and construction since 2013. This reflects the economy's shifting composition toward services, the gradual diversification away from steel and cement production toward high-value activities in machinery and chemicals, and energy efficiency improvement both through technologies and regulatory measures (IEA 2020a).[21] Steelmaking and cement production now have energy intensities that are slightly below the G20 average. Efficiency improvements[22] between 1998–2013 amount to 408 percent for steel, 201 percent for textiles, 134 percent for cement, 296 percent for petrochemicals, and 157 percent for papermaking. These improvements are calculated to have conserved a total of 1.99 billion tce of energy over this period, with substantial further gains in subsequent years. Improvements in efficiency are most prominent in the eastern provinces, with central and western regions improving but at a slower rate.

Although the carbon intensity of the iron and steel sector has been declining, substantial opportunities for further gains remain. This sector alone contributes 14 percent of China's total energy-related CO_2 emissions (Ren et al. 2021). Energy intensity in China's iron and steel sector decreased from 3.2 tCO_2/tce in 2000 to 1.6 tCO_2/tce in 2019 but continues to substantially lag world leaders (for example, 0.47 tCO_2/tce in the US). China continues to rely on blast furnace-basic oxygen furnace (BF-BOF) technology for 90 percent of its production, compared to 72 percent for the global average (and 30 percent in the US, 76 percent in Japan, and 44 percent in India). Electric arc furnace (EAF) alternatives have emissions of around one quarter per unit of production (Lin et al. 2021). This may also produce co-benefits in terms of dioxins pollution reduction.

What we recommend

Even though the growth rate of industrial process emissions has been declining since 2005 thanks to rapid improvements in energy efficiency, decarbonizing China's large heavy industries will require important changes. The transition will be challenging because low-carbon production technologies remain costly (for instance, use of hydrogen and carbon capture in steel production) or do not yet exist (as in the cement industry). Fundamental changes are necessary to the industrial structure, material, and energy efficiency, with new production processes, greater material recirculation, and carbon capture technologies. Benefits, however, would be both global and local. In addition to the economy-wide reforms discussed further below, which will likely have important impacts on the decarbonization of the industrial sector, specific opportunities to make further progress exist.

21 Such as the Top 1,000 and Top 10,000 programs.

22 Calculated as single factor eco-efficiency improvements. World Bank Analysis, using the data from China Statistical Yearbooks, China Environmental Statistical Yearbooks, China Energy Statistical Yearbook. Date range is constrained by the availability of microdata.

- **A shift from traditional investment-led stimulus toward measures that support consumption would reduce trade-offs between the authorities' short-term growth and long-term climate objectives.** China has relied heavily on traditional investment stimulus to support the economy during downturns, most recently in the context of the COVID-19-induced slowdown. Such traditional infrastructure investment stimulates demand for steel, cement, and other carbon-intensive outputs of heavy industries and thereby increases emissions. At the same time, the economic returns to such investments have also been declining. Instead of stimulating further accumulation of physical capital, using government stimulus to support consumption would be consistent with China's objective of economic rebalancing toward services and consumption while simultaneously mitigating the trade-off between short-term growth and ambitious emissions targets.
- **Greater attention to circular economy opportunities would reduce emissions intensity and help overcome material supply bottlenecks.** Promotion of the circular economy can support emissions reductions. Electric Arc Furnace (EAF) production is currently constrained by domestic scrap steel supply and cost. A standardized scrap steel recycling system would facilitate increased use of scrap, important in the context of China's end-of-life steel availability quantities, which are expected to increase rapidly over the coming decade as existing infrastructure reaches end-of-life. At the same time, tighter design standards for new buildings can be used to mandate more recycled content.
- **In the longer term, there is a need to support direct and indirect drivers of technological advancement.** A range of technologies is available to reduce emissions but requires price incentives to support uptake. Technologies available range from well-established to experimental and can dramatically reduce emissions (Lin et al. 2021). Background analysis of firm-level data in China's major industries, undertaken for this report, demonstrates the correlation between research investment, technological innovation, and industrial efficiency across sectors.[23] It also highlights the role of foreign investment in driving efficiencies by diffusing advanced management experience and cleaner technologies. The planned expansion of the ETS will motivate efficiency measures when it is expanded to cover areas of the economy beyond power generators.
- **Decarbonizing the industrial sector may also induce relocation of industries toward provinces with higher renewable energy potential.** China's industrial capacity, especially its carbon-intensive heavy industries, is spatially concentrated in the northwestern provinces, reflecting historical industrialization patterns that were in part driven by the endowments with carbon-intensive energy sources (such as coal). The low-carbon transition may shift comparative advantages to areas with high renewable energy potential. Access to energy will increasingly be determined by renewable sources of electricity (solar, wind, hydro) and fuels derived from these inputs (hydrogen, ammonia) and this will likely reshape the economic geography. Enabling flexible factor markets could ease this relocation where it contributes to most cost-effective low-carbon production.

3.4.3. Transport (8 percent of emissions, growing by 6 percent annually)

A major driver of economic growth, China's infrastructure investment soared at a compound annual growth rate of almost 20 percent from 2007 to 2016, after which the growth slowed to around 4 percent.[24] The results include the longest expressways and high-speed rail network in the world, along with significant expansions in rural roads and urban rail systems.[25] Such rapid growth has supported corresponding growth in demand: the number of vehicles doubled in just 10 years, from 192 million in 2010 to 372 million in 2020; freight transport grew from 14 to 20 trillion ton-km over the last 10 years, along with the growing trade and seven-fold increase in e-commerce transactions over the same period (CSY 2021; CER 2019, 2020).

23 Background note on determinants of industrial eco-efficiency, prepared by Yutao Wang et al. (Fudan University).

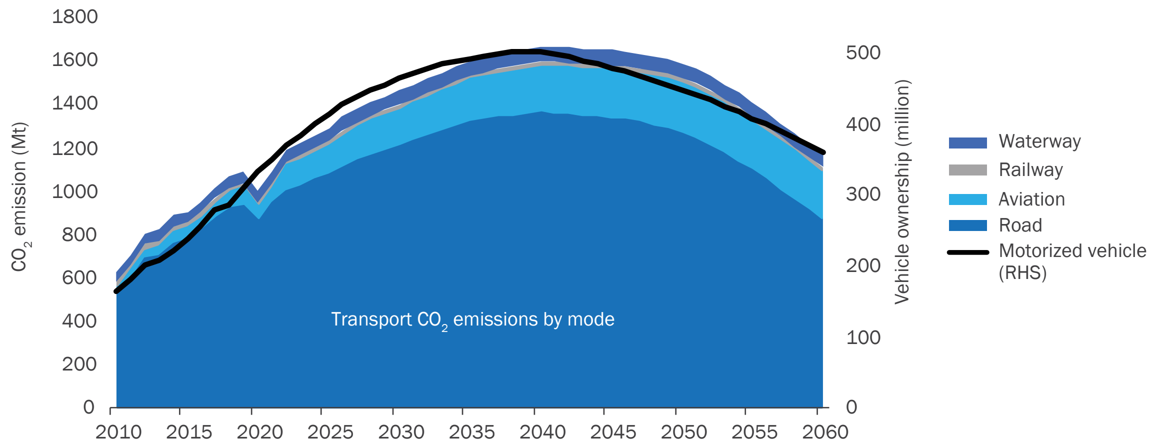
24 National Bureau of Statistics; The Economist Intelligence Unit.

25 By 2019, China's road network reached 5 million km, including about 150,000 km of expressways, and railways about 140,000 km, including 35,000 km of high-speed rail. China Transport Sector Development Statistical Bulletin (2020).

With rapid growth of both supply and demand, the transport sector has become a major contributor to energy consumption and GHG emissions in China. Its share continues to increase with the highest growth rate among all sectors, reaching over 11 percent in 2019 before temporarily decreasing during 2020 due to COVID-19-induced travel restrictions (see Figure 23). If unmitigated, transport emissions are estimated to continue rising until they peak at about 150 percent of the current level around 2040, much later than China's target peaking year of 2030, before decreasing to the current level by 2060.

Figure 23. If unmitigated, transport emissions are estimated to continue rising until they peak around 2040, and still emit over 1Gt of CO_2 annually in 2060

Transport Sector CO_2 Emissions in China – Trends and Business as usual (BAU) Projection



Source: World Bank analysis.

Decarbonizing the transport sector requires concerted efforts encompassing policies, pricing, regulatory measures, infrastructure investments, and technological innovation. Through these, motorized trips can be avoided or shifted to lower energy-intensity modes, or their energy efficiency improved. China has excelled at development of single-mode infrastructure (e.g., urban rail systems, high-speed rail network, airports, and seaports) as well as the early market penetration of electric vehicles and supporting infrastructure, at least in public buses and taxis. On the other hand, key gaps remain: (i) market-based policy and pricing mechanisms to manage transport demand and motivate individual travelers and businesses to shift to greener modes and fuels (see Box 5); (ii) scaling electric vehicle and other clean fuel technologies beyond public transport services, especially in freight transport; (iii) integrated transport systems, especially in large metropolitan regions, for modal shift to low-carbon and low-energy intensive modes; and (iv) shift from an emphasis on construction to a greater focus on asset management and maintenance by involving the private sector.

Box 5. Motor fuel taxes in China

China's motor fuel taxes, levied at a uniform rate of ¥1.52 per liter (equivalent to US 23₵), have not changed since 2015. First implemented in 1994 under the Provisional Regulations of the People's Republic of China on Excise Tax, the refined oil excise tax system is levied upstream—that is, at the stage of production, commissioned processing, and imports, rather than downstream usage. Globally, average fuel efficiencies of motor vehicles are inversely correlated with fuel prices: for instance, the average fuel efficiency in Germany is about 45 percent greater than that of the US, where the fuel prices have remained at much lower level—about 50 percent of Germany—over the past decade.[26] Although China's vehicle ownership is still low, the average fuel efficiency of passenger cars in China is lower than that of its European counterparts. As China further motorizes, it will be critical to phase out inefficient fuel subsidies (see section 3.5.1) to provide price incentives to set the transport sector on the path of higher energy efficiency, while considering the affordability of transport, especially for lower-income population, including through provision of public transport and other low-carbon options.

Even with higher fossil fuel prices, substantial subsidies would still be needed to support the price parity between internal combustion engine vehicles (ICEVs) and electric vehicles. To bring the lifecycle cost of an EV to parity with that of an ICEV (without subsidies on EV manufacturing or purchasing or carbon pricing), the price of motor fuel would need to increase from the current ¥7.5/liter to ¥13.9/liter (US$2.19/liter). This translates to a fivefold increase in the fuel tax from the current ¥1.52 per liter to ¥7.9 per liter (equivalent to US$1.24), which is unrealistic. In other words, even with phasing out of inefficient fuel subsidies, substantial amounts of subsidies would still be required to equalize life-cycle costs of ICEVs and EVs in the near future.

Policy reforms, significant investments, and technology advancements are needed to achieve decarbonization goals in the transport sector. To evaluate policies and understand their influence on transport demand and their emissions, three scenarios were considered: *(i) Reference Scenario (REF)*, based on policies that are currently being implemented and already announced and scheduled for implementation in the short term; *(ii) Enhanced Policy Scenario (EPS)*, which includes measures that are announced but without clearly defined timeline or resources for implementation, resulting in carbon emissions peaking in 2035, and 0.23 $GtCO_2e$ of residual emissions in 2060; and *(iii) Accelerated Decarbonization Scenario (ADS)*, which includes measures that are more ambitious but attainable, based on consultation with policy makers and sector experts, resulting in emissions peaking in 2030, and 0.07 $GtCO_2e$ of residual emissions in 2060.[27] Specific policy targets under EPS and ADS are presented in Table 4.

26 Calculated using data from World Development Indicators, GlobalPetroPrices.com, Eurostat, STATISTA, the Global Ethical Finance Initiative (GEFI).

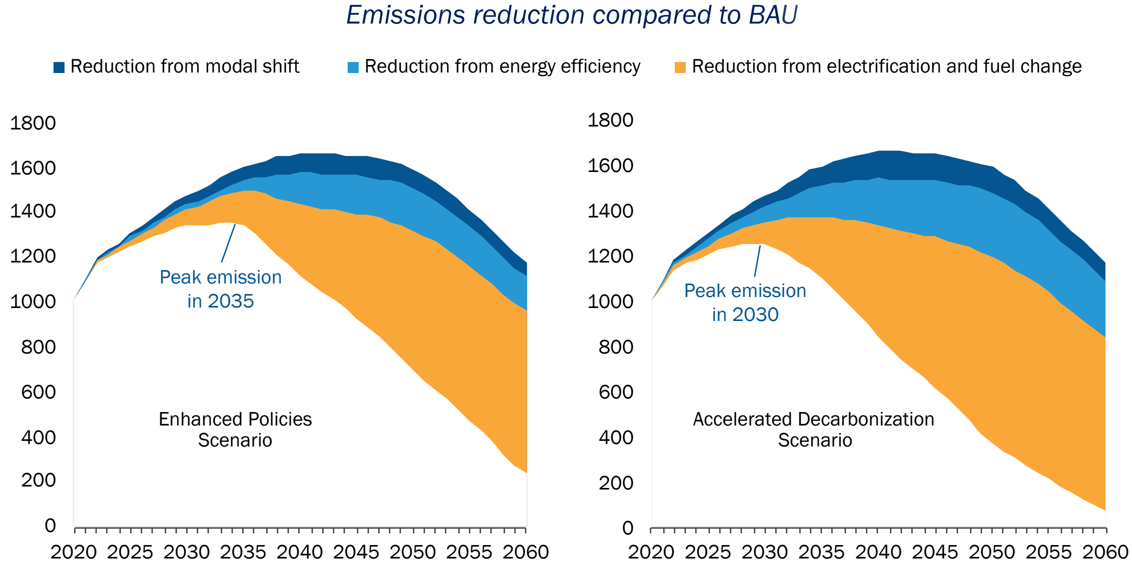
27 The LEAP (Long-Range Energy Alternatives Planning) model was used to build a bottom-up transport sector model covering all subsectors, road, railway, waterway, and air transport, excluding international shipping and international aviation.

Table 4. Transport modeling scenarios, key policy parameters, and results

Key policies, investments, technology development		Targets in key parameters compared to REF by 2060		Emissions reduction in metric tons (Mt)	
		Enhanced Policies (EPS)	Acc. Decarbonization (ADS)	EPS	ADS
Modal shift	• Invest in urban green modes (metros, BRTs, shared bikes, and so forth), waterways and railways	• Share of green modes in cities 15% higher • Freight modal shift from road 6 billion tons greater	• Share of green modes in cities 20% higher • Freight modal shift from road 8.5 billion tons greater	2,392 Mt	3,307 Mt
Energy efficiency	• Incentivize private sector investments in fuel saving technologies, digitalization/automation for operating efficiency, behavioral changes	• Road: Share of autonomous freight vehicles 20% higher • Rail: Share of fuel-saving locomotives 30% higher • Water: Share of large ships 15% higher	• Road: Share of autonomous freight vehicles 75% higher • Rail: Share of fuel-saving locomotives 60% higher • Water: Share of large ships 30% higher	4,251 Mt	7,040 Mt
Electrification and fuel change	• Encourage new energy applications: electrification, biofuels, and other new energy sources	• Road: EV shares in private vehicle sales 100% • Rail: Share of electric freight locomotives 35% higher • Water: Share of new energy ship sales 50% higher • Air: Share of new energy aircraft 40% higher	• Road: EV shares in private vehicle sales 100% by 2055 • Rail: Share of electric freight locomotives 49% higher • Water: Share of new energy ship sales 80% higher • Air: Share of new energy aircraft 60% higher	13,952 Mt	18,382 Mt
Total	REF emission: 60,274 Mt	• Additional investments: **¥62 trillion (US$9.5 trillion)**	• Additional investment: **¥74 trillion (US$11.4 trillion)**	**20,596 Mt (34% reduction)**	**28,729 Mt (48% reduction)**

The above combinations of policies and investments under the EPS are expected to advance transport emissions peaking to 2035 and result in a total emissions reduction that is 34 percent higher, from now until 2060, than that for the Reference Scenario. Shown in the emissions trajectory in Figure 24, about 68 percent of total emissions reduction would come from electrification and fuel change, 20 percent from energy and operating efficiency, and 12 percent from modal shift. These decarbonization pathways would require additional investments in infrastructure and vehicles—expansion of networks of low-carbon modes such as high-speed railway and mass transit systems, intermodal facilities, charging infrastructures, and incremental costs of new energy vehicles, which would amount to US$9.5 trillion over the 40-year period until 2060. Faster transition under ADS would advance the carbon peaking for this hard-to-decarbonize sector to 2030 and result in additional emissions reduction of 8 Gt from now until 2060, bringing the remaining emissions from the sector to 0.07 $GtCO_2e$, compared to 0.23 $GtCO_2e$ under EPS. Such added ambition would require an additional investment of US$1.9 trillion until 2060.

Figure 24. EPS and ADS policy scenarios could bring forward the transport emissions peak from 2040 to 2035 and 2030, respectively



Source: World Bank calculations.

What we recommend

- **Advance electrification beyond public transport vehicles, which account for less than 5 percent of transport emissions, to include private and commercial fleet, by ensuring price parity (through taxes and incentives) and providing adequate charging infrastructure.** EVs in China take up less than 2 percent of the total fleet and are concentrated mostly in public bus and taxi fleets in large urban areas, with about a quarter of the country's total EV charging infrastructures located in Beijing and Shanghai (where only 3 percent of the population resides). This needs to be scaled to include private and commercial fleets, which would require incentives (such as subsidies to lower total cost of EV ownership and preferential licensing and parking rights for EV users), investment in charging infrastructures (including in residential areas and other privately owned lands), and technology improvements. This is challenging due to the lack of coherent leadership, as the above policies and investments are governed separately by multiple jurisdictions responsible for industrial policies, urban planning, environment, and general economics. Early actions to accelerate electrification would be critical for advancing emissions peaking in transport, from 2040 or later under REF to 2030–35 under accelerated decarbonization scenarios and can bring about an emissions reduction of about 14.0–18.4 Gt from now until 2060, under EPS and ADS, respectively. While electrification can achieve some emission reduction even with China's existing power mix, as pointed out above, frontloaded decarbonization of electricity supply is crucial to realize the full abatement potential of electrification in the sector.
- **Combine regulatory measures with pricing—on fuel use or carbon emissions—to encourage fuel and energy efficiency improvement by the private sector.** China has effectively implemented administrative measures toward stricter fuel economy and energy efficiency standards of vehicles over time. These regulatory tools, if combined with gradually internalizing externalities[28] through fuel taxes or carbon

28 It is estimated that the average externalities costs of each private vehicle in Beijing is about ¥8,500 (8,500 yuan) per year, and only about one-third of it is borne by the car user. The calculation is based on the average annual emissions of CO_2 and various local pollutants—carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), and hydrocarbon (HC)—per private passenger vehicle and applying the EU's carbon price and marginal abatement cost for each pollutant. For instance, in 2015, when the report was produced, MAC (Marginal Abatement Costs) for CO was ¥4,941/ton, for NOx it was ¥29,100/ton, for PM it was ¥52,832/ton, and for HC it was¥4,541/ton. (CATS [China Academy of Transportation Science] 2015, *Study on Low Carbon Development Strategy of Urban Transportation in China).*

pricing, would provide strong incentives to private and commercial fleet operators to reduce their fuel consumption—through, for instance, investing in fuel-efficient vehicles, minimizing empty mileage, increasing occupancy rates, introducing eco-driving, and so on. This would lead to significant improvement in energy efficiency beyond meeting the minimum standards and is estimated to bring about an emissions reduction of about 4.3 to 7.0 Gt from now until 2060, under EPS and ADS, respectively.

- **Promote substantial modal shifts from private road transport to public mass transit (for passenger transport) and to railway and waterway (for freight transport), through deeper integration across modes and pricing incentives.** Despite the success in rapidly building an extensive network of high-speed railways and urban metros, the integration between modes has been weak in China due to the lack of institutional coordination, as planning, site selection, and construction are separately managed by individual modal entities. This is aggravated by a current pricing structure that does not reflect most of the environmental externalities generated by vehicular trips, which has resulted in the decrease in the relative prices of carbon-intensive modes (road and air transport) compared to lower-carbon modes (rail and waterway) over the last 10 years. Meaningful shifts to low-carbon modes, which require both physical and operational integration across modes and relative pricing that reflects externalities, can bring about an emissions reduction of about 2.4 to 3.3 Gt over the 40-year period, under EPS and ADS, respectively.
- **Promote technology development for alternative low-carbon fuels for harder-to-decarbonize sectors, in coordination with energy sector policies.** Accelerated electrification of road transport and modal shift will still leave waterborne and air transport systems, which account for about 15 percent of transport emission and are growing rapidly, to rely on high-polluting fuels. Although it is difficult to electrify these modes with the current technologies, due to the long distances between refueling/charging stations and the low energy-to-weight ratio of current batteries, it is expected that alternative options can become commercially viable in the coming decades. Economy-wide policies to promote technology innovations, including through R&D support, can encourage further development of blue or green hydrogen/ammonia and enhanced batteries in conjunction with innovations in the energy and industrial sectors.

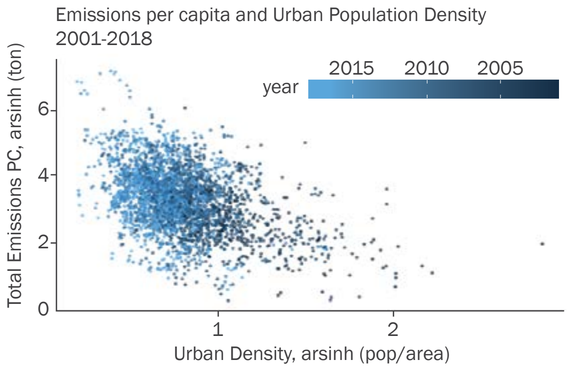
3.4.4. Low-carbon cities and buildings

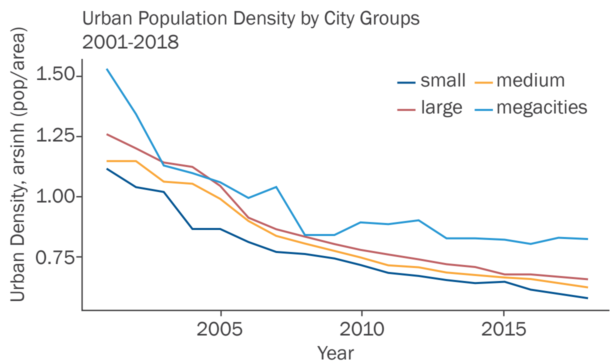
In 2018, the building sector in China accounted for about 5 percent of total carbon emissions, and progress on greening the sector has been modest. The Ministry of Housing and Urban-Rural Development (MoHURD) set out its objective to increase green construction areas as a percentage of newly built urban construction areas to 70 percent by 2022 and has introduced comprehensive regulations and guidelines related to low carbon and green buildings. The green building market has seen a rapid growth in recent years, aided by subsidies[29] and regulations that require all newly constructed buildings to have at least a one-star green certificate. China's top-tier developers are getting more committed to green buildings, as they understand the commercial benefits of green certified buildings. Nonetheless, only about 4 percent of existing buildings meet green standards set by the MoHURD.[30] Financing for the green building sector is also lagging: only about 6 percent of green bonds are used for green buildings, contrasting with 30 percent globally.

29 In China, two-star green buildings can get a 45-yuan subsidy per sqm (about $7 per sqm), and three-star green buildings can get an 80-yuan subsidy per sqm. And 22 provincial and municipal governments also provide extra subsidies for green certified buildings. (Guidance To Accelerate Development of Green Buildings 2012)

30 According to the China Construction Science Academy, retrofits can help reduce carbon emissions per sqm by 42 percent, and new green construction can reduce carbon emissions per sqm by 51 percent. By the end 2020, there are 65 billion sqm of buildings, only 4 percent with green certification.

Figure 25. Denser Chinese cities have lower per capita emissions (panel A), but density has been declining over time (panel B)





Source: World Bank calculations. Note: Urban density is calculated by urban population/built area and the unit is the inverse hyperbolic sine of 10 thousand people per square kilometer. Emissions are total emissions per capita, and the unit is log of tons. City groups are defined as follows: small cities—less than 1 million (50 cities in 2018), medium cities—between 3 and 5 million (52 cities in 2018), large cities— between 5 and 10 million (62 cities in 2018), megacities—more than 10 million (11 cities in 2018).

Addressing emissions in the building sector will benefit from being part of a more comprehensive approach to building denser, lower-carbon, and more resilient cities. Cities in China play an important role in realizing carbon goals and the green transition. The urbanization rate, currently at 60 percent, is projected to reach 80 percent in 2035, with an expected urban population of over 1 billion (Li and Sun 2020). Urban built-up areas currently represent up to 90 percent of total CO_2 emissions in China.[31] Lowering the emissions intensity of existing cities, as well as ensuring new urbanization follows a low-carbon path, will be crucial for the transition to carbon neutrality. One important element of this will be to promote the development of compact, livable, and well-connected cities. Research for this CCDR shows that there is a strong statistically significant negative relationship between population density and per capita emissions over the past two decades, even after controlling for income, economic structure, and proxies for environmental policy (see Figure 25a). Denser cities have both lower transport emissions per capita and lower residential emissions per capita. It has also been well-documented that denser, better connected, and more people-oriented cities tend to be more productive, with agglomeration benefits particularly for high-skilled services industries.

Despite the benefits of compact cities, recent urbanization in China has been characterized by declining population density. China is the only country in East Asia to have declining population density in its large cities, as the expansion of urban boundaries has outpaced population inflows (WBG 2015). Urban population density has declined across all city size groups, with density lowest for small cities (see Figure 25b). This is due in part to the combination of China's land tenure and public finance system, which has provided strong incentives for local governments to generate local revenue from land sales. Various reforms have been made to improve land management and markets.[32] China's megacities also have increasingly stringent

31 The modeling work was constructed from National Land Use Composition Data from between 2009 and 2018 from the Ministry of Natural Resources, and from national CO_2 emissions inventory based on 10 km-by-10 km grids from 2015 from the Ministry of Ecological Environment.

32 The Amendment of Land Management Law in 2019 was the most significant reform action. It permits village collectives to sell the use right of their rural construction land for urban use (except for residential real estate development) as long as the urban use conforms to the spatial plan and land use control. This new provision breaks the state monopoly in converting rural land for urban development. The Amendment also defines the public purposes for state expropriation of rural land, and requires better compensation and social insurance to affected farmers. The Amendment requires the government to exercise land use control on the basis of a national spatial planning.

population controls. However, recent analysis shows that if the current urban development pattern and industrial layout remain broadly unchanged, a doubling of constructed land (urban built-up area) will come with a 2.7 times increase in CO_2 emissions.[33] An important component of the transition to carbon neutrality will thus be altering these incentives to ensure cities expand upwards rather than only outwards, and that cities are livable and well connected.

What we recommend

It is crucial both to decarbonize existing urban areas and ensure that new urbanization follows a low-carbon and green path. A delay in low-carbon city development may lock in excessive carbon, land, or water intensity and create or expand settlements that prove vulnerable to changing climatic conditions. Several policy options can be considered.

- **To achieve a low-carbon urban growth path, city planners have a number of regulatory and pricing tools at their disposal.** These include: (i) regulatory measures such as floor area ratios to influence the density of development, (ii) land use regulations to discourage urban sprawl and promote compactness, (iii) coordinated urban expansion and public transport investment strategies to encourage transit-oriented development, and (iv) area master plans to promote walkable neighborhoods and small-block development. The dependence of China's cities on land sales for revenues has encouraged sprawl, the introduction of property taxes, and alternative sources of local revenues could thus greatly encourage more low-carbon urbanization.
- **Strengthening city-level GHG inventories would be crucial to help cities identify key emissions reduction potentials and monitor progress toward the achievement of carbon goals.** Methodologies for GHG accounting also need to be further standardized across cities, to facilitate emissions trading and guide private investments. For instance, China's Guidelines for Provincial Greenhouse Gas Inventories, adopted by the National Development and Reform Commission (NDRC) in 2010 as the standard for city GHG emissions calculation, could be updated to identify emission reduction potential from a consumption perspective.
- **Cities in China could prioritize neighborhood regeneration and retrofitting for low-carbon and green development, which would generate adaptation and mitigation synergies.** International examples of community-level low-carbon retrofitting include energy-efficient street lighting, green roofs, rainwater harvesting, greater nature-based solutions such as constructed wetlands, ecological restoration, and permeable paving, accompanied with participatory planning and community engagement. Community-level awareness campaigns for behavior changes can complement bottom-up community level interventions. These interventions would also have co-benefits, including improved quality of life and livability, urban ecosystems protection and hazards prevention, and amelioration of urban heat island effects. In particular, techniques for urban heat islands' cooling are being increasingly adopted in Chinese cities, including leveraging "green" and "blue" spaces for increasing cooling effects—using, enhancing, and channeling wind flows. A combination of urban regulations such as updating urban design code and incentives for developers would be needed to scale up ongoing pilots.
- **In the building sector, there is an opportunity to use fiscal incentives, develop disclosure requirements, and improve green standards.** Fiscal incentives for the building sector can be shifted to incorporate ex-post performance measures for energy conservation and emissions reduction, and to enhance the role of government funds in better leveraging private capital. Carbon markets can be used as collateral to facilitate private sector participation. This will require the establishment of detectable, verifiable, and reportable building carbon-reduction technologies and standard systems. Moreover, reliable monitoring systems and requirements for information disclosure of building energy efficiency can be very important

33 The modeling work was constructed from National Land Use Composition Data from between 2009 and 2018 from the Ministry of Natural Resources, and national CO_2 emissions inventory based on 10-km by-10 km grids from 2015 from the Ministry of Ecological Environment.

for developers, financial intermediaries, and consumers. Regulators can also improve domestic standards to match international standards to attract more international investment.

- **Effective coordination and collaboration among city officials and agencies will be central to tackling interlinked climate challenges and avoiding fragmentation.** Climate actions require integrated solutions and actions from different government entities and organizations. Institutional coordination mechanisms for multijurisdictional metropolitan regions and city clusters are nascent. Chinese cities have traditionally implemented government programs and public investment focusing solely on their own jurisdictions, almost in competition with neighboring cities. Responding to climate mandate and actions, especially in large urban agglomeration areas, would require a metropolitan region's perspective and approach, which go beyond the administrative boundaries of single cities.

3.4.5. Agriculture, land use, land use change, and forestry (6 percent of emissions, shrinking by 5 percent annually)

Agriculture

China's agriculture sector is large and has grown fast. In 2020, China's agricultural GDP amounted to US$1.13 trillion (US$ constant, 2010), equivalent to 7.7 percent of national GDP. China produces 18 percent of the world's cereal grains, 29 percent of the world's meat, and 50 percent of the world's vegetables.[34] China also plays an important role in international agricultural trade. The country is the largest importer of soybeans, maize, beef, and aquatic products. During the last four decades, China's real average annual growth rate of agricultural output value and agricultural GDP were 5.3 percent and 4.5 percent, respectively.

But this growth has been accompanied with mounting environmental costs. Growth was driven mainly by increases in total factor productivity (TFP), technological changes, and large producer subsidies provided mainly for rice, wheat, and maize production. Agricultural support has led to excessive use of chemical fertilizers, resulting in high pollution and environmental degradation. Livestock, synthetic fertilizer use, and rice paddies are the largest sources of agricultural GHG emissions in China, in that order. Breaking down sector emissions by gas, methane (CH_4) leads the way (46 percent), followed by nitrous oxide (N_2O, at 39 percent) and CO_2 (15 percent).[35]

Agriculture and food production are not only an important source of emissions and environmental pollution but would also be among the most severely affected by climate change. Specific adaptation challenges are discussed in Chapter 4 of this report. Suffice to say that adopting climate-smart agricultural practices could in many cases also strengthen resilience of the sector to the impact of rising temperatures and increased frequency of droughts and floods.

Encouragingly, agricultural GHG emissions may have already peaked. After increasing for several decades, China's farm-related GHG emissions took an upward leap during the 1990s, before declining between 2016 and 2019. According to UN Food and Agriculture Organization (FAO) statistics (2021), GHG emissions on agricultural land peaked at 842 Mt CO_2e in 2016. Between then and 2019, they declined by 6 percent, returning approximately to their 2007 levels of about 792 Mt CO_2e. The agricultural sector also recorded a steady decline in carbon intensity from 2.7 in 1991 to about 1.0 in 2019.

However, emissions from domestic food consumption have outpaced emissions from domestic food production. China's current food-related greenhouse gas emissions could already account for 13 to 19

34 The country is the world's largest producer of rice (212 million tons), wheat (131 million tons), and fresh vegetables (174 million tons), and second largest producer of maize (392 million tons).

35 About 90 percent of sector methane is due to enteric fermentation (50 percent) and rice paddies (40 percent). As for agricultural nitrous oxide emissions, 60 percent are due to soil amendment practices—the application of synthetic fertilizer (52 percent) and manure (8 percent). And another 18 percent arise from the decomposition of manure on pastures resulting from the grazing of livestock. Of note, these estimates are based on FAO statistics (2021), and estimates of sector emissions and their breakdown vary by source.

percent of the 2050 target for global agriculture, with estimates of sector emissions for 2017, 2018, or 2019 ranging from 667–967 Mt per year (FAO 2021, Climate Watch 2020, Crippa et al. 2021, Zhang et al. 2022). According to modeling by Kim et al. (2020), by midcentury, China's food-related greenhouse gas emissions would increase by 82 percent over baseline were it to adopt the average consumption pattern of OECD countries (derived from supplemental data).

What we recommend

- **Repurpose subsidies to support low-carbon land use.** In the agriculture sector, subsidies affecting water use, energy use in irrigation, and fertilizer production should be reviewed and repurposed to ensure net support for low-emissions practices for example, supporting increased use of organic fertilizer alongside balanced use of inorganic fertilizers, which has significant soil carbon sequestration potential). Subsidy reform will need to be coordinated with targeted investment in measurement, reporting, and verification (MRV) systems at farm level, to allow the gradual shift in payments toward environmental outcomes, agricultural extension, and infrastructure (such as infrastructure for water-saving irrigation methods). Green production practices can achieve yields comparable to those of conventional agriculture but come with higher demands on farmer skills and upfront capital investments. The resulting economies of scale would require farm consolidation and a strengthening of producer cooperatives, a trend consistent with China's demographic developments in rural areas.
- **Cut food loss and waste (FLW) and increase efficiency in trade and food supply.** Research shows that 27 percent of food that is produced in the country for human consumption (349 million tons) may be lost or wasted (Xue et al. 2021). Among the challenges to be addressed to tackle FLW is the need to improve monitoring and adapt policies as better information becomes available (Cattaneo et al. 2021).
- **Reuse agricultural waste.** According to FAO statistics, mainland China accounted for 17 percent of global open burning of agricultural residues in 2019, burning 23 percent more biomass than all of Africa, and 40 percent more than India (FAO 2021). Returning straw to the soil decreases pollution and increases soil fertility, thus improving soil carbon. However, lack of knowledge and equipment to properly handle residues leads to the prevalence of burning practices, particularly among smallholder farmers. The reuse of straw as fertilizer, feed, energy, and raw material could be promoted by repurposing agricultural subsidies and introducing mechanization services. Reducing FLW and reusing crop residues are further examples of policies that would make China more resilient to climate change while also reducing emissions. Nature-based solutions are a further example.

Table 5. Estimates of annual sequestration potential from different NbS

NbS Activity	Mitigation potential (Mt CO_2e yr^{-1})	
	2030	**2060**
Nutrient management [a]	137	198
Forest management [a]	380	228
Afforestation [a]	99	49
Grazing land management [b]	152	
Total	**768**	**627**

Source: The Nature Conservancy and Wang et al. (2014). Temporal distinction for grazing land management is not known.

Ecosystems and nature-based solutions (NbS)

Nature-based solutions could contribute to China's GHG mitigation while delivering ecosystem and human health co-benefits. NbS are activities that protect natural resources and restore and conserve ecosystems to enhance carbon sequestration. These include afforestation, improved forest management, nutrient management, improved grazing land management, drinking water source protection, flood control, and wetlands restoration. Analysis prepared for this report further shows that NbS need not come at the expense of other land use—for example, for food production (Box 6). A more efficient allocation of productive and protective land uses across space can enhance the efficiency of both and thus achieve greater resilience as well. The mitigation potential of NbS is not well-quantified in China; however, preliminary estimates suggest potential of at least 768 Mt CO_2e per year in 2030 or 8 percent of China's total by 2060 (see Table 5). NbS timelines, which allow for rapid sequestration within this decade, complement longer-term mitigation strategies in the industrial and energy sector that require large capital investments. An additional advantage of NbS is that sequestration can be used to offset difficult-to-mitigate emissions, substantially reducing total costs of achieving carbon neutrality.

China has had considerable success with land restoration and management techniques at scale over the past three decades. China invested over US$380 billion in land management (around 0.3 percent of GDP annually) from 1990–2018, in response to natural disasters linked to ecosystems degradation (Bryan et al. 2018). As a result, China's forest cover grew from 12 percent in the early 1980s to over 23 percent of total land area today, and between 2000 and 2010, national carbon sequestration increased by 23.4 percent, soil retention by 12.9 percent, and sandstorm prevention by 6.1 percent (Ouyang et al. 2016, Chen et al. 2019). Despite these successes and further potential, and despite synergies with China's enhanced biodiversity conservation goals,[36] further improvements in land management are not emphasized in the NDC or other high-level planning documents.[37]

36 China hosted the first part of the 15th Conference of Parties of the Convention on Biological Diversity in Kunming, China, in October 2021. The draft (at the moment of writing), Post-2020 Global Biodiversity Framework, has multiple targets, including targets related to protected areas and targets to enhance ecosystem connectivity and integrity, and to reverse the trend of species extinction.

37 The NDC targets an increase in the forest stock volume (by 6 billion cubic meters from the 2005 level), but no other nature-based carbon sequestration activities, such as forest management, nutrient management, and grazing land management.

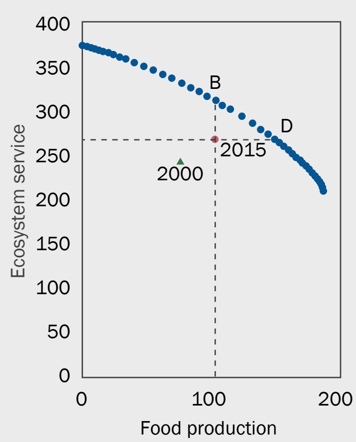
Box 6. Synergies between carbon sequestration, food production, and other ecosystem services

NbS may face trade-offs between carbon sequestration, agricultural production, and other ecosystem services. Trade-offs may arise when the same area of land is suitable for food production, carbon sink through fast-growing tree species, or natural landscape conservation/restoration. Spatial planning that identifies locations where trade-offs are minimized can ensure that NbS do not impact livelihoods and food security. To explore the potential for synergies and tradeoffs, the World Bank and Chinese Academy of Sciences used a spatially explicit landscape model. Within the model, each point in the landscape generates ecosystem services as a function of its ecosystem type, vegetation cover, climatic conditions, terrain conditions, soil conditions, biomass, and the condition of the surrounding points. The model is calibrated using high-resolution spatial data from the national ecosystems assessment in 2015.

The analysis found that China's "land use efficiency" had improved considerably since 2000, meaning that ecosystem services and food production have improved in tandem (Figure 26). The analysis also found further opportunities for improvement. China can increase land-based carbon sequestration by 33.9 percent, through restoration of natural ecosystems, with no net decrease in food production. There is a high degree of synergy between carbon sequestration and wildlife habitat, with biodiversity score (wildlife habitat) increasing by 27.6 percent, water retention by 30.9 percent, and soil retention by 3.9 percent. This analysis shows that many NbS can benefit both climate resilience and climate mitigation. Factoring in these co-benefits turns them into one of the lowest-cost abatement measures.

Figure 26. China's land use efficiency has improved since 2000

Estimated production possibilities frontier for China's ecosystem services and food production.



Source: Chinese Academy of Sciences and World Bank.

What we recommend

Harnessing nature-based solutions (NbS) potential for carbon neutrality will require a range of land-use planning and regulatory reforms, technical guidance, and new sources of financing. The most important pathways toward unlocking NbS potential include:

- **Accelerate forestry sector reform.** Despite significant reforms in the past two decades, the sector remains dominated by fast-growing single-species plantations, which have expanded forest cover at the cost of forest quality and forest resilience (in the context of fire, pests, and diseases). Profitability remains low, and thus the investment needed for improved management is lacking. Improvements could be obtained through simplifications to the timber harvesting quota system, with reallocation of rights to allow individual forest operations to set their own timber-harvesting plans. Remote sensing now provides monitoring opportunities that reduce moral hazard risks. These changes can be conditioned on application of updated forestry guidance that would require multispecies plantations with improved biodiversity, climate resilience, and greater carbon sequestration potential.
- **Harness carbon finance for NbS:** The introduction of China's emissions trading scheme (ETS) provides an opportunity to finance NbS through the sale of carbon offsets. Credits for forest activities are available under China Certified Emission Reduction (CCER) procedures and may be used to meet firms' obligations under the ETS. World Bank estimates suggest that the ETS could support around US$7.50 billion to carbon NbS projects, and up to US$22.5 billion annually when the ETS expands to cover all major sources of emissions in China's economy.[38] There is a need to formally issue full regulations for CCER methodologies, projects, and transactions, as well as develop a wider range of NbS-related methodologies (for activities beyond forestry).[39] Premarket purchase mechanisms (such as purchase price guarantees by the government) could be used to incentivize private investment in NbS types that are more experimental (such as wetland restoration) and for which risks may be higher.
- **Improve the efficiency of eco-compensation schemes:** Despite the potential of CCERs and other carbon finance programs, land-use-based investments will still rely on forest and agricultural commodity revenues or public funds. Financing NbS at scale will thus go hand in hand with continued use of ecological compensation programs, which provide public subsidies (over US$30 billion annually) for environmentally beneficial land-management actions. There is significant room for improvement in efficiency of eco-compensation by conditioning payments on ecosystem outcome proxies (such as plantation diversity) rather than outputs (plantation area), tighter spatial targeting (that is, prioritizing areas with the highest biodiversity and carbon sequestration potential), and use of reverse auction mechanisms (WBG 2021).
- **Support demand for NbS-related products:** Recognizing product certification systems (such as the China Forest Certification Council [CFCC]) in public procurement policies could be used to increase demand for certified low-carbon (and environmentally sensitive) timber products that increase returns on (and thus incentivize investment in) NbS. In addition, inclusion of the steel and cement industries in the ETS would create a level playing field between their products and long-lasting timber alternatives in construction.

38 The use of CCERs is capped at 5 percent of ETS participants' emissions obligations. Raising of the cap could increase demand for offsets and thus NbS financing.

39 Methodologies for shrub forest restoration, mangrove restoration, and wetlands and drip irrigation in arable land have been developed but not yet approved. Methodologies related to fertilizer use efficiency have yet to be developed.

3.5. Economy-wide and enabling policies for carbon neutrality

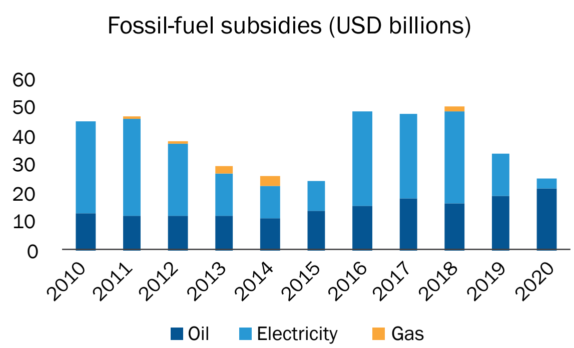
A growth-friendly and inclusive decarbonization strategy requires carefully designed economy-wide policies to complement sectoral climate policy actions. Economy-wide climate policies are necessary to internalize both the negative externality of carbon emissions and the positive externalities from innovation that result in the underprovision of low-carbon technologies. But achieving carbon neutrality will require more than low-carbon policies alone. How quickly and smoothly the economy adjusts to a change in relative prices depends in large measure on how flexible and efficient factor and product markets are. Broader structural reforms to promote a more decisive role of market forces in guiding the allocation of capital, labor, and R&D investment are hence critical to enable the economy to adapt more efficiently to changing price signals and regulations, thereby lowering adjustment costs. Adopting climate actions within such comprehensive policy framework would help ease the inevitable trade-offs and maximize the potential synergies between China's climate and development objectives. This section will explore the options for economy-wide policies that can facilitate the transition—macroeconomic and structural policies, green finance and labor markets, and the just transition.

3.5.1. Macroeconomic and structural policies: carbon pricing, competition, innovation, and trade

1. Expand the role of carbon pricing

Carbon pricing is widely seen as one of the most efficient ways to drive economy-wide abatement (see, for example, Stiglitz et al. 2017). Unlike administrative measures, carbon pricing does not require policy makers to make detailed centralized decisions on the most cost-effective abatement investments. Instead, carbon pricing signals the costs of emissions, allowing decentralized market participants to discover cost-effective abatement options, reallocate resources, and dynamically drive innovation. However, there are several prerequisites for carbon pricing to be effective; foremost, functioning markets where price signals drive the behavior of both producers and consumers. In heavily regulated or state-owned-monopoly market structures, however, the effects of price signals are often muted.

Figure 27. China still subsidizes fossil fuels to the order of 0.2 percent of GDP



Source: Energy Monitor

China's national emissions trading system has started to lay the foundations for a market-driven abatement policy approach. With tradable emissions rights covering more than 4 billion tons of CO_2—40 percent of China's emissions or roughly 12 percent of total global CO_2 emissions—China's ETS is the world's largest carbon market. At present it covers China's power sector, with 2,225 of the largest coal and gas-fired power plants. The ETS is a rate-based system, meaning that it targets reductions in carbon emissions intensity, defined as emissions per unit of output. As such, China's ETS is not yet a cap-and-trade system. Enterprises under China's ETS receive allowances that are calculated based on two factors: the plant's output and the relevant carbon intensity benchmark for the plant, with different benchmarks for different fuel and plant types. For example, gas-fired power plants face a different carbon intensity benchmark than coal-fired power plants, and different-sized coal-fired plants face different benchmarks. The initial allowances are allocated free of charge rather than auctioned. Plants can then buy or sell permits in the ETS, as well as purchase China Certified Emissions Reduction (CCER) certificates in a complementary market to offset their emissions. Allocations are also subject to several "ex-post adjustments," which give extra allowances in certain circumstances. Compliance obligations for coal power plants are also capped at 20 percent above their verified emissions. In addition, the maximum penalty for noncompliance is ¥30,000 (about US$4,400).

The current ETS design has several important implications. First the rate-based design and allocation system primarily incentivizes plant-based improvements in energy efficiency, rather than fuel switching. It also means that there are varying carbon price signals across benchmark groups, further diminishing competition between different groups of plants—for example, less- and more-efficient coal-fired plants. Second, the compliance framework results in an implicit price ceiling, as beyond a certain carbon price, firms may find it more profitable to pay the penalty for noncompliance than buy more permits. Finally, the lack of an absolute emissions cap means that firms are not incentivized to reduce absolute emissions, but only to improve emissions intensity.

In addition, energy market distortions dampen the potential effect of carbon pricing. For example, in the power sector, dispatch quotas limit the effect of price signals on the composition of output. Power system investments and asset retirement decisions are also largely centrally planned, rather than guided by price signals. Electricity prices are set administratively, muting price effects on end-user behavior. For price signals to be effective, prices would need to be more reflective of costs (including carbon charges), generators would need to face competition, and power would need to be traded across integrated regional or indeed national power markets. In other words, without power market reforms, carbon pricing might have limited effects on encouraging fuel switching and reducing power sector emissions and simply impose higher costs on an inflexible sector. Finally, China still subsidizes fossil fuels to the order of 0.2 percent of GDP (Figure 27).

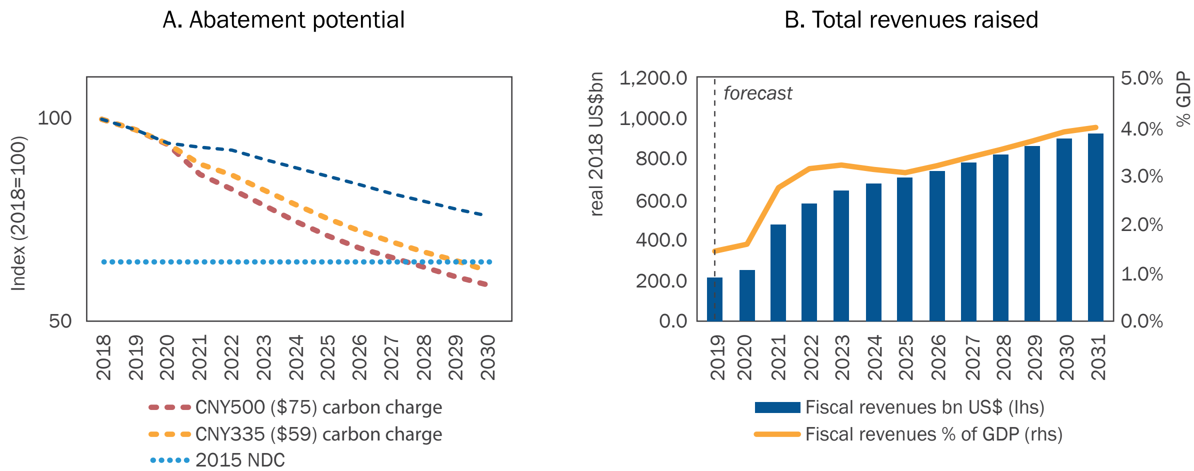
Assuming some of the market distortions mentioned above are simultaneously addressed, simulations suggest that a more broadly applied carbon price could help China achieve carbon emissions targets and also become an important source of revenue. A more broadly applied and higher carbon price rising to US$50 to US$75 per ton of carbon by the end of this decade could help reduce China's emissions by about 15 to 20 percent (Figure 28).

Adverse effects of carbon pricing on growth and equity could be addressed by recycling revenues to compensate the most affected households. Compensating income losses is important both from a distributional perspective and for social acceptability of the reform.[40] Simulations in section 3.3 provide a stylized illustration of how revenue recycling mechanisms can alter the distributional implications of low-carbon policies if welfare losses are fully compensated. In practice, perfect compensation of household income losses may neither be practically feasible nor socially desirable, as they likely imply disproportionate transfers to richer households. More realistically, existing government transfer systems could be deployed to

40 Although revenue recycling through transfers to households is primarily considered here, the literature has also documented alternative recycling mechanisms, including schemes based on the "double dividend theory" (that is, using carbon taxation to reduce other more distortionary taxation, such as labor taxation). Double-dividend recycling schemes have positive effects on the economy from an efficiency perspective, although they have the disadvantage of being less visible to the public and thus may not contribute to social acceptability of the policy. On the contrary, even though direct rebates can be more attractive for public opinion and be less harmful for low-income households, they tend to be less efficient. Garcia-Muros et al. (2022) show that the potential trade-offs between equity and efficiency of the isolated revenue recycling schemes can be addressed by combining recycling regimes that compensate low-income households while also reducing distortionary taxes, because they have positive synergies that translate into greater efficiency gains and progressive impacts.

target compensation (table 6). The targeting of compensation mechanisms could be improved by expanding coverage of safety nets among the poorest households and setting an income threshold above which households are considered ineligible for the compensation.

Figure 28. A carbon charge rising to $75/tCO$_2$ by 2030 could reduce emissions by 15 to 20 percent (panel A), while raising additional revenues of 2.7 percent of GDP (panel B)



Source: Simulations using World Bank Carbon Pricing Assessment Tool (CPAT).

Table 6. Revenue recycling using existing government transfers and pension systems

Share of households

	Share of households that ...				Share of households that receive government transfers OR pensions AND would not lose income *(Inclusion error)*	Share of households that would lose income AND do not receive government transfers OR pensions *(Exclusion error)*
	Receive government transfers	Receive pensions	Receive government transfers OR pensions	Lost income under NDC		
All	**25.9**	**55.2**	**67.2**	**96.9**	**1.4**	**31.6**
Q1	51.7	55.3	78.7	98.9	0.4	20.7
Q2	43.5	47.8	68.9	96.3	2.9	30.6
Q3	31.3	45.9	62.6	97.7	1.1	36.6
Q4	16.2	56.7	64.6	97.7	0.9	34.5
Q5	12.4	61.2	65.5	95.4	1.7	32.5

Source: World Bank calculations based on the 2018 China Family Panel Survey and Computable General Equilibrium (CGE) modeling results for scenario 1 relative to BAU.

What we recommend

For carbon pricing to become a more effective, growth friendly, and inclusive instrument in driving efficient decarbonization, several options could be considered:

- **Further strengthen the ETS design:** First, benchmarks for different types of power plants could be converged and unified to strengthen price signals. Transitioning from the current differentiated allowance allocation toward a unified allocation would generate uniform carbon price signals and enhance incentives to optimize abatement across different technologies and assets, encouraging not just efficiency improvements within a given benchmark group, but also fuel switching. Second, over time a mass-based ETS design, with a fixed total emissions cap and clear and predictable forward guidance on expected annual tightening of the cap, could increase effectiveness while allowing investors to plan ahead and factor expected carbon price increases. The ETS should be expanded to other high-carbon sectors such as steel, iron, and cement, but an economy-wide system would deliver the greatest efficacy and efficiency. Reforms of power markets—discussed in section 3.3.1—are a prerequisite for the ETS or any other form of carbon pricing to be effective and should be a top priority.
- **Recycle revenues from carbon pricing to mitigate potentially adverse growth and distributional impacts.** Introduce auctioning as the default allocation mechanism of initial allowances to provide consistent price signals and generate revenues that can be recycled. Recycling could be tailored to balance improving distributional effects through transfers to households and to pursue growth-enhancing investments of cuts to factor taxes to boost economic activity. The coverage of the social protection system could be expanded to reach vulnerable households that are expected to lose relatively more from higher carbon prices but are not currently covered by the system. Imposing an income upper-bound threshold for eligibility would further improve the progressivity of the compensation mechanism and lower the negative impact on growth.
- **Strengthen policy coordination with other instruments.** Even with an effective cap and trade ETS, complementary policies aiming to reduce emissions—for example, subsidies for low-carbon investment—may end up affecting the composition but not the volume of emissions.[41] To mitigate this effect, permit supply or emissions volumes will need to be adjusted if other policies complement the ETS, thereby reducing demand. Notably, Chinese energy market regulatory authorities should work to ensure an alignment of the ETS and the Energy Consumption Permit (ECP) trading mechanism for energy savings and energy consumption permits, currently under construction by the NDRC. Supervised and regulated offset markets can also enhance efficiency of emissions trading, allowing companies that find it too costly to reduce their emissions in the short term to purchase offsets.
- **Reforming remaining fossil-fuel subsidies will also be key, whereas complementary carbon taxes could be considered for sectors not covered by the ETS.** A basic first step to alter price incentives would be to phase out existing inefficient fossil-fuel subsidies. Carbon taxes, which are administratively much easier to implement than the ETS, could be applied in sectors for which the ETS would entail high transaction costs.

41 For a given emissions cap, additional non-ETS policies to reduce emissions will imply a fall in prices and hence lower marginal abatement incentives, thereby offsetting the initial fall in emissions with rises elsewhere. Another way to say this is that ETS is directly targeting (and always achieving) a specific emissions volume.

2. Foster decarbonization through SOE reforms and competition

State-owned enterprises (SOEs) continue to play a dominant role in China's economy, especially in carbon-intensive sectors. SOEs are estimated to account for around 25 to 40 percent of GDP and around 40 percent of employment.[42] SOEs control value chains for sectors responsible, directly or indirectly, for the majority of China's emissions: coal, electricity, oil, gas, steel, and cement. It is estimated that SOEs generate about half of the country's total GHG emissions (Clark and Benoit 2022). Addressing emissions generated by SOEs will therefore form a key component of reaching China's goal of carbon neutrality before 2060.

SOE dominance has some advantages but could also impair efficient decarbonization. State dominance has given the government significant capacity to implement low-carbon policies, including for instance the rapid scale-up of renewable energy in recent years. However, there is also evidence that suggests that China's state sector is one of the constraints to faster productivity growth, with SOEs exhibiting large and persistent productivity gaps with private firms (Kroll and Kou 2018, Song 2018). Research has shown that the total factor productivity (TFP) performance gap is greater in key carbon-intensive industries such as utilities, transportation, steelmaking, and chemical manufacturing (Jurzyk and Ruane 2021). Yet, SOEs tend to have easier access to bank credit and more favorable loan terms, compared to private companies (Lam and Schipke 2017, Gatley 2018; Geng and Pan 2021, Lardy 2019). Moreover, dominant market positions of SOEs and an unpredictable regulatory environment may impair dynamic market entry by private sector investors, which can play an important role in driving innovation and diffusion of new technologies. For example, following abrupt regulatory changes to China's renewable subsidy policy and feed-in-tariffs in 2018, the private market share in solar power fell from more than 70 percent of installed capacity to less than 40 percent by the end of 2019.

What we recommend

Reforms to level the playing field and enhance competition in key sectors could play an important role in enabling the structural transformation of the economy, with SOE reform an important component of this agenda.

- **Improve market access and competition.** Although market entry is allowed for private or foreign firms in many fields, licensing, capital requirements, and access to physical infrastructure networks pose major challenges, raising overall barriers to entry. Renewed efforts would also be needed to enhance entry of new firms and increase product market competition, particularly in services sectors, which will need to expand substantially over the coming decades and are currently far from the global productivity frontier.
- **Encourage low-carbon corporate strategies in SOEs.** Although enabling stronger private sector participation is crucial, SOEs are likely to remain key players in China's economy. Encouraging them to adopt strategies that are aligned with China's overall climate goals will thus be important. A number of state-owned Chinese companies, including large oil and energy players, are already developing carbon emissions reduction plans with the aim of achieving the target before 2030. Moving into implementation, SOEs and their shareholders could identify and adopt specific targets to support national climate-related goals. Adopting carbon accounting and monitoring systems together with enhanced transparency and disclosure around climate-change-related practices, including the publication of SOE-specific climate objectives and performance as part of the SOE sector annual reporting, would help inform SOE corporate management as well as monitoring and oversight. SOEs could also be required to undertake climate risk screening, when appraising and approving an investment and financing, and to adopt green procurement policies to encourage low-carbon supply chains.

42 Estimating the share of SOEs is challenging because statistics are not released by ownership status. See Zhang (2019) (link) or Lin et al. (2020) (link) for estimates and discussion.

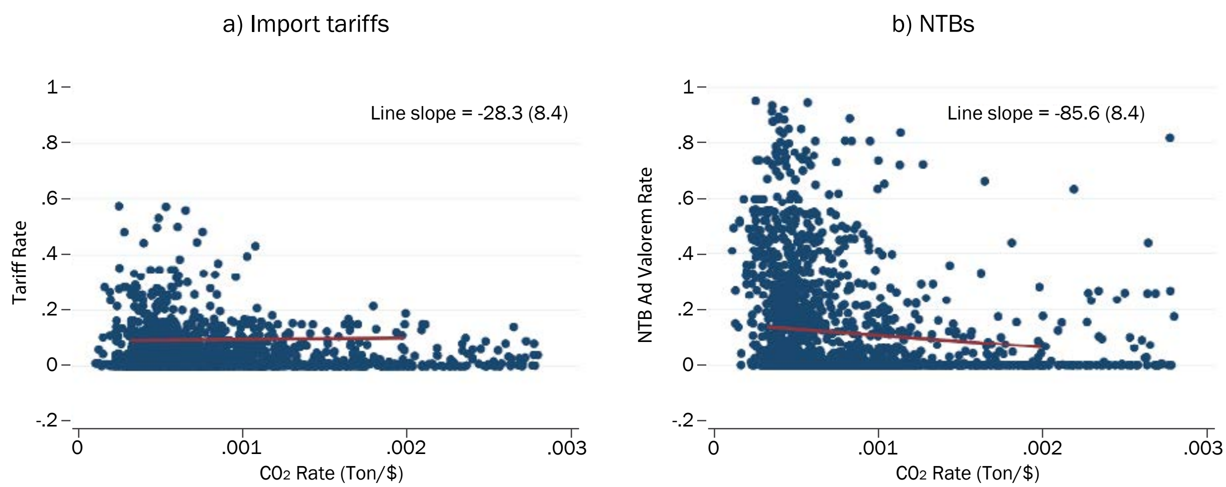
- **Strengthen insolvency and corporate restructuring frameworks.** These would be critical to manage stranded assets, facilitate orderly and efficient market-based market exit, and reduce excess capacities, while ensuring financial markets start to adequately price regulatory transition risks.

3. Level trade costs for low-carbon production

Like elsewhere in the world, there are implicit trade policy distortions that favor trade in high-carbon products. Analysis for this report demonstrates that China's Non-Tariff Barriers (NTBs) and import tariffs are on average higher on lower-carbon products (Figure 29). This is estimated to result in an implicit subsidy on imports of high-carbon products equivalent to around $68 per ton of CO_2. This pattern of incentives that favor high-carbon products has started to change over the past decade. Since the announcement of the 30-60 targets, there has also been an increased discussion around changing the export and import tariff structure. In April 2021, the Customs Tariff Commission declared that it would scrap import tariffs on certain steel products and raw materials, increase export tariffs for iron and other products, and remove export rebates for certain steel products. This has been accompanied by further planned import tariff reforms in 2022. The country has also introduced eco-efficient industrial parks and green special economic zones in an attempt to boost low-carbon production. However, fewer than 5 percent of industrial parks were green certified in 2019 (WBG 2019).

Figure 29. Import tariffs and NTBs are higher on lower-carbon products

Correlation between carbon intensity and the value of import tariffs/NTBs



Source and Notes: World Bank calculations based upon Shapiro (2021. Each point is an industry, and CO_2 rate is total (direct+indirect) emissions measured from inverting an input-output table. The solid red line is the linear trend. Each graph excludes the top 1 percent of CO_2 rates, tariffs, and the NTB rate. Standard errors are clustered by industry.

What we recommend

- **Review and revise NTBs, export promotion, and investment incentives to level the playing field for low-carbon production.** In addition to the existing planned tariff reforms to reduce the incentive to export high-carbon goods, NTBs could be reviewed to identify critical high-carbon product groups that are implicitly being subsidized or low-carbon supply chains that are being negatively affected. A new framework to monitor and reduce the use of industrial policy incentives that implicitly benefits higher-carbon industries will be needed. On the other side of the coin, further fiscal and financial support to promote and develop eco-industrial parks could further reorient incentives in favor of lower carbon production.

4. Strengthen low-carbon innovation policy

Innovation policy will also play a critical role in the low-carbon transition by resolving market failures that can lead to underinvestment in low-carbon technologies. These market failures include knowledge spillovers from innovation that are not taken into account by private firms; path dependency of research, which gives established technologies an advantage and creates entry barriers due to economies of scale; sunk costs; and network effects. They also include difficulties in accessing financing for emerging technologies due to high uncertainty/risk, a long lag until innovation pays off, and lack of knowledge and information among investors (Stiglitz et al. 2014, Acemoglu et al. 2016, Aghion et al. 2016). Global evidence suggests that targeted innovation policies such as feed-in tariffs for low-carbon products have more significant impacts on low-carbon innovation than rising energy and carbon prices, which tend to have more incremental impacts within existing firms (Grubb et al. 2021).

China has mobilized immense resources for low-carbon R&D investment, fueling rapid growth in low-carbon technologies and intellectual property. China accounted for 24 percent of global energy R&D spending in 2019, with growth of 70 percent relative to 2015. China's start-ups have attracted more than one-third of global early-stage energy venture capital over the past five years, according to the IEA (2021). China has also seen rapid growth in climate-related patenting over the past decade, as discussed in Chapter 2, mirroring the country's overall growth in innovation activity. Patenting has been particularly strong in low-carbon information and communication technologies, buildings, and solar. However, in terms of high-value low-carbon inventions patented in two or more patent offices, performance has been more moderate, with China remaining well below Japan, the US, and Germany. Low-carbon patenting also represents only a small share of total patenting, at 5 percent of inventions, compared with twice that percentage for most industrialized countries (Glachant and Touboul 2021).

To stimulate the wide range of low-carbon technologies needed to reduce carbon emissions, China will need to prioritize further reforms to the innovation system to reduce distortions, accelerate diffusion, and foster discovery. During the past decade, China has made reforms to national innovation policy a priority, with success in several technological fields, but some reforms remain incomplete. There is evidence that innovation inputs in China do not consistently translate into successful technology innovation outputs (Kennedy 2017). State-led R&D investment tends to exhibit a bias toward large SOEs and incumbents. In contrast, global evidence has shown that new entrants are more likely to pursue disruptive technologies, so renewed efforts will be needed across a wide range of reform areas to enhance and support entry of new firms. Reforms to enhance the innovation system will be even more important for the successful development of far-from-market low-carbon technologies—like carbon capture and storage (CCS) and nuclear and green hydrogen. Historically, China's innovation policy has been particularly successful in manufacturing-oriented technologies and cost-based competition among producers that commoditize and drive down manufacturing costs of existing technologies. Future carbon neutral technologies, like CCS and nuclear and green hydrogen, differ from wind, solar, and storage. They have been described as "complex product systems," which will require more design-intensive and breakthrough innovation (Roy et al. 2021).

China will also need to ensure that industrial policies support innovation and do not hinder it. The joint Development Research Centre (DRC) and World Bank Innovative China report in 2019 identified several ways in which China can support innovation and productivity growth, which remain more relevant than ever for the net-zero transition. A key message is that for industrial policies to be effective, they have to be less distortionary and support and complement market competition. Industrial policies are less effective when they undermine open and fair market competition, when markets are protected, and favored firms benefit from targeted support. It will be crucial to streamline industrial policies, improve government-industry dialogue and monitoring of industrial policies, instill greater discipline in local governments' policies to ensure that all types of businesses can enjoy equal support for low-carbon innovation, and ensure the timely exit of nonviable firms.

What we recommend

To improve innovation for the low carbon transition, the following could be considered:

- **Pursue further reforms to the innovation system and move from quantity to quality of research and patenting.** Increase transparency and strengthen evaluation of research, making greater use of objective peer reviewing; reward high-quality, rather than high-output, research; and redirect public support to high-quality domestic and international patents. Particular focus could be given to potential breakthrough technologies that are currently at the prototype stage. There will also need to be a focus on improving the private sector's R&D access and spending and leveling the playing field between SOEs and the private sector in receiving innovation support.
- **Develop an enhanced, coordinated approach to far-from-market technologies.** Foster interministerial and interprovincial coordination for far-from-market technologies to bring together different stakeholders and generate knowledge spillovers.
- **Upgrade support for early-stage green innovation, especially for start-ups.** Consider upgrading an existing institution to centralize financing for enterprise green innovation. Enhance support of ecosystems and expand the network of incubators organized around existing science and technology parks, with links to existing businesses and professional networks.
- **Provide greater support for facilitating diffusion of energy-efficient technologies.** Develop a nationwide and/or provincial system for helping small-to-medium-size enterprises (SMEs) to deploy energy-efficient technologies. Use public procurement to create markets for innovative green products and technologies, especially for SMEs. Enhance targeted support and incentives for energy-efficient technologies.
- **Promote a more open and globally integrated green innovation system.** The urgency of the climate challenge necessitates global cooperation on innovation. It will be essential to expand support for international cooperation in research and patents on green innovation, including by engaging international researchers and companies in government-funded green innovation projects. Expand support for interfirm and business–science cooperation in research and patents.

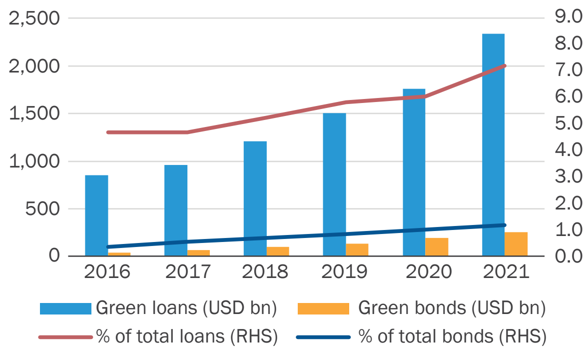
3.5.2. Green finance

China has a large financial system that holds great potential to support its decarbonization goals. With a high domestic savings rate and a large financial system equivalent to over four times its GDP, China can mobilize a substantial amount of commercial capital and reorient it toward sectors that are most in need. Financing from domestic policy financial institutions can help unlock further commercial capital, while insurance can increase household and business resilience against climate-related risks.

Marked progress has been made in the past decade to establish a green financial system. At the end of 2021, the outstanding green loans of major Chinese banks reached US$2.3 trillion, up from US$0.85 trillion in 2016, while outstanding green bonds increased to US$254 billion from US$37.6 billion. Despite this rapid growth, green assets still account for only a fraction of China's financial market, with green loans and bonds making up about 8 percent and 1 percent, respectively, of the total (Figure 30). Green equity markets, especially for early-stage risk capital necessary to spur innovation, remain shallow. The banking and capital market authorities have devised a host of measures to create new markets (such as green bonds) and guide financial institutions toward climate-friendly financing. New instruments, such as sustainability-linked bonds and sustainability-labeled investment products, have also emerged. Important standards, such as the green project taxonomy, have been developed and updated to reflect the latest international consensus.

Figure 30. Green-labeled loans nearly tripled between 2016 and 2021

Growth in green financial markets



Source: CBIRC, PBC, Wind Info

However, the financial system faces significant challenges in delivering commercial financing, given the sizable green investment demand, particularly to the energy sector and early-stage ventures. As noted above, the power sector and transport infrastructures alone would require between US$14-17 trillion worth of additional investments in 2020–60, or 1.14 percent of GDP. Other studies suggest the total financing gap till 2060 could amount to US$7 trillion (CICC 2022; Ma et al. 2019, 2020). The energy sector, particularly, presents the largest source of climate finance demand, but it has experienced consistently large financing gaps. For example, to support clean power generation, energy storage, and grid investments, the electricity industry is estimated to require 49 percent of total net-zero financing.[43] However, less than 28 percent of green loans and bonds go to clean energy and power sectors currently. Breakthroughs and commercialization of climate technologies will be central to China's decarbonization success, but the necessary early-stage risk financing is critically lacking. At the same time, private equity and venture capital (PEVC) investments in climate-tech remain small: in 2021, only US$8.7 billion worth of PEVC financing went to cleantech sectors, which is less than 4 percent of the market total.[44] The share of seed stage and Series A capital was even lower.[45] The system faces the following five critical challenges:

First, carbon accounting infrastructure is lacking, while the risk of greenwashing is high, as regulatory frameworks for climate-related disclosure and the audit and assurance market are yet to be formulated. Reliable and accessible corporate emissions information is critical for the proper functioning of climate financial markets. Despite past efforts by the NDRC and the Ministry of Ecology and Environment (MEE), existing corporate emissions data is fragmented, rarely verified, hard to access, and hard to use due to the lack of standardization. Under the MEE's new policy, disclosure of carbon emissions will be mandatory for more clearly defined groups of enterprises, but the scope of reporting is still limited.[46] Clear specifications on carbon accounting methodologies, as well as arrangements for data quality control, access, and sharing with commercial entities and other government agencies, are lacking. The existing data on green loans and

43 According to China International Capital Corporation Ltd. (CICC) estimates, the transport sector has the second largest financing need, equivalent to US$5.9 trillion in 2020–60, or 2 percent of total net-zero financing, followed by the building sector (US$3.5 trillion, 16 percent), industrials (US$1.3 trillion, 6 percent), and agriculture (US$0.6 trillion, 3 percent).

44 Based on Zero2IPO data (link).

45 Asset Management Association of China (AMAC) data in 2019 shows PEVCs allocate 36–42 percent of raised funding to seed and start-up-stage companies.

46 Administrative Measures of Enterprise Environmental Information Disclosure (MEE No. 24 2021). Only enterprises that are subject to the MEE's mandatory clean production audits, heavy polluters, publicly listed companies, and corporate debt issuers that received environmental protection penalties in the previous year are included.

sustainability-labeled investment products are self-reported and subject to limited scrutiny, meaning the risk of greenwashing is high. Even though the reporting level of green bonds is high, the reporting quality is low, as compared to other countries (CBI 2021). Meanwhile, the environmental audit and assurance industry is yet to be properly regulated. Existing service providers vary in qualification, service quality, appraisal process, and methodologies.

Second, partially as a result, financial institutions are yet to factor climate-related risks into portfolio management. Commendable initial steps have been taken to carry out climate stress tests among major banks and to pilot financial institution environment-related regulatory reporting. But climate-related financial risks are yet to be integrated into financial institutions' risk management, governance, and financial decision-making, while initial high-level analysis shows that 29.4 percent of bank loans (US$6.8 trillion), 43 percent of corporate bonds (US$3.9 trillion), and 30.4 percent of stocks by capitalization (US$4.7 trillion)[47] could be exposed to adverse impact under a disorderly transition scenario and 39.3 percent of lending (US$9.1 trillion) could be exposed to physical risk perils through flood and tropical cyclone damages.[48]

Third, China is yet to fully harness financial product innovations for the transition. Green loans account for about 95 percent of total green financing (Lan 2021). Despite market expansion, the share of bond financing remains small. Moreover, there is a significant shortfall of equity financing. Green equity funding, including from private and public markets, remains very limited and accounts for only 3 percent of total green-labeled financing (Lan 2021). In addition, the boundary for policy and commercial lending is often blurred. Contrary to principles of crowd-in and additionality, policy banks sometimes end up competing with commercial banks.[49] Finally, financial product innovations are lacking. Sustainability-linked bonds were inaugurated in 2021 but authorized in a subsegment of the bond market only. Lacking authorization and regulatory guidance, similar instruments for banking sector and other financial markets do not exist. Carbon derivatives have not been applied to the national ETS,[50] although they can increase market liquidity and facilitate better price discovery.

Fourth, commercial banks and credit markets favor SOEs, even though private firms are more productive in low-carbon transformation. As noted above, private firms exhibit significant higher levels of productivity in key decarbonization sectors, but their access to green credit is limited: most renewable energy bank lending has gone to SOEs, which also received more long-term financing than private firms.[51] Private issuers have become an increasingly marginal group in the green bond market, accounting for only 3.3 percent of issuances and 1.6 percent of total bonds value in 2021.

Fifth, state investors also dominate private equity markets, lowering efficiency of capital deployment. State capital to PEVC funds—mainly from SOEs and Government Guidance Funds—rose rapidly in recent years, becoming the largest source of PEVC funding.[52] Yet the use of SOE and guidance fund capital is often subject to administrative reviews and audits, requirements to preserve and appreciate state assets, and geographic and industry restrictions, which tend to slow capital deployment and result in suboptimal investments. As noted above, state capital thus favors expansion—and mature-stage companies—which

47 Using the Battiston et al. (2017) classification of Climate Policy Relevant Sectors (CPRS).

48 The characterization of physical financial risk here is geography based and describes the impact on outstanding loans only, due to limited available data for other asset classes with geographic breakdowns.

49 China's policy banks have been large green credit providers. China Development Bank is the largest green lender among all 24 major banks, whose outstanding green loans accounted for about 15.5 percent of total outstanding green loans in 2021.

50 This is in part because financial institutions cannot participate in the carbon market for the time being. Legal ambiguity around the nature of carbon credit—whether it qualifies for security—could be another reason.

51 SOEs are estimated to have received 79 percent of total bank lending for renewable energy projects and 61 percent more long-term loans (over 10 years) in value terms than unlisted private borrowers (Bloomberg Finance L.P. 2021).

52 Including in forms of SOE subsidiaries, local government investment platforms, and government-guided fund of funds. State capital in total makes up about 40 percent of funds raised in 2020, according to Zero2IPO data.

is unconducive to climate technological innovations and can crowd out commercial financing. Despite regulatory encouragements, participation of domestic institutional investors (such as life insurers and pension funds) remains limited in recent years,[53] accounting for 5.5 percent of total funds raised in 2021. Lacking experience and expertise, these investors remain highly cautious of PEVC investments in general and of early-stage ventures in particular.[54]

What we recommend

- **Establish a high-quality corporate emissions accounting system.** The authorities could start by targeting large enterprises and requiring mandatory reporting on corporate GHG emissions with external assurance.[55] Existing technical specifications on carbon accounting could be expanded and standardized with appropriate exceptions and simplifications to avoid overburdening SMEs. Capital market authorities could also consider imposing enhanced disclosure requirements for public companies, especially those operating in high-transition risk industries. Material climate effects could be reflected in financial statements, following applicable accounting standards. The carbon accounting system could then be made accessible to a wide range of financial institutions and interoperable with existing financial sector databases.
- **Mandate climate-related financial reporting and enhance market conduct supervision.** Large banks, insurance companies, investment funds, and asset managers should be encouraged to account for financed emissions,[56] for regulatory reporting and/or public disclosure purposes. Financial authorities should set clear regulatory expectations with respect to indicators and metrics, methodologies, and mandatory assurance. Regulation of assurance and audit market should be formalized, to provide clarity on market entry and qualification requirement of service providers. Scrutiny over climate- and sustainability-labeled financial product offerings should be increased to safeguard integrity of green finance markets.
- **Integrate bottom-up climate scenario analysis into prudential supervision.** Building on ongoing climate stress testing, financial sector authorities could consider carrying out additional bottom-up climate scenario analysis, possibly among domestic systematically important banks and insurers. Guiding tools such as data templates and qualitative questionnaires could be considered, while financial institutions gain experience and build capacity. Such an exercise, together with other top-down analysis, should be regularized over time and become part of climate-related prudential supervisory tools.
- **Use blended finance to mobilize commercial capital for underfinanced climate ventures and sectors.** Financial sector authorities could explore ways to unlock the catalytic function of available concessional finance, including from domestic policy banks, public capital, donor and philanthropic funds, and international development financial institutions. Given the significant shortfall of early-stage climate financing, supervisors of the investment fund industry (the China Securities Regulatory Commission [CSRC] and the Asset Management Association of China [AMAC]) may want to add blended finance to their work priorities, authorize pilots, and devise regulatory measures.

53 It should be noted that commercial banks and insurance companies had been large PEVC funding sources in the past. But in context of shadow banking crackdown and asset management market reforms, the share of financial institution funding shrank from about 35 percent in 2016 to about 10 percent in 2020, according to Zero2IPO data.

54 According to Zero2IPO, insurance companies allocated only about 5 percent of assets to private equity (PE) deals in the first three quarters of 2021; the share of capital allocated to early-stage firms was only 0.4 percent.

55 It should be noted this effort will be in synergy with the authorities' ongoing work to expand the national carbon market, which also requires reliable statistics from companies in key industries and credible MRV schemes.

56 Accounting-financed carbon avoidance and removals could be a possible next step.

- **Tighter scrutiny should be applied to guidance funds, whereas market access by foreign institutional investors could be relaxed.** Relevant authorities should significantly tighten conditions for establishing new guidance funds and implement additionality requirements for existing funds. Financial sector authorities should explore ways to increase participation of commercial institutional capital. Even though domestic insurers and asset management firms gain experience in the PEVC market, authorities should consider relaxing market access for foreign institutional investors, especially those that demonstrate good climate investing records. Numerous local pilots of the Qualified Foreign Limited Partner (QFLP) program could be converted into a national scheme, with a streamlined approval process and larger quota.
- **A more active and coordinated policy approach is needed to bring about useful climate finance innovations.** The authorities should seek to address fundamental bottlenecks (such as legal status of carbon assets) that preclude climate financial innovations and actively establish regulatory frameworks for new products such as sustainability-linked instruments for transition financing. The authorities should also strengthen coordination among themselves, given the still segmented bond market and sometimes overlapping green finance mandates between the banking regulator and the central bank. Collaboration with other line ministries for important financial products that embody a more cross-sector nature, such as disaster risk insurance and carbon derivatives, should also be actively sought.
- **Accelerate broader financial sector reforms.** In addition to addressing the unique challenges of green finance, the authorities should accelerate financial sector reforms that will improve capital allocation across the board, particularly eliminating implicit guarantees in financing and setting a clear boundary between policy and commercial lending. Overall, the financial sector authorities should take a systematic view toward climate finance policymaking and reinforce it with ongoing financial sector reforms.
- **Green finance reforms would support both adaptation and mitigation.** Improved accounting of emissions and assessment of climate risks is key to allowing markets to signal adjustment needs and ensuring risks are properly priced. Green finance reforms would thus serve both China's mitigation and adaptation needs.

3.4.3. Ensuring a just transition

The low-carbon transition will have distributional implications. Households will be affected through several channels. Rising energy prices—either because of explicit carbon pricing or regulations—will affect household consumption, with poorer households often less able to adjust and substitute into lower-carbon alternatives. Households will also be affected by changes in the labor market, with some experiencing job losses and transitions, and positive or negative impacts on their wages and other sources of income. The specific policies adopted also matter. As discussed in section 3.5.1, carbon revenues could be recycled to mitigate some of these impacts through compensation to households through transfers, with an expanded social safety net that is able to effectively cover vulnerable households.

Rough estimates illustrate that between 10 to 15 percent of China's workforce may be employed in high-carbon-intensive industries.[57] Most of the high-carbon jobs are concentrated in mining, energy, manufacturing, and transport, with an important role for informal employment. Many of the jobs have relatively low skill intensity. Employment in these industries has been declining over the past five years, while employment in low-carbon industries has been rising to more than offset the losses. The number of green jobs in China was about 54.42 million in 2015.[58] Around a third of green jobs are in transport, and over a fifth in manufacturing. Green jobs are more concentrated in coastal areas. Among the provinces in mainland China, Shandong, Jiangsu, and Guangdong stand out for the absolute number of green jobs in

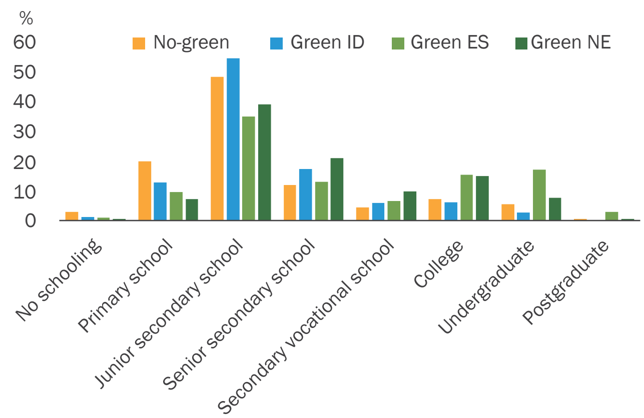
57 The analysis is using the 3-digit industry code and carbon-intensity data from the UK. Excluding agriculture, 432 subindustries in China are classified into five groups: extremely high, high, medium, low, and extremely low in carbon intensity.

58 Using China's occupational classification and the O*NET definition of green jobs.

2015. Green jobs tend to have higher human capital requirements with important implications for education and skills development. In 2015, the proportion of green jobs requiring a college degree or above was 15.7 percent, compared to 13.3 percent for the nongreen jobs (Figure 31).

Figure 31. Currently workers in green jobs have higher educational attainment than in nongreen jobs

Educational attainment by job type in 2015



*Source and Notes: The 2015 National Sample Survey of 1 percent of the population. Green jobs defined using the O*NET classification.*

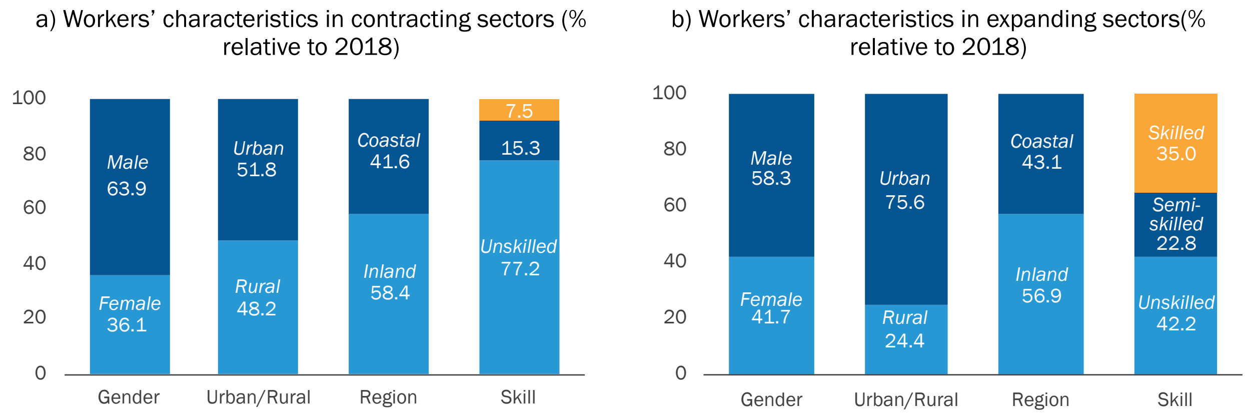
Achieving carbon neutrality will require a sizable labor market transition. Of course, not all high-carbon jobs will be lost but many will be subject to changing technologies and hence skill requirements. Employment estimates from the macroeconomic modeling provided above demonstrated that, although job gains are predicted to outweigh job losses due to the relatively low labor intensity of high-carbon sectors, the job gains are likely to be in different sectors, occupations, and regions. The macroeconomic simulations suggest that the energy transition would lead to an employment decline of around 600 thousand workers in the coal industry between 2019 and 2030. This is on top of the estimated 2 million jobs that would be lost merely by continuing existing energy policies. This is broadly consistent with the IEA's (2021) modeling estimates of declines of 1.6 to 1.9 million workers.

Male low-skilled workers in rural interior provinces are particularly at risk. Based upon China's current employment structure and on the CGE model's Scenario 1, relative to 2018, 77 percent of job losses are concentrated among the lower skilled, 58 percent in China's inland provinces, and 64 percent would affect men. Job gains would take place in sectors that require predominantly high-skilled or semiskilled labor (Figure 32). Net job gains are larger in urban coastal areas whereas rural areas in interior provinces experience net job losses. The low-carbon transition would result in an estimated 52 million additional high-skilled jobs by 2030, highlighting the challenge of upskilling the labor force. Other modeling estimates, such as those by Della Vigna et al. (2021), suggest even greater job gains in areas like renewable electricity generation, power networks, electric vehicles and their infrastructure, copper, batteries, and biofuels.[59]

59 Della Vigna et al. (2021), Carbonomics China Net Zero: The Clean Tech Revolution. (link)

Figure 32. Job losses will disproportionately affect lower-skilled men, working inland, whereas job gains are more likely to be in urban, skilled jobs in coastal regions

Distribution of jobs lost and gained in CGE NDC Scenario 1 relative to 2018, holding job characteristics fixed



Source and Notes: World Bank calculations based upon CGE modeling results 2030 relative to 2018, combined with average sector characteristics based upon 2018 China Family Panel Survey household survey data. Sector characteristics are held fixed at their 2018 levels.

The geographic concentration of the economic and social impacts of the coal exit will require special attention. Three provinces alone account for two-thirds of direct coal sector jobs.[60] To achieve carbon neutrality before 2060, China's transition away from coal will have to happen at a scale and pace that is historically unprecedented. Even though rapid progress in the development of cost-effective, low-carbon energy technologies has made a faster energy transition technologically and economically feasible, the social and economic transition risks of the coal phase-down will nevertheless need to be carefully managed. Although China's coal sector is small in relative employment size, like elsewhere in the world, China's coal regions are characterized by heavily specialized, often mono-industrial economic structures and are reliant on coal-intensive value chains for employment, income, and fiscal revenues. Even within provinces, coal mining jobs are often in geographically isolated places, and in communities with a strong sense of coal identity. Experience suggests that concentrated job and financial losses can have long-lasting impacts on local economies and communities if broad and forward-looking measures are not taken to soften the labor market, financial, and social impacts of the transition; assist workers to move to new opportunities; and provide other forms of growth, employment, and revenues in affected communities.[61]

Targeted place-based interventions, education policy, retraining, flexible labor markets, and social security are critical components of enabling a just transition. Many workers will need to move to new opportunities, meaning that policies that enable greater labor mobility across regions, sectors, and occupations and from rural to urban areas can reduce the negative impacts felt by workers in contracting firms and industries. A labor force with strong foundational and transferrable skills will be able to more readily adapt to evolving skills demand, while retraining programs, vocational education, and lifelong learning could mitigate losses to older individuals who lack the skill sets required to obtain jobs in expanding industries. In addition, strong social security systems with portable benefits will need to support labor market reallocations and protect workers in declining industries.

60 He et al. (2020), "Enabling a Rapid and Just Transition Away From Coal in China" (link).

61 The potential risks are well illustrated by Britain's coal phase-out in the 1980s, whereas by contrast, the Dutch 10-year coal phase-out case shows that well-planned coal transitions that include support for—and receive support from—workers, unions, and affected communities can go relatively smoothly and without long-term adverse impacts.

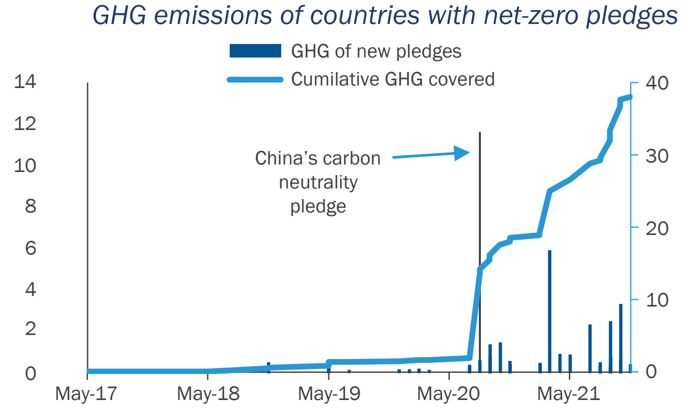
What we recommend

- **Continue deepening labor market policy and hukou reforms to enhance labor mobility and advance labor market integration.** The hukou system still creates barriers for migration to large municipalities and megacities. Most social safety nets are fragmented, and benefits are not portable. Therefore, further labor market policy and hukou reforms, including pooling social insurance schemes and creating portable benefits, could not only facilitate the green and low-carbon transition but also bring multiple benefits to the economy and society.
- **Develop a comprehensive and coordinated labor market policy package**, including (i) compensation and income support measures for laid-off workers and their families; and (ii) active labor market programs such as public employment services, training, re-skilling, and entrepreneurship to help re-employment of laid-off workers.
- **Targeted place-based support and investment, focusing on economic growth, diversification, and regeneration in coal regions.** Although it will be important to improve labor mobility and enable workers to transition to growing areas of the economy, it will also be essential to concurrently focus on boosting the economies of coal regions to ensure they are not left behind. Diversifying the economies of these regions through policies that promote regional growth and regeneration could play an important role. Investments to improve livability and natural environment of coal regions could be part of this. Temporary subsidies and/or tax incentives could be provided to attract new businesses and help galvanize private investments in industrial repurposing. As subnational revenues will be constrained by economic restructuring, mobilizing national fiscal support through additional intergovernmental transfers will be required to ensure sustainable financing of basic public services and social support, including assistance to workers affected by job losses.
- **Develop a green-skills strategy and pathway to mainstream green skills into training and education for green jobs.** Increased investment in green technologies will also bring opportunities for job creation. To meet the increasing demand of green skills for green jobs, the government should revisit its skills development strategies and systems and work with schools, training institutions, employers, and workers to incorporate green skills into the relevant programs, particularly in the technical and vocational education and training (TVET) programs. This retooling should include modular and competency-based curricula/training materials in training and re-skilling programs and promote life-long learning for the workforce to learn the skills required in green jobs through on-the-job training or in-service training and apprenticeship.

3.6. External policies for a carbon neutral global economy

China can play an important role in steering global climate coordination. There is no viable path for the world to stay within the 1.5C (2.7 F) degrees warming limit without decarbonization in China. In addition to direct contributions to emissions reduction, the actions of large emitters, like China, can also strategically influence the decisions of other countries, by altering expectations over potential positive future climate outcomes and optimal choices for other countries (Box 9). This strategic importance of China's decisions was demonstrated by China's carbon neutrality pledge in September 2020. China's pledge was followed by a wave of new pledges in other countries, with the share of global GHG emissions covered by a net-zero pledge reaching almost half of the global total (Figure 33).

Figure 33. China has unique potential to influence the climate policy choices of other countries and shift global prices



Source and Notes: a) World Bank calculations using NetZeroTracker data. This includes the pledges of the world's top 40 largest economies only. b) WITS and Our World in Data.

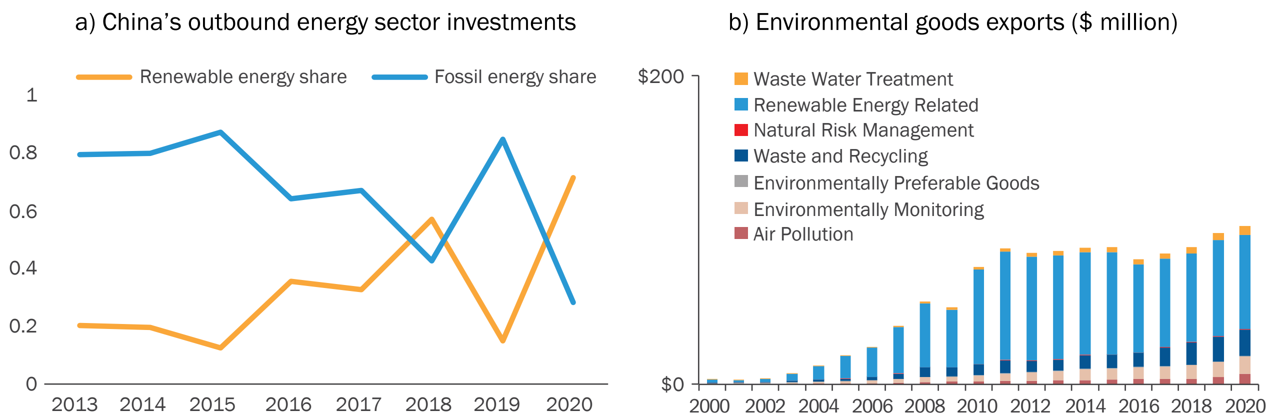
Note: Solar panels trade data are sum of HS854140 (solar cells) and HS901380 (solar heliostats).

Beyond the strategic impact of China's climate action for global coordination, China is also large enough to shift the relative prices of fossil fuels and low-carbon alternatives, altering abatement costs for other countries. China is already the largest export destination for 120 countries globally. On the consumption side, China's low-carbon transition will change the composition of the country's imports, with a shift in demand from fossil fuels and carbon-intensive value chains to lower-carbon ones. This has direct negative implications for countries exporting fossil fuels; China is the world's largest importer of coal, oil, and natural gas, with 7, 72, and 42 percent of China's supply in 2019 coming from imports, respectively. Global nuclear, hydroelectricity, and renewables markets and exporters of environmental products to China, on the other hand, are clear beneficiaries of China's climate action. Indeed, China's imports of environmental goods increased by 15 percent annually from 2000 to 2020, according to World Integrated Trade Solution (WITS) data. Della Vigna et al. (2021) estimate that electrification and clean energy will also raise Chinese demand for aluminum, copper, lithium, and nickel by 8 to 32 percent annually between 2019 and 2060.

China is already a leader in terms of green export competitiveness, and expanded production of low-carbon technologies could create new global trade and investment opportunities. China ranked fifth on the Green Competitiveness Index in 2019, above Japan and Korea. China outperforms all advanced economies in terms of its Green Complexity Potential, an index that measures how much potential a country has to diversify into complex green technology products. China is also the leading downstream producer of key environmental goods like solar cells, wind turbines, and batteries for electric vehicles. In the solar value chain, China dominates upstream production, producing around 70 percent of the world's solar panels, and accounts for more than 50 percent of wind turbine suppliers. Lastly, China has the largest production capacity for lithium-ion batteries of electric vehicles, accounting for 70 percent of global capacity by the end of 2020 (IEA 2020b).

As a large and growing consumer market, China's import demand also has major climate ramifications. For example, it has been shown that 29 to 39 percent of tropical deforestation-related carbon emissions have been driven by international trade of agricultural commodities, particularly beef and oilseed exports (Pendrill et al. 2019). In major producing countries such as Brazil and Indonesia, the loss of tree cover in the last two decades is closely linked to the production of these commodities (oil palm and pulp and paper in Indonesia; beef and soybeans in Brazil). China is now the world's largest single country importer of soy, beef, and timber, and China's imports of agricultural commodities have been shown to induce deforestation in producer countries (WWF 2021). Data from Pendrill et al. (2020) shows that over three-quarters of China's trade-related deforestation was linked to soy and beef products from Brazil. Steps such as the joint US-China pledge to ban imports emanating from illegal deforestation in November 2021 and China's revised Forest Law in July 2020, which requires Chinese firms to trace their timber to a legal source, are pushing forward this agenda. However, strict enforcement of the Forest Law, with clarity on covering imported timber, along with stepped-up ambition on other commodities, could catalyze positive change to halt deforestation and biodiversity loss across the global economy.

Figure 34. China can also shift global abatement costs and climate outcomes through its infrastructure financing and exports



Source and Notes: a) World Bank staff, based on data from AEI Investment tracker. Fossil includes investment in coal and oil and gas assets. Renewables include hydro, solar, wind, and alternative sources. b) WITS.

China is also a major outward investor, particularly in infrastructure, and can shape global climate outcomes through its investment portfolio. China provides more infrastructure finance to developing countries than any other country does, and China's past outward investment has been more brown than green, although that was starting to change in 2020 with China's growing comparative advantage in renewables (Figure 34a). In October 2021 China announced that the country will no longer build coal-fired power plants abroad, with the announcement being quickly followed by an announcement to halt funding for new coal mining and coal-fired power projects abroad by the Bank of China. This reflects the importance of China's influence over whether new infrastructure projects—power plants, pipelines, roads, railroads, and the like—built in developing countries are high-carbon or low-carbon and hence emissions trajectories not only at present but for decades to come. In addition, the country has also announced that it will step up support for other developing countries in developing green and low-carbon energy. However, beyond these initial recent steps, there is more that could be done to decarbonize China's foreign infrastructure finance portfolio.

Box 7. The potential impacts of global climate policy action on China's economy

In addition to China's impacts on the world economy, mitigation efforts by China's trading partners could also have sizable ramifications for China's economy. For instance, the EU's Green Deal aims to cut the block's carbon emissions by 55 percent in 2030 relative to 1990 levels (the FIT for 55 package), and the EU is one of China's largest export destinations. To complement the Green Deal, the EU also intends to add a Carbon Border Adjustment Mechanism (CBAM), where EU imports of specific products included on the EU's Emissions Trading Scheme (ETS) become subject to a carbon tax. To understand the prospective impacts of global climate action on China's economy, this report has modeled three scenarios: an "NDC" scenario where signatory countries of the Paris Accord implement carbon pricing policies to reach their NDC commitments (this includes the EU's initial NDC target); an "EU Green Deal" scenario where the EU achieves the 55 percent decline in emissions using carbon pricing; and a "CBAM" scenario on top of the EU Green Deal, with a tax on EU imports equivalent to the difference between the carbon price in the EU and the carbon price of the import destination, on all EU ETS sectors. Scenarios are modeled using the global ENVISAGE CGE model following Chepeliev et al. (2022). The NDC scenario is used as a reference, and impacts of the more ambitious mitigation action by the EU, as well as implications of the EU CBAM scenario, are measured relative to this reference path.

The aggregate impact of the implementation of these EU climate policies on China's output, trade, and real income by 2030 may be relatively small, but the impacts on specific industries could be substantial. The combination of these measures could lower China's real income by around 0.07 percent, relative to the baseline, by 2030. This decline of real income for China would mostly be the outcome of the more ambitious EU mitigation efforts, which could result in a 0.05 percent drop in real income, whereas the EU CBAM results in a 0.02 percent decline. More stringent EU climate mitigation combined with border carbon adjustments would result in a declining demand for energy intensive goods produced in China. Exports of chemicals, nonmetallic minerals, and wood products could all decline substantially—in a range of 4 to 8 percent. This would translate to the reductions in domestic production by 0.2 to 0.7 percent across listed commodity groups.

Some Chinese producers could benefit from global climate policies. More ambitious climate mitigation efforts would alter the composition of global demand and trade patterns. Although adversely impacting demand for fossil fuels and energy-intensive commodities, stringent climate policies would shift global trade toward services and light manufacturing goods, such as electronics. For instance, expansion of renewable energy generation in the EU would result in rising demand for Chinese-produced solar panels and wind turbines, while further electrification of the transport sector would boost demand for EV batteries and other parts. As a result, Chinese exports of electronics, motor vehicles and parts, and other manufactured goods could increase by 0.3 to 0.8 percent, translating into a 0.3 to 0.4 percent increase in output for these sectors. Global climate policy efforts would also boost integration of these high-valued commodities into global value chains (GVCs). Estimates suggest that EU climate mitigation efforts combined with the CBAM policies could increase GVC participation rates for Chinese electronics, motor vehicles and parts, and other manufactured goods by around 0.2 percent.

What we recommend

- **Strengthen measures to encourage sustainable production patterns and reduce the import of commodities that are illegally harvested in their country of origin, particularly beef, soy, and timber.** This could build upon the provision regarding the legality of timber in the latest revision of the Forest Law and gradually expand to cover other commodities. Strict enforcement of the Forest Law, and clarification on its application to imported timber, could provide a strong signal on the importance of such regulations. The Chinese government could also incorporate measures to mitigate the deforestation effects of commodity imports in bilateral and multilateral trade agreements. In addition, the State-owned Assets Supervision and Administration Commission (SASAC) could also mandate SOEs to assure the sustainability of the commodities they buy.
- **Create stricter rules for outward foreign finance**: Wider mandates beyond coal, to other types of foreign infrastructure investment, could extend this further. Information disclosure and guidance on standards would also be important. Chinese authorities have been moving to compel companies to disclose more clearly the environmental impacts of their domestic investments; rules compelling corporate disclosure of the environmental effects and carbon footprint of overseas investments would be a valuable extension, along with guidelines on environmental standards and carbon footprints more broadly.
- **Assist other developing economies with low-carbon projects**: China could take steps to encourage developing economies in which it finances infrastructure to opt for lower-carbon projects.Technical assistance using China's own experience in ramping up renewable energy could help other countries forge a viable lower-carbon path and deepen markets for low-carbon technologies.
- **Conduct energy and financing policy reforms within China**: Reforms to China's domestic energy market, as discussed above, could improve incentives for China's dominant state-owned energy companies (along with new firms) to focus on lower-carbon endeavors in their overseas infrastructure investments. Domestic financing reforms could free up lower-cost capital for deployment domestically and abroad and incentivize borrowing specifically for low-carbon endeavors.

4.

Policy Pathways for resilience to a changing climate

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4. Policy Pathways for resilience to a changing climate

4.1. Climate risks and vulnerabilities

The previous chapter has analyzed China's mitigation policy options in some detail, given China's prominence in global emissions, but China's adaptation needs also require attention. Even with strong mitigation efforts, climate risks will remain in part because global climate outcomes will depend on the actions of other countries. Fortunately, in several areas, such as city planning, agricultural and land management practices, the development of green finance, nature-based solutions (NbS), and the creation of an offset market, and in building more resilient social protection systems, mitigation and adaptation actions are synergetic. This chapter highlights priorities for government action.

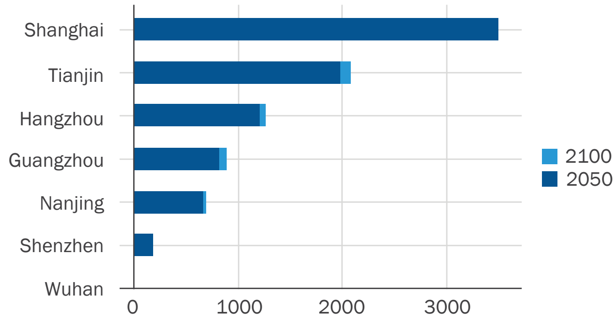
China is already experiencing rising temperatures as a result of climate change. From 1951 to 2020, China experienced a temperature rise of 0.26°C per decade, significantly higher than the global average (CMA 2021). The last 20 years have been the warmest years since the beginning of the 20th century, with 9 out of the 10 hottest years since 1900 occurring after 2000 (CMA 2021). The average temperature of 10.53°C in 2021 was the highest on record since 1951 and around 1°C higher than usual, based on calculations by the China Meteorological Administration (CMA) (CMA press release, 01/06/2022). In 2021, both average and highest temperatures in many cities were record-breaking, while the average number of hot days across China was second highest on record since 1961 (CMA press release, 01/06/2022).

Extreme weather events have become more widespread, intense, and frequent. From 1961 to 2020, average annual precipitations have also been increasing, at a rate of 5.1 mm/decade, while displaying significant regional differences (CMA 2021). During the same period, extreme precipitation events have been increasing. Moreover, extreme high temperature events have increased significantly since the mid-1990s, while the average intensity of typhoons landing in China has strengthened since the late 1990s (CMA 2021). In 2021, several climate events have broken historical records, including that for the highest average temperature and the highest rainfall, which occurred in Zhengzhou city of Henan province with catastrophic floods in 2021, and that for typhoon length (CMA press release, 01/06/2022).

Climate change is projected to pose significant further risks. Surface average temperatures are projected to rise to around 0.6°C to 8.7°C by the end of the century (World Bank Climate Change Knowledge Portal[62]). Overall annual precipitation is estimated to increase in the next several decades. From 2011 to 2100, the rate of precipitation increase is projected to be about 0.6 percent to 1.6 percent per decade which are higher than the global average (MEE 2018). Studies also predict that sea levels along the Chinese coast may rise between 52 cm to 109 cm on average, relative to 1986–2005 (Arnell et al. 2018). China's richest cities are in coastal areas, and many of them will likely witness the full scale of climate change impacts already by 2050, resulting in the immediate need to protect themselves from rising sea levels and the growing risk of floods, storms, and typhoons (Figure 35). By 2050, Shanghai is expected to have over 3,500 sq km of exposed settlements, which is almost the entire settlement area in the city. The story is nearly identical in other coastal cities, as well as in cities along the Yangtze River (Nanjing and Wuhan) that would nevertheless bear the consequences of sea-level rise.

62 https://climateknowledgeportal.worldbank.org/country/china/climate-data-projections.

Figure 35. Settlement area exposed to 10 percent annual chance of flooding, given median projected sea-level rise (sq km)



Note: The climate projections in this analysis are directly adapted from the Climate Change Knowledge Portal (CCKP), which computes a range of climate indicators using median values of multimodel ensembles derived from the sixth phase of the Coupled Model Intercomparison Project (CMIP6).

Source: City Resilience Program team (World Bank).

Shifts in climatic patterns will influence China's ecological systems in the 21st century. Spring phenology will occur earlier, and autumn phenology will be postponed, affecting the growth of plants. Distribution and coverage of wetlands in China will change, with a contraction of 60 percent of wetlands area under a low-emissions scenario and 86 percent under a high-emissions scenario in 2100, jeopardizing important functions of wetlands, such as carbon sequestration, water retention, and wildlife habitat (MEE 2015, 2018). The composition and structure of tree species in the forests will be altered, while the area suitable for afforestation with current prevalent species as well as rare tree and endangered species will shrink by more than 9 percent (MEE 2015). Climate models predict that the probability of fire occurrence would increase by around 80 to 99 percent and the burned area would increase by around 1700 km^2 per year by 2050 (CMCC 2021). In addition, the length of the forest fire season will be significantly prolonged under future climate change scenarios, adding costs to fire prevention and management.

Extreme weather events such as heat waves, floods, and droughts will become more frequent and severe. According to the World Bank (2021), if current climate trends continue, the median annual heat wave probability will be 5 to 22 percent by the end of the 21st century, up from 2 percent currently. Climate change is forecast to increase the fluvial flood risk, including flash flood risk, in China, as extreme precipitation events become more frequent and more intense. For example, by midcentury, the chance of a once-in-50-years extreme precipitation event may increase three to four times in parts of Western China (Woetzel et al. 2020). Overall, the average estimate of various climate models suggests that flood risk (risk of occurrence) in China will increase by about 10 percent by 2030 and 20 percent by 2100 (ADB 2015), which is going to cause damages to human lives, property, and infrastructure. Most parts of China are forecast to experience droughts with higher severity and frequency, as well as longer duration, by midcentury because of climate variability. Based on the 3rd National Assessment Report (2015), runoff in major Chinese river basins is going to decline by about 2 to 11 percent under different scenarios.

4.2. China's existing adaptation policy context

China's policy framework for adaptation follows a hierarchical system of "top-level design—national strategy—sectoral and local action" (Peng et al. 2015). The National Strategy on Addressing Climate Change 2014–2020, released by the State Council, sets the top-level design guidance on climate adaptation, which stipulates the objective to "substantially increase national climate adaption capacity." The National Strategy for Climate Change Adaptation, released in 2013, sets out the overall policy requirements for adaptation and priority tasks in key sectors such as infrastructure, agriculture, water resource management, marine and coastal zone management, human health, tourism, and other industries. Central ministries managing different sectors develop their sectoral strategies and technical guidance, while local governments and their subsidiary technical departments in relevant sectors issue local government work programs on climate adaptation. In June 2022, China released the National Strategy on Climate Adaptation 2035. A separate implementation plan is expected to complement the strategy.

Strategies and programs have also been put in place at the sectoral level, with progress made on increasing urban infrastructure resilience. All key ministries have either produced their respective sectoral strategies and programs on climate adaptation, or incorporated adaptation-related requirements in their regular sectoral programs. For example, adaptation in urban infrastructure has improved over time (Fu et al. 2021). The National Development and Reform Commission, the Ministry of Housing and Urban-Rural Development, and other line ministries released the Action Plan on Climate Change Adaptation in Urban Areas in 2016, clarifying the main action areas for adaptation in cities and proposing to select urban areas with climate representation to carry out pilots for climate-adaptive cities. The China Meteorological Administration, the leading ministry in climate science in China, has developed its work plan on continuously assessing and monitoring climate change impacts. Over the period of 2007–16, a total of 184 domestic climate-related policy documents (laws, policies, strategy, action plans, and white papers) have been issued, many of which include provisions on climate adaptation (Zhang et al. 2018).

4.3. Adaptation and resilience policy pathways

Despite progress in setting a national policy framework, there are opportunities to improve adaptation efforts both at the national and sector level. Adaptation policy gaps are analyzed following the framework provided in Hallegatte et al. 2020, which proposes six principles: (i) Foundations: rapid, robust, and inclusive development; (ii) Priority Area 1: facilitate the adaptation of people and firms; (iii) Priority Area 2: adapt land use plans and protect critical public assets and services; (iv) Priority Area 3: help firms and people manage residual risks and natural disasters; (v) Priority Area 4: manage financial and macrofiscal issues; and (vi) Application: prioritization, implementation, and monitoring progress. Using quantitative indicators, Figure 36 shows that China compares relatively well, relative to other BRICS countries, with respect to the foundations, and Priority Areas 1 and 4. It performs relatively worse with respect to Priority Area 3: helping firms and people manage residual risks. Using both quantitative and qualitative measures (the latter based on expert interviews), key gaps can be found in the application of adaptation principles (Figure 37). These include the lack of guidance and information for decision-makers at the local level, insufficient resource mobilization and monitoring, the lack of institutional coordination, and the lack of sector-specific guidance in highly vulnerable sectors such as agriculture and water.

4.3.1. Facilitate the adaptation capacity of people, firms, and local governments

China's adaptation policy landscape needs to be further strengthened. Coordination across institutions and levels of government could be enhanced to provide better information and incentives for private actors to prepare for and insure against the effects of a warming climate. Risk assessment reports are produced by separate agencies and in a scattered manner, hindering the ability of households, firms, and local governments to make effective decisions (Fu et al. 2021). Moreover, less than 10 percent of climate adaptation policies are developed and released as multi-agency efforts, indicating a fragmented sectoral approach (Zhang et al. 2018). In 2018, the Ministry of Ecology and Environment (MEE) took over from the National Development and Reform Committee (NDRC) as the lead agency on climate change. At the local level, the bureaus for ecology and environment have limited ability to guide or supervise local-level climate actions, as they are at the same hierarchical level as agencies reporting to other line ministries. The periodic reporting process, led by the MEE, relies on sectoral self-reporting and lacks coherent assessment criteria frameworks. An interministerial taskforce on climate adaptation might provide the necessary platform to strengthen cooperation. Issues of fragmentation and policy coordination are also present in climate mitigation, such as in urban planning or the development of NbS. The creation of an interministerial taskforce could aim to look at both policy areas comprehensively.

Figure 36. Adaptation principles in BRICS (Brazil, Russia, India, China, and South Africa) countries (quantitative analysis)

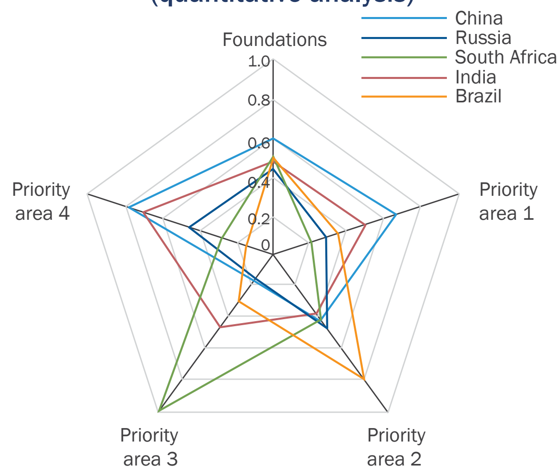
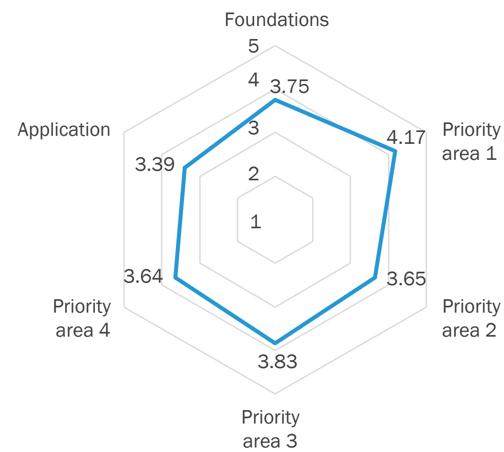


Figure 37. Adaptation principles ratings in China (qualitative and quantitative analysis)



Source: World Bank staff, based on qualitative indicators and expert interviews, drawing on the Adaptation Principles framework proposed in Hallegatte et al. 2020.

National guiding policies do not provide a coherent effectiveness evaluation framework, while local government lacks quantitative targets and monitoring systems on climate adaption (Zhang et al. 2018). This results in local authorities neglecting adaptation in actual policy implementation (Peng et al. 2015). Similarly, urban infrastructure adaption efforts have yet to provide sufficient protection against increased risks of climate disasters (Fu et al. 2021). The Henan floods in July 2021 exposed the low awareness at the local level of the potential destructive impacts of extreme climate events and the failure of lifeline infrastructure to withstand severe shocks (State Council 2022). A more streamlined and coherent monitoring and reporting framework is required to monitor progress on climate adaptation.

Adaptation policy relies heavily on regulatory approaches and public finance, while providing little incentive for private-sector-led adaptation efforts (Zheng & Lin 2021). China is expected to require US$0.25 trillion annually for fully financed adaptation programs (Chai et al. 2019). This implies a financing gap of US$127 billion each year, highlighting the need to broaden financing channels such as blended public-private finance, resilience bonds, and carbon trading mechanisms to reward green solutions and foster ecosystem-based adaptation (Ding et al. 2021). Despite years of exploration and its establishment, catastrophic insurance continues to have room for improvement, particularly in terms of the underlying catastrophic risk models.

What we recommend:

- **Strengthen interinstitutional collaboration and vulnerability data access to households, firms, and local governments.** A first step toward improved collaboration would be to make existing databases on climate vulnerability more broadly accessible to government and nongovernment actors. Without such information, planning processes can be misguided and permission can be significantly delayed, while private decisions fail to take climate risks into account. Beyond data sharing, the creation of an interministerial task force or leading group on adaptation could raise the prominence of the issue and facilitate coordination across agencies.
- **Enhance local government capacity to address pluvial flooding and landslide hazards.** Climate projections for Chinese settlements show intensifying extreme precipitation in the coming decades. This alarming trend could exert differential impacts in different locations: in urban centers, elevated pluvial flood hazards could expand the reach of localized flooding and cause more disruptions; in the peripheries, especially in places like Hangzhou and Chengdu, communities in mountainous areas could face heightened probabilities of landslide. Local governments, by and large, still lack the capacity

and knowledge to overcome the implementation challenges and engage the residents on the ground. Therefore, to bring the ideas into reality, capacity building has to be incorporated into the broader climate adaptation framework to allow for institutionalization of knowledge and participatory governance. Moreover, governments at the subcity district level could benefit from peer learning and collaboration between urban and rural districts to jointly address the challenge of extreme precipitation.

- **Develop an adaptation effectiveness evaluation framework.** Given serious implementation weaknesses, better tools are needed to assess the actions of stakeholders at the local level and make adjustments as appropriate. China's target setting and cadre evaluation system provides high-powered incentives when targets are easily measurable and made binding. However, basic components of improved adaptation management are often missing, such as asset management systems that account for climate-related lifecycle asset costs. Moreover, given competing demands on local officials, targets may need to be combined with fiscal tools, such as targeted intergovernmental transfers to encourage greater attention to climate adaptation in public investment plans. A shift in the structure of PPP contracts in public infrastructure for low-cost delivery toward minimizing lifecycle operating costs could leverage private sector expertise for improved adaptive management.
- **Develop new financial tools to attract private funding for adaptation investments.** With improved data availability on disaster risk, private insurance markets can set appropriate incentives and help mobilize funding for risk mitigation. Where affordability constraints limit the ability of households and businesses to purchase adequate insurance, fiscal support could make insurance contracts viable, and where moral hazard is a key risk, insurance can be made mandatory. The government could also insure its own fiscal risks through the issuance of disaster risk management bonds, thereby strengthening its own incentives for risk reduction.

4.3.2. Integrate adaptation in land use and water use plans

Physical risks from climate change will affect the country's agricultural production potential. Changes in crop yields and the availability of arable land will affect agricultural output and could increase risks unless production practices are adapted. Observed changes in agricultural flooding in different parts of China could influence farming systems and crop areas (Zhang et al. 2016), as extreme events intensify. In northern China, rising temperatures and varying precipitation patterns will shift the boundaries of cultivation further northward, thus increasing suitable cultivation areas. However, crop yields may be impacted negatively and there will be an expansion of pests and disease incidence (MEE 2015). The vulnerability of agriculture in this region will be further increased by the frequent occurrence of intense droughts predicted by climate models (MEE 2015, Zhang et al. 2015). Frequent and intense heat waves will not only hurt agricultural production, but also threaten human health and reduce labor productivity. Provinces in the central region could experience large negative effects on the productivity of outdoor workers, ranging from -2 percent to -15 percent by 2060 (Liu et al. 2021).

Water resources are already being impacted by climate variability, and climate change will severely affect China's water systems. A quantitative assessment for China, based on a multimodel dataset during the 1971–2010 period, suggested that climate variability dominated the changes in streamflow in more than 80 percent of river segments, while direct human impact dominated changes mostly in northern China (Liu et al. 2019). An assessment of future water supply and demand scenarios for Asia, based on global climate change and socioeconomic scenarios (Satoh et al. 2017), found that water demand in sectors such as irrigation, industry, and households will increase by 30 to 40 percent between 2010 and 2050. Water stress is likely to become more pronounced. By mid-21st century, the large river systems in China and international transboundary river basins could face severe water scarcity challenges with climate change acting as a stress multiplier. The Yangtze River Delta and Pearl River Delta will face substantial risks from sea-level rise, estimated to reach up to 80 cm relative to 1986–2005 (Arnell et al. 2018).

What we recommend

- **Develop guidance and plan investments that promote science-based adaptation measures in agriculture.** Both agriculture and water resources management have yet to develop dedicated sectoral guidance on climate action and adaptation response. Of the three country-level functional zones defined in the national land planning framework (agriculture, urban, and ecological), the agricultural function zone does not yet have an overarching adaption policy framework (Fu et al. 2020). Adaptation in agriculture focuses on promoting water-efficient and high-standard farmland, mainly designed for better yield rather than climate adaptation. It is necessary to plan the layout and structure of crop production, and to improve agricultural production conditions based on scientific climate research, taking into account available adaptation technologies (Zhou et al. 2016). Note that investments in improved agricultural practices that lower the excessive use of chemical fertilizers would not only have significant climate mitigation benefits, but by reducing eutrophication of water bodies, would also increase freshwater availability for ecosystems, strengthening climate resilience in the face of greater variability in water resources.
- **Invest in proactive water-related risk management.** Water resources management in China is primarily focused on dealing with current flooding and drought risks through infrastructure upgrades and water-saving. The focus is often on efficiency improvement rather on the impacts of a changing climate. Water scarcity is a familiar issue in northern Chinese cities. Despite massive water diversion projects to buttress cities' water supply, growing deserts and shrinking aquifers still seriously jeopardize water security. However, even in southern China, water supplies are increasingly strained. Guangdong Province, where Guangzhou and Shenzhen are located, recently endured a drought in December 2021 due to historically low rainfall and saline intrusion. As it stands, China's per capita water resources is only 2,100 cubic meters, one-third of the global average. As climate change brings more unpredictability into the weather pattern, there is a significant possibility of worsening drought in certain parts of China in the near future, depending on the emissions and socioeconomic development scenario. The National Water-Saving Action Plan (2019), a key strategy that guides national efforts on water-saving, makes no reference to climate or adaptation. To ensure greater resilience for all water users, from households and cities to farmers and industrial enterprises, the latest climate science needs to be incorporated into integrated climate and hydrological models to understand the spatial and temporal patterns of water availability. Such science-based analysis should then be reflected in national targets for water-use efficiency, water withdrawals, and industry codes such as ecological flow requirements. This will require not only the effort of the Ministry of Water Resources and provincial water departments, but also the collaboration of line agencies on economic planning, agriculture development, and industry and ecosystem management. In the public sector, proactive water-related risk management enables governments to diversify infrastructure that makes optimal use of stormwater and urban waterways, flood control, aquifer recharge, and water reuse. Private-sector actors should also understand their water impacts and risks and engage in water stewardship efforts focused on measurable impact in watershed health.
- **Strengthening the role of nature-based solutions in climate adaptation.** Currently NbS policies are applied in six different ecosystem types under the responsibilities of four different line agencies[63] (Yan et al. 2021). Policy tools are most advanced in sectors governing natural ecosystems (forests, grassland, wetlands) as a result of past experience and existing expertise, whereas for agriculture and urban ecosystems, the policy frameworks are weaker. There is a lack of a systematic nationwide policy framework that integrates NbS in existing policy-making processes, as NbS falls under the jurisdiction of multiple ministries without a shared understanding of its role in climate adaptation or effective coordination and communication. In particular, the key ministry leading government response to climate

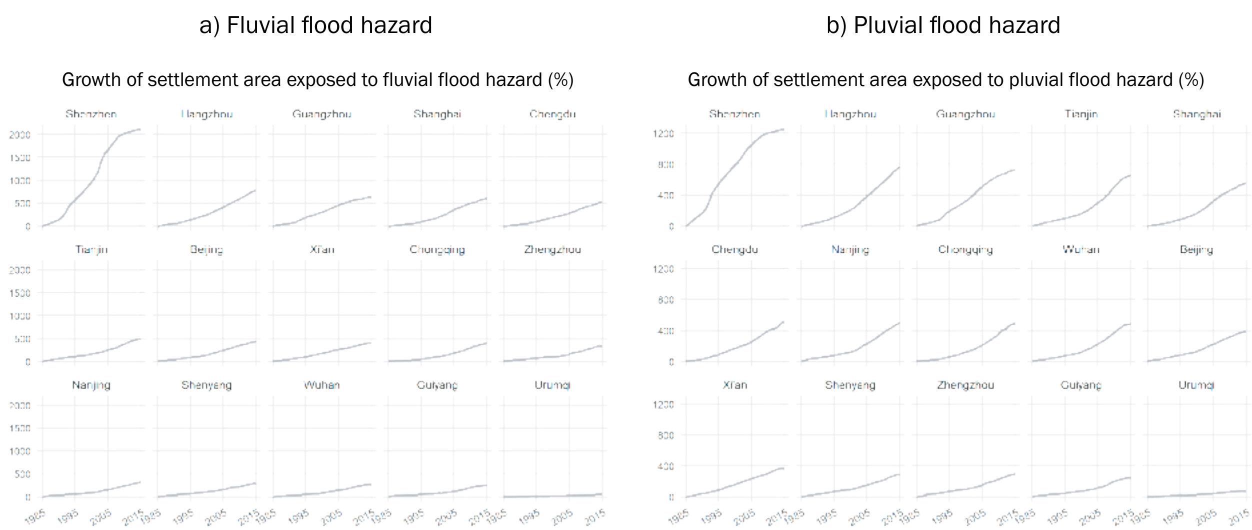
63 The six ecosystems and corresponding line agencies are forest, grassland, wetland (National Foresty and Grassland Administration), farmland (Ministry of Agriculture and Rural Affairs), ocean (Ministry of Natural Resources), and cities (Ministry of Housing and Urban-Rural Development).

change (the Ministry of Ecology and Environment) has not yet fully recognized the role of NbS in climate response.

4.3.3. Protect critical public assets and services, particularly in urban areas

Climate change also threatens China's urban spaces, with cities expanding more rapidly in areas exposed to climate risks. China's rapid urbanization rate often means that cities are expanding into hazardous fluvial and pluvial flood zones. Cities in China will be at high risk of coastal flooding, while coastal erosion will cause damages to lands, beaches, piers, shore protection dams, and protective forests. Based on estimates by The Financial Times (Bernard and Shepherd 2021), the GDP at risk (in 2019 purchasing power parity) in Shanghai and Guangzhou, together with their surrounding areas, could surpass, respectively, US$1.6 trillion and US$291 billion a year by the end of the century under a high-emissions scenario. In the East Asia and the Pacific region, risky urban growth is outpacing safe growth, with high-risk settlements expanding 60 percent faster than safe ones. China's trends are a key driver: between 1985 and 2015, built-up areas in China increased by 165 percent, and settlements in the highest flood hazard category grew by 223 percent (accounting for 46 percent of the world's new high-risk settlements). Analysis prepared for this report shows that large urban areas such as Shenzhen, Hangzhou, Guangzhou, Shanghai, and Tianjin all saw their exposed settlements expand by over 500 percent during 1985–2015, exacerbating the already serious fluvial flood hazard (see figure 38).

Figure 38. Growth of settlement areas exposed to flood hazards (1985–2015)



Source: City Resilience Program team (World Bank).

Moreover, sea-level rise and storm surge constitute a serious and imminent threat to Chinese cities. Climate Central estimates that the homes of 43 million people in China could be below the high-tide level by 2100, and in most cases as early as 2050, and many of these homes are currently located in one of the dense, low-lying coastal cities. The scale of impact is tremendous, but local governments tend to lack the expertise and incentive to address this urgent issue. Although the national government has unveiled the Action Plan for Urban Adaptation to Climate Change in 2016, the policies and initiatives have not yet fully trickled down to the city level. The resulting mismatch between the imminent threat and the dearth of adaptation actions could cause catastrophic outcomes when the next coastal flood inevitably occurs.

What we recommend

- **Combine grey and green infrastructure solutions in managing flood and drought risks to cities, settlements, and key infrastructure.** Section 3.4.4 argued that regulatory measures such as floor-area ratios and land-use regulations to discourage urban sprawl and promote compactness can influence the density of development. This will contribute to reduce expansion in high-risk areas. However, residual risks are unavoidable. Most urban adaptation in South, East, and Central Asia has been reactive in nature (Dulal 2019, Singh et al. 2021), raising questions on preparedness, proactive building of adaptive capacities, and whether present actions can lock certain cities/sectors into maladaptive pathways. Adaptation options range from typical infrastructural measures such as building flood protection measures and sea walls, and climate-resilient highways and power infrastructure, to scaled-up, sustainable land-use planning through zoning; developing engineering construction standards; and adoption of nature-based solutions measures such as protecting urban green spaces, improving permeability, and mangrove restoration in coastal cities (Brink et al. 2016, Fink 2016, Yu et al. 2018). Water infrastructure will also require a detailed understanding of the vulnerability attributes of infrastructures, including their exact location, the beneficiaries that they serve, and their existing flood protection standards.[64]
- **Localize adaptation strategies against sea-level rise and storm surge.** Fortunately, cities in China are equipped with some existing adaptations. Shanghai, for example, is already surrounded by hundreds of kilometers of seawalls to fend off the intrusion of seawater, but with climate change, intensifying extreme precipitation, and possibilities of compound disasters, the current flood protection might prove to be inadequate and overly costly. Furthermore, other coastal cities may not enjoy the same level of protection and resources that Shanghai does. Therefore, effective, large-scale adaptation, such as early warning systems, coastal mangroves, and improved drainage, become especially crucial. Moreover, to maximize the benefits for communities, city governments should involve local residents in the implementation process to not simply raise awareness, but also to leverage community resources for disaster prevention and response.

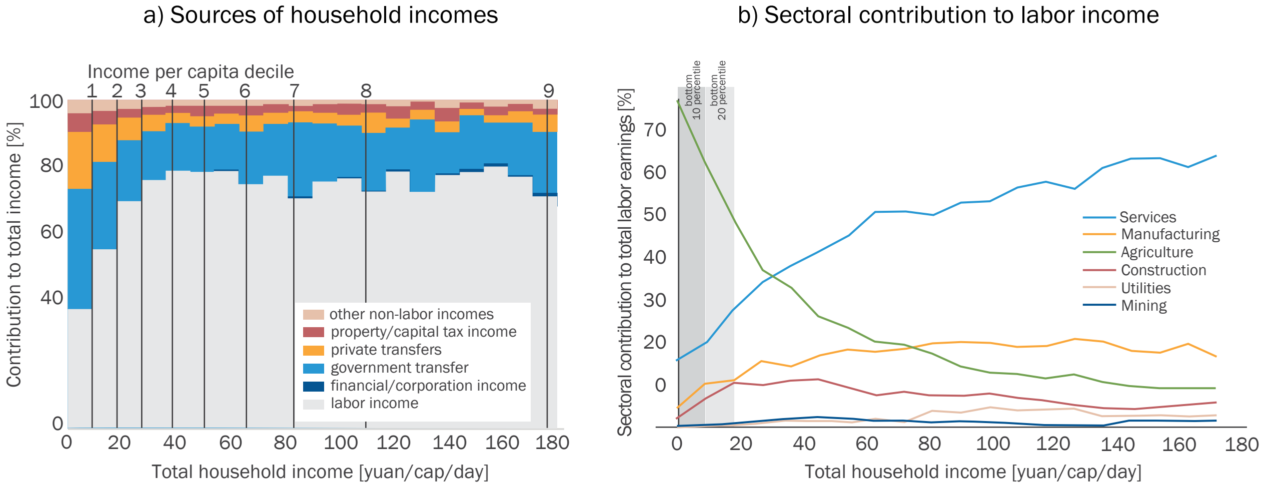
4.3.4. Help the most vulnerable manage residual risks and natural disasters

Food price shocks and climate-change induced agricultural production shocks will be key challenges faced by the vulnerable populations in China over the next few decades. The impacts of climate change on the poor will be very different depending on where they live, which sector they work in, and the sources from which they derive their income (Hallegatte, Przyluski, and Vogt - Schilb 2011). Even though agro-climatic zones and climate risks differ substantially across the country, the concentration of poorer households in rural areas with a high dependence on agricultural incomes makes them highly sensitive to changing yields and higher consumption prices.[65] What happens to agricultural prices is also critical for the vulnerable in urban areas in light of their impact on the purchasing power and real income of poor households.

64 A case study of China's wastewater treatment plants (WWTPs) to understand the level of risks faced by this critical water infrastructure for river floods and earthquakes (Hu et al. 2019) shows that climate change will significantly increase the exposure of Chinese WWTPs to floods, even over the short term, with large potential impacts on users. For an event with a 30-year return period under a scenario of moderate climate change, 35 percent of the WWTPs (472 out of 1,346 plants) supplying 176 million people could experience significantly higher flood risk by 2035.

65 Strikingly, however, expenditure distribution across various expenditure categories remains fairly constant across the income spread. Households spend on average 37 percent of total expenditure on food and another 25 percent on services like education, medicine, fitness, insurance, entertainment, and communications.

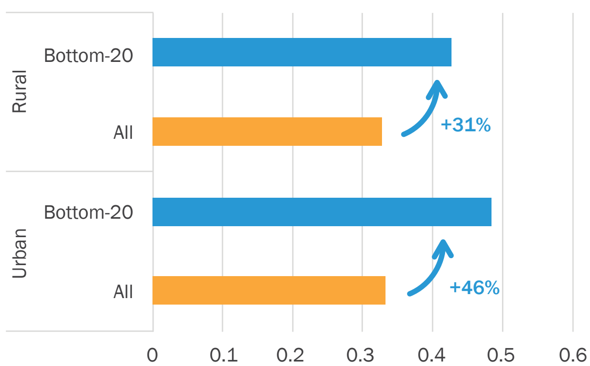
Figure 39. Households in the lowest income deciles highly depend on government transfers and labor income particularly from agriculture



Source: World Bank calculations using Hallegatte et al. (2017), Shockwaves Modeling for China

Figure 40. The welfare of poorer households is particularly sensitive to the impact of food prices

Sensitivity of total household expenditure to food expenditure shocks (percent change as a result of a 1 percent shock in household food expenditure)



Source: World Bank staff estimates

Analysis prepared for this report evaluates the sensitivity of household welfare to hypothetical climate change impact shocks. Sources of household incomes are grouped into five mutually exclusive and collectively exhaustive streams: labor income, financial income, property income, public transfers, and private transfers. Over successive iterations, the methodology for the analysis generates random and independent perturbations for each channel. Moreover, to represent food price shocks, the analysis includes shocks to food expenditure. Although these abstract shocks do not represent climate change directly, they are devices for studying different transmission channels of climate risks. The sensitivity of household expenditure to these income and expenditure shocks is used as a welfare impact metric.

While this report did not investigate gender differentiated impacts, climate shocks and climatic disasters may also wield negative impacts on gender equality.[66] When it comes to vulnerability and adaptation, gender

66 Using a panel data series over 100 low and middle income countries between 1981 and 2010, Eastin (2018)

differences are also noted in China. Research on a sample of 31 major cities in China shows that heatwaves tends to increase mortality for women, the elderly and those with low education (Yang et al 2019; Yang et al 2013). Empirical evidence also points at differences in the way male-headed households and female-headed households respond to climate change. Male-headed households are more likely to adopt new technology for water conservation and to increase investment in irrigation infrastructure (Jin et al 2015).

The labor productivity impacts of climate change are likely to dominate the overall welfare impacts to the Chinese population at large. The modeling exercise suggests that a 1 percent reduction in labor income through a labor productivity shock is estimated to reduce household expenditure by roughly 0.4 percent on average. As noted above, climate change impact on labor productivity may be as high as 15 percent (Y. Liu, Z. Zhang et al. 2021), resulting in a potential 6 percent reduction in household expenditure, in the absence of adaptation.

Lower income households will be impacted mainly by changes in food prices, particularly in urban areas. Whereas labor productivity impacts of climate change are likely to matter most for aggregate GDP, agriculture price shocks matter more for the welfare of the poor. Simulations suggest that a 1 percent price rise in food prices—with no change in agriculture productivity and consumption substitution—leads to a 0.45 percent reduction in total household expenditure for the poorest 2 deciles of the population, on average. The higher share of income that poor people spend on food makes them particularly vulnerable to rising prices or price volatility on food items. Poorer households in urban areas are 46 percent more sensitive to food expenditure shocks than the average urban household (Figure 40). In rural areas, poorer households are 31 percent more vulnerable than the average household. The modeling estimates suggest that poorer households in urban areas are 13 percent more sensitive to food expenditure shocks than their rural counterparts. This is because they spend a larger share of their total expenditures on consumption of food items.

There is considerable regional variation in the severity of the type and magnitude of climate change impacts on welfare. Whereas the poorer populations in the bottom 2 deciles in the coastal and central region are roughly 40 percent more sensitive to food price shocks than the average population in those regions, those in the western region are about 30 percent more sensitive than the average household in the western region. The total share of food expenditure is lower in the western region, which explains some of these differences. The poor in the western region are, however, more sensitive to climate change shocks to labor productivity than those in other regions. This is in part driven by the larger dependence on outdoor workers in agriculture in this region.

What we recommend

- **Improve the targeting of social transfers to address climate vulnerabilities.** Climate impacts, particularly climate-induced disasters, are increasingly a direct cause of poverty in China (Liu 2019). There is a significant overlap between climate-vulnerable areas, ecological-sensitive areas, and poverty-stricken rural areas (Oxfam 2015). Poor rural householders are directly exposed and sensitive to climate impacts (especially disasters) and have lower adaptive capacity (Zhang et al. 2019). Moreover, the ability of the poor to benefit from government-funded projects may be hampered by elite capture (Zhang 2014). There is a potential mismatch between direct government subsidies and the critical needs to target the most vulnerable groups in climate-affected regions. At the planning level, poverty alleviation programs should incorporate climate considerations and the uneven impacts on different socio-economic groups. Targeted efforts to improving poor communities' climate adaptation capacity include improving local social adaptive capacities through fostering local institutions and cooperatives (Zhang and Ai 2018) and improving access to climate insurance, small loans, and education and training opportunities (Zhou and Sun 2016).

shows that deviations from long term mean temperatures and increasing incidence of climate-related disasters are associated with declines in women's economic and social rights. Rao et al (2019) emphasize the need for adaptation policy to move beyond the counting of numbers of men and women exposed to climate change to a more detailed unpacking of the relations of power at play, the analysis of inclusion and exclusion patterns in decision-making, and ingrained cultural beliefs related to equal opportunities and rights to people across social hierarchies.

5.
From analysis to action

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5. From analysis to action

This CCDR has asked, and attempted to answer, how China can achieve the best possible outcomes both for the climate and the country's development. The report has identified ways in which China can achieve climate and development goals in parallel. Table 7 provides a summary of short-term priorities by detailing why they matter and how they ought to be implemented. The measures combine economy-wide and sector-specific reforms in the key emitting sectors. They are sequenced to take advantage first of no-regret steps and lower-hanging fruit—for example, the availability of low-cost renewable technologies in the power sector. Some of the measures, like the accelerated rollout of renewable energy generation capacity, may therefore result in speedy reductions in emissions. Others—for example, refining China's ETS or investing in low-carbon research and development—may not cause large immediate gains but could establish important foundations for deep decarbonization in the long run. Together, these measures constitute critical first steps that China could take over the next five years. Given the uncertainties involved, policies and their impacts will have to be monitored and adapted over time.

Table 7. Short-term (the next 5 years) policy priorities

Rationale	Policy Options
1. Define the trajectory to carbon peaking and deliver clear signals to firms	
China has made long-term commitments, but short-term emission targets remain ambiguous.	• Provide clear forward guidance by setting annual mass-based emissions caps over the next decade, supported by a consistent carbon accounting framework for firms, provinces, and cities.
2. Accelerate the power sector transition with market reforms and investments in renewables	
The sector is highly reliant on coal, and it occupies the largest share of total emissions. Green energy technologies are increasingly available and affordable. The demand for electrification in downstream sectors (transport, industry) is rising.	• Increase, by 2030, solar and wind power generation capacity to 1200 GW-1,700 GW, supported by additional energy storage of 200 GW and more flexible electricity grid. • Adopt international best practice in system planning, reliability regulations, and variable renewable energy (VRE)) generation forecast and dispatch to enable phasing down of coal use. • Expedite electricity market reforms, including pricing reforms, development of ancillary service and capacity markets, and interprovincial power trade. • Promote demand management measures, including energy efficiency, distributed renewable energy, and demand response programs.
3. Decarbonize key energy demand sectors— industry and transport	
Emissions from transport and industry are increasing. There is potential to switch to clean energy sources, including electrification, efficiency improvement, and demand management.	• Adopt macroeconomic policies to support rebalancing from industry and investment-led to services and consumption driven growth. • Set clear and ambitious emissions reduction targets and technology standards in the cement and iron and steel industries. • Accelerate electrification of the private and commercial fleets, moving away from focus on public buses, providing tax incentives toward price parity, nonmonetary incentives, and adequate charging infrastructure (in conjunction with the low carbon energy transition to decarbonize power supply). • Incentivize transport users to improve fuel and operating efficiency through pricing and regulations on vehicle and fuel standards. • Promote modal shifts to public mass transit and low-carbon freight modes (railways and waterways) through modal integration and pricing incentives.

Rationale	Policy Options
4. Enhance climate resilience and adaptation in rural landscapes and urban areas	
The land-use sector can be harnessed to increase resilience, and it can become a net carbon sink providing opportunities to offset hard-to-abate emissions in other sectors.	• Develop an adaptation policy framework for agriculture, increase the use of nature-based solutions, and use scientific and meteorological information to inform water use and water resources planning. • Increase the profitability of investments in NbS by accelerating forestry sector reform, reorienting eco-compensation, and leveraging carbon offset markets. • Repurpose public sector support to agriculture to support low-carbon land use and promote the reuse of agricultural waste. • Strengthen policy framework on urban land-use and spatial planning, to discourage sprawl. • Strengthen standards and provide fiscal incentives for energy conservation and emissions reduction in the building sector. • Strengthen interinstitutional collaboration and vulnerability data access to households, firms, and local governments, and develop an adaptation effectiveness evaluation framework.
5. Harness markets to drive cost-effective economy-wide abatement and innovation	
Economy-wide climate policies are necessary to internalize both the negative externality of carbon emissions and the positive externalities from innovation.	• Expand the use of carbon pricing mechanisms, including the ETS, with a focus on (i) building market infrastructure, (ii) unifying performance benchmarks, and (iii) introducing permit auctioning as the foundation for a gradual transition toward an effective cap and trade system with an absolute emissions cap. • Enhance competition between SOEs and non-SOEs to allow market forces to drive allocation of capital and R&D resources. • Revise nontariff trade barriers to eliminate incentives to trade in high-carbon products. • Reform R&D support for low-carbon technologies, moving from quantity to quality of research and patenting. • Harness the financial sector by establishing corporate emissions accounting systems, mandating climate-related financial disclosures, and using blended finance to favor innovation.
6. Mitigate the social costs of the transition and prepare the labor force for the low-carbon economy	
The low-carbon transition will have distributional implications. Households will also be affected by rising energy prices and by changes in the labor market.	• Improve labor mobility through hukou reform and active labor market programs. • Provide targeted assistance to communities that will experience concentrated job losses. • Revisit government skills development strategies and systems and work with schools, training institutions, employers, and workers to incorporate green skills into the relevant programs.
7. Foster global climate action	
With China being the largest source of infrastructure financing in low-income economies, adopting climate-friendly investment practices would amplify global impact.	• Encourage Chinese lenders, including policy banks -China Development Bank and China Exim to adopt clean financing principles (“the Equator principles”), and operationalize the phasing out of financing of coal and other carbon-intensive infrastructure.

Policies to achieve decarbonization and climate resilience differ in terms of impact and urgency. Each priority is assessed on a three-dimensional scale: (i) climate impact, (ii) development co-benefits, and (iii) ability to avoid lock-ins (Figure 41). Impact is defined as the ability to substantially contribute to mitigate GHG emissions, whereas urgency is defined as the ability to avoid locking the country into high-carbon/maladapted pathways. Many investments can have long-term implications and are difficult to reverse. This is shown in Figure 42, which represents policy options along the two dimensions of climate impact and ability to avoid lock-ins. The figure shows the importance of an early definition of a clear path to carbon peaking (# 1); the definition of targets for the iron and steel industries (# 7); and the promotion of investments in solar and wind power generation capacity, together with steps to phase down coal (# 2). These would all have strong climate mitigation impacts and would help reduce the lock-in of investments in high-carbon infrastructure. Key to avoiding locking into an unsustainable pattern is reducing urban sprawl through better land use and city planning (# 11). Key to achieving high climate impacts is the expansion of carbon pricing through the ETS (# 16) and, to maximize resilience, developing an adaptation policy framework for agriculture and strengthening adaptation in water and through the use of nature-based solutions (# 26).

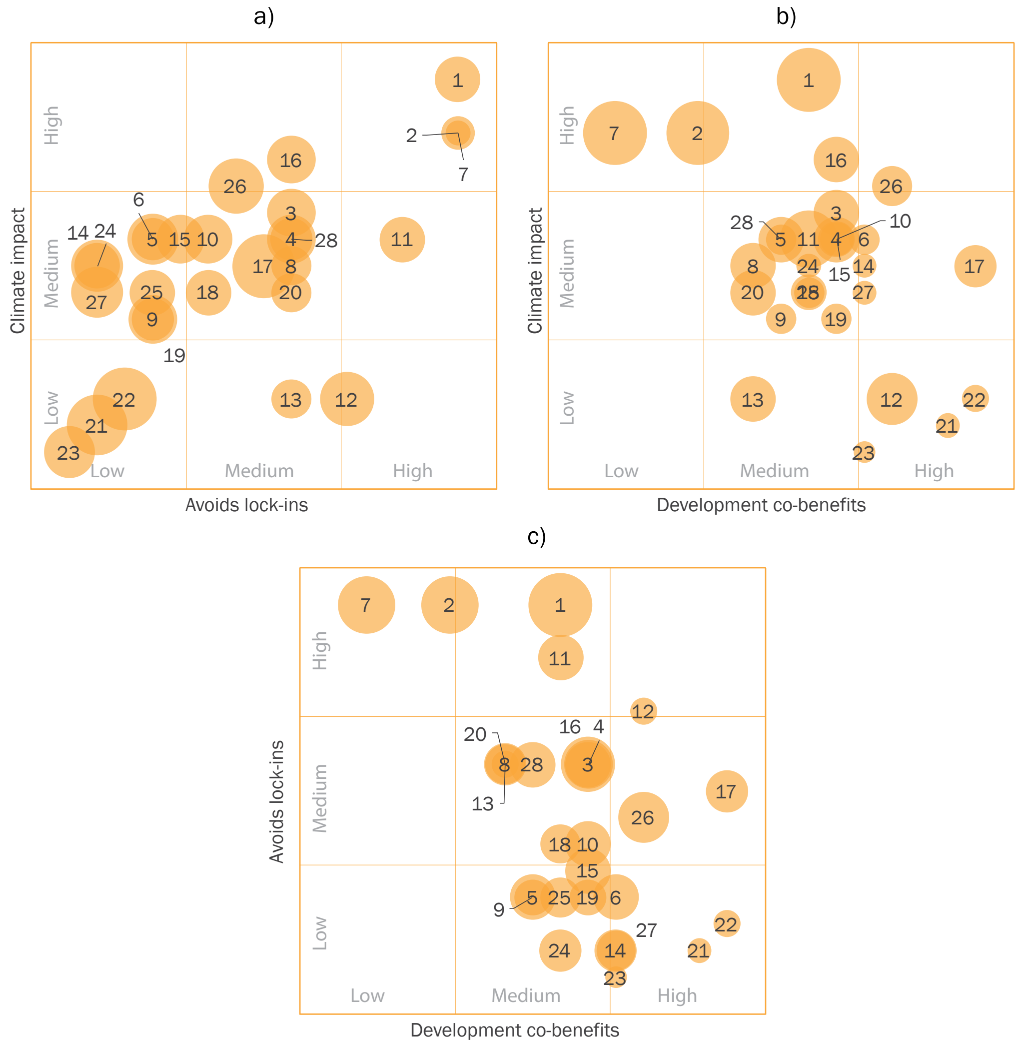
Figure 41. Prioritization approach for recommendations

Avoid Lock-ins: When to act			**Impact** Expected climate and development outcomes		
High	3		3	3	High
Medium	2		2	2	Medium
Low	1		1	1	Low-moderate
			Climate	*Development*	

Notes: Rated by a qualitative (1–3) scoring.

A range of complementary measures would reduce adjustment costs and maximize development co-benefits. Figure 42 (b) and (c) show how policy actions rank in terms of development co-benefits versus climate impacts and versus avoiding lock-ins, respectively. Developing an adaptation policy framework for agriculture, increasing the use of NbS, and using scientific and meteorological information to inform water use and water resources planning (# 26) appears as a top priority. Actions to accelerate decarbonization can also generate development co-benefits. Such is the case with efforts of local governments to prioritize neighborhood regeneration and retrofitting for low-carbon development, especially in areas with large potential for pollution reduction, livability improvement, and urban ecosystem restoration (# 12). Promoting private sector investments and innovation by enhancing competition between SOEs and non-SOEs to allow market forces to drive allocation of capital and R&D resources (# 17) can generate efficiency gains that benefit both growth and reduce emissions.

Figure 42. Prioritizing policy actions to maximize climate and development outcomes



Note: Short-term actions are evaluated using three dimensions, or filters: climate impact, development co-benefits, and avoiding lock-ins. Each dimension is assessed according to a "Low/Medium/High" scale. The three panels show the three dimensions in a pair-wise fashion, with a third dimension represented by the size of the bubble. Priority actions are shown in the top-right quadrants of each chart.

Legend: 1. Define the trajectory to carbon peaking; 2. Increase solar and wind power capacity; 3. Expedite electricity market reforms; 4. Promote energy demand management measures; 5. Incentivize clean heating in buildings sector; 6. Enhance policy predictability and access to finance for firms; 7. Set targets for iron and steel industries; 8. Accelerate electrification of private transport; 9. Vehicle and fuel standards; 10. Modal integration and pricing incentives in public transport; 11. Reduce urban sprawl and planning; 12. Neighborhood regeneration and retrofitting for low-carbon development; 13. Energy conservation and emissions reduction in the building sector; 14. Support climate-smart agriculture and waste re-use; 15. Increase profitability of nature-based solutions; 16. Expand carbon pricing; 17. Enhance competition between SOEs and non-SOEs; 18. Eliminate incentives to trade in high-carbon products; 19. Shift from quantity to quality of research and patenting; 20. Promote climate-related financial sector reform; 21. Hukou reform and active labor market programs; 22. Targeted assistance to communities with concentrated job losses; 23. Revisit professional skills development strategies; 24. Strengthen climate-risk data access to households, firms, and local governments; 25. Develop an adaptation effectiveness evaluation framework; 26. Adaptation policy framework for agriculture, water, and NbS; 27. Improve training and awareness for local communities; 28. Green financing principles for outbound investments.

Source: World Bank Group staff assessment.

List of abbreviations

ADB	Asian Development Bank
ADS	accelerated decarbonization scenario
AMAC	Asset Management Association of China
BAU	business as usual
CAIT	Climate Analysis Indicators Tool
CCDR	Country Climate and Development Report
CCER	China Certified Emission Reduction
CCS	carbon capture and storage
CEADs	Carbon Emission Accounts and Datasets
CFCC	China Forest Certification Council
CGE	Computable General Equilibrium
CHPs	combined district heating plants
CSRC	China Securities Regulatory Commission
EPS	enhanced policy scenario
ETS	emission trading schemes
EU	European Union
EVs	electric vehicles
FAO	Food and Agriculture Organization
FDI	Foreign Direct Investment
FLW	food loss and waste
GDP	Gross Domestic Product
GEC	green electricity certificate
GHG	Global Greenhouse Gas
ICEVs	internal combustion engine vehicles
ICT	information and communications technology
IEA	International Energy Agency
IMF	International Monetary Fund
MANAGE	Mitigation Adaptation and New Technologies Applied General Equilibrium model
MEE	Ministry of Ecology and Environment
MoHURD	Ministry of Housing and Urban-Rural Development
MRV	measurement, reporting, and verification system
NBS	National Bureau of Statistics of China
NbS	nature-based solutions

NDC	Nationally Determined Contribution
ND-GAIN	Notre Dame Global Adaptation Initiative
NDRC	National Development and Reform Committee
OECD	Organization for Economic Co-operation and Development
PEVC	private equity and venture capital
PWT	Penn World Tables
QFLP	Qualified Foreign Limited Partner
RCP	Representative Concentration Pathways
REF	reference scenario
SMEs	small and medium enterprises
SOEs	state-owned enterprises
TFP	total factor productivity
TOU	time-of-use
UK	United Kingdoms
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
VAT	value-added tax
VRE	variable renewable energy
WDI	World Development Indicators
WHO	World Health Organization
WITS	World Integrated Trade Solution
WTO	World Trade Organization

Appendix: Detailed Results of Macroeconomic Simulations (MANAGE CGE)

	Baseline					Carbon Neutrality with Compensation (NDC)				
	2022	2030	2040	2050	2060	2022	2030	2040	2050	2060
						Deviation from Baseline (Percent)*				
Average Growth, %										
Real GDP	5.04	4.41	3.39	2.51	1.74	0.12	-0.01	-0.11	-0.26	-0.31
Real GDP per capita	4.66	4.22	3.39	2.67	1.95	0.12	-0.01	-0.11	-0.26	-0.31
Per Capita Income and Consumption										
Real GDP Per Capita (Constant 2020 USD)*	11,761	16,760	23,797	31,591	35,719	0.05	-0.02	-1.05	-2.79	-5.94
Real Household Consumption Per Capita (Constant 2020 USD)*	4,755	7,152	11,084	16,268	19,846	-0.01	-0.09	2.01	0.38	-4.11
Real Expenditure Shares in Real GDP										
Private Consumption (% of GDP)	40.43	42.67	46.58	51.50	55.56	-0.02	-0.03	1.44	1.68	1.08
Government Consumption (% of GDP)	14.12	14.12	14.12	14.12	14.12	0.00	0.00	0.00	0.00	0.00
Private Investment (% of GDP)	45.99	43.06	38.59	33.24	28.87	0.02	0.03	-1.46	-1.75	-1.26
Government Investment (% of GDP)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net exports (% of GDP)	-0.54	0.15	0.71	1.15	1.45	0.00	0.00	0.02	0.07	0.18
Sectoral Shares in GDP										
Agriculture	4.78	4.22	3.60	3.03	2.64	0.00	0.00	0.06	0.08	0.13
Industry	45.16	42.65	39.46	36.64	34.84	0.01	-0.04	-0.19	-0.60	-2.35
Services	50.07	53.13	56.93	60.33	62.51	-0.01	0.04	0.13	0.52	2.22

	Baseline					Carbon Neutrality with Compensation (NDC)				
	2022	2030	2040	2050	2060	2022	2030	2040	2050	2060
						Deviation from Baseline (Percent)*				
Employment										
Number of employed (Thousand)*	693,778	694,567	683,631	667,213	643,143	0.00	-0.02	-0.18	-0.52	-1.43
External Balance										
Current Account Balance (% of GDP)	-0.92	-0.90	-0.89	-0.90	-0.91	0.00	0.00	-0.01	-0.03	-0.06
Fiscal Aggregates										
Fiscal revenue (% of GDP)	28.32	27.34	26.47	26.24	26.44	0.02	0.10	0.00	0.20	1.49
Fiscal expenditure (% of GDP)	19.44	18.01	17.32	16.98	17.05	0.00	0.03	1.99	2.33	2.55
Budget deficit (% of GDP)	2.8	2.63	1.64	0.87	-0.19	0.03	0.08	-2.08	-2.33	-1.55
Emissions										
Emissions (millions of tons CO_2)*	12,336	13,137	10,336	8,946	7,584	-1.0	-3.0	-18.7	-59.3	-86.3
Emissions per unit of output (tons CO_2)*	109.6	80.1	44.0	29.0	22.0	-1.0	-3.0	-17.8	-58.1	-85.4
Memorandum Items										
Population (Millions)	1,451	1,483	1,494	1,481	1,462	0.00	0.00	0.00	0.00	0.00
Working Age Population (Millions)	1,010	986	906	869	815	0.00	0.00	0.00	0.00	0.00

	Carbon Neutrality with Revenue Recycling to Investment (NDC)					Carbon Neutrality with Revenue Recycling to Investment (ADS)				
	2022	2030	2040	2050	2060	2022	2030	2040	2050	2060
	Deviation from Baseline (Percent)*					Deviation from Baseline (Percent)*				
Average Growth, %										
Real GDP	0.12	-0.01	0.00	-0.14	-0.18	0.13	0.01	-0.05	-0.19	-0.19
Real GDP per capita	0.12	-0.01	0.00	-0.14	-0.18	0.13	0.01	-0.05	-0.19	-0.19
Per Capita Income and Consumption										
Real GDP Per Capita (Constant 2020 USD)*	0.05	-0.02	-0.12	-0.71	-3.12	0.06	0.14	-0.04	-1.52	-2.31
Real Household Consumption Per Capita (Constant 2020 USD)*	0.00	-0.11	-0.09	-0.99	-4.98	-0.02	-0.36	-0.66	-2.92	-4.52
Real Expenditure Shares in Real GDP										
Private Consumption (% of GDP)	-0.02	-0.04	0.01	-0.14	-1.07	-0.03	-0.21	-0.29	-0.73	-1.26
Government Consumption (% of GDP)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Private Investment (% of GDP)	0.02	0.04	-0.01	0.12	0.94	0.03	0.21	0.28	0.67	1.18
Government Investment (% of GDP)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net exports (% of GDP)	0.00	0.00	0.00	0.02	0.12	0.00	0.00	0.01	0.06	0.07
Sectoral Shares in GDP										
Agriculture	0.00	0.00	0.00	0.00	0.04	0.00	-0.01	-0.01	0.00	0.02
Industry	0.01	-0.04	-0.01	-0.34	-2.09	0.00	-0.24	-0.40	-1.21	-1.69
Services	-0.01	0.04	0.01	0.34	2.05	0.00	0.25	0.41	1.20	1.67
Employment										
Number of employed (Thousand)*	0.00	-0.02	-0.01	-0.14	-0.82	0.00	-0.07	-0.10	-0.42	-0.71
External Balance										
Current Account Balance (% of GDP)	0.00	0.00	0.00	-0.01	-0.03	0.00	0.00	0.00	-0.01	-0.02

	Carbon Neutrality with Revenue Recycling to Investment (NDC)					Carbon Neutrality with Revenue Recycling to Investment (ADS)				
	2022	2030	2040	2050	2060	2022	2030	2040	2050	2060
	Deviation from Baseline (Percent)*					Deviation from Baseline (Percent)*				
Fiscal Aggregates										
Fiscal revenue (% of GDP)	0.03	0.10	-0.12	0.15	1.52	0.07	0.75	0.73	1.29	1.79
Fiscal expenditure (% of GDP)	0.01	0.02	-0.03	-0.04	-0.04	0.02	0.15	0.12	0.07	0.06
Budget deficit (% of GDP)	0.03	0.08	-0.09	0.13	1.26	0.06	0.62	0.61	1.13	1.71
Emissions										
Emissions (millions of tons CO_2)*	-1.0	-3.0	-18.7	-59.3	-86.3	-2.0	-18.2	-43.4	-73.7	-86.3
Emissions per unit of output (tons CO_2)*	-1.0	-3.0	-18.6	-59.0	-85.9	-2.0	-18.3	-43.4	-73.2	-86.0
Memorandum Items										
Population (Millions)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Working Age Population (Millions)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
* Deviations from baseline are expressed as percent of baseline level for Real GDP Per Capita, Emissions, and Carbon Price. For all other variables, deviations from baseline are expressed as percentage points of GDP in the corresponding scenario.										
Average Growth, %										
Real GDP	0.17	0.05	0.05	-0.11	-0.15	0.13	-0.02	0.04	0.02	-0.06
Real GDP per capita	0.17	0.05	0.05	-0.11	-0.15	0.13	-0.02	0.04	0.02	-0.06
Per Capita Income and Consumption										
Real GDP Per Capita (Constant 2020 USD)*	0.17	0.40	0.81	0.58	-1.73	0.06	0.04	0.07	0.06	-1.25
Real Household Consumption Per Capita (Constant 2020 USD)*	-0.04	-0.07	0.08	-0.65	-4.49	-0.01	-0.06	-0.02	-0.38	-3.45
Real Expenditure Shares in Real GDP										
Private Consumption (% of GDP)	-0.09	-0.20	-0.34	-0.63	-1.56	-0.03	-0.04	-0.04	-0.22	-1.24
Government Consumption (% of GDP)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Private Investment (% of GDP)	0.09	0.21	0.35	0.62	1.44	0.03	0.04	0.04	0.22	1.16

	Carbon Neutrality with Revenue Recycling to Investment (NDC)					Carbon Neutrality with Revenue Recycling to Investment (ADS)				
	2022	2030	2040	2050	2060	2022	2030	2040	2050	2060
	Deviation from Baseline (Percent)*					Deviation from Baseline (Percent)*				
Government Investment (% of GDP)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net exports (% of GDP)	-0.01	-0.01	-0.02	0.01	0.12	0.00	0.00	0.00	0.01	0.08
Sectoral Shares in GDP										
Agriculture	-0.02	-0.04	-0.06	-0.05	0.01	0.00	0.00	0.00	-0.01	0.02
Industry	0.17	0.44	1.00	1.11	-0.36	0.00	-0.04	-0.03	-0.39	-2.20
Services	-0.15	-0.40	-0.95	-1.07	0.35	-0.01	0.04	0.03	0.40	2.18
Employment										
Number of employed (Thousand)*	0.02	0.05	0.14	0.08	-0.57	0.00	-0.01	0.02	-0.02	-0.45
External Balance										
Current Account Balance (% of GDP)	0.00	0.00	0.01	0.01	-0.02	0.00	0.00	0.00	0.00	-0.01
Fiscal Aggregates										
Fiscal revenue (% of GDP)	0.14	0.37	0.33	0.73	2.20	0.02	0.10	-0.15	0.11	1.49
Fiscal expenditure (% of GDP)	0.07	0.19	0.28	0.35	0.37	0.00	0.02	-0.07	-0.09	-0.11
Budget deficit (% of GDP)	0.09	0.19	0.00	0.20	1.34	0.03	0.09	-0.05	0.25	1.56
Emissions										
Emissions (millions of tons CO_2)*	-1.0	-3.0	-18.7	-59.3	-86.3	-1.0	-3.0	-18.7	-59.3	-86.3
Emissions per unit of output (tons CO_2)*	-1.2	-3.4	-19.3	-59.5	-86.1	-1.1	-3.0	-18.7	-59.3	-86.1
Memorandum Items										
Population (Millions)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Working Age Population (Millions)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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