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Consumers Can Help Deliver A Carbon Neutral China

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Editor's Note: This is a cross-divisional thought-leadership report on "China In Transition," issued by S&P Global with contributions by S&P Global Platts and S&P Global Ratings. Each are separate, individual divisions of S&P Global/SPGI. This report does not constitute a rating action, neither was it discussed by a rating committee.

- Economic rebalancing to consumption from investment can make a decisive contribution to China's efforts to become carbon neutral by 2060.
- China's carbon emissions could fall by about one-third if private consumption rises to 55% from 38% of GDP by 2040, bringing the country closer to high-income economies, and energy use follows the Platts Analytics base case.
- Rebalancing with a more ambitious "2-degree scenario" results in an even more dramatic 61% fall in emissions by 2040 and puts China firmly on the path to carbon neutrality.
- Both scenarios are plausible but tough. The pace of rebalancing will need to double over coming decades. The upcoming five-year plan will need to set out a clear roadmap to accelerate the energy transition.

President Xi Jinping told the United Nations in September 2020 that China aims to become carbon neutral by 2060. This commitment is a global game-changer. In recent years, China was the planet's largest emitter of carbon dioxide (CO_2), accounting for about 30% of the total. [1] If China succeeds in its aim, this would provide a huge contribution to global efforts to stall climate change.

Getting to carbon neutrality will not be easy. China will need to transform its economy, including what it produces and how. The aim will be to reduce the amount of energy the country uses, per unit of GDP, and ensure that whatever energy it does use emits less CO_2. This implies much less coal, a far larger role for renewables, and potentially the use of carbon capture, utilization, and storage technology.

China's new carbon commitment neatly dovetails with another of its key objectives, to rebalance the economy. Rebalancing means many things. This includes a shift in the economy from manufacturing to services, from capital-intensive to innovation-led and asset-light activity, from exports to domestic demand, and from investment to consumption. All these shifts are mutually reinforcing; delivering on one facilitates progress in the others.

Rebalancing will contribute to the energy transition by shifting from energy-intensive to energy-light activity. For example, if capital and labor over time move from the production of steel, cement, and capital goods to the provision of education, healthcare, and leisure, the economy would likely consume less energy for each unit of GDP produced.

PRIMARY CONTACTS

Shaun Roache
S&P Global Ratings
Singapore
+65-6597-6137
shaun.roache@spglobal.com

Sebastian Lewis
S&P Global Platts
Shanghai
+86-21-5110-5477
sebastian.lewis@spglobal.com

Xu Han
S&P Global Ratings
New York
+1-(212)-438-1491
xu.han@spglobal.com

Mark Mozur
S&P Global Platts
New York
+1-(212)-686-6808
mark.mozur@spglobal.com

RESEARCH CONTRIBUTORS

Lavanya Kaushal
CRISIL
lavanya.kaushal@spglobal.com

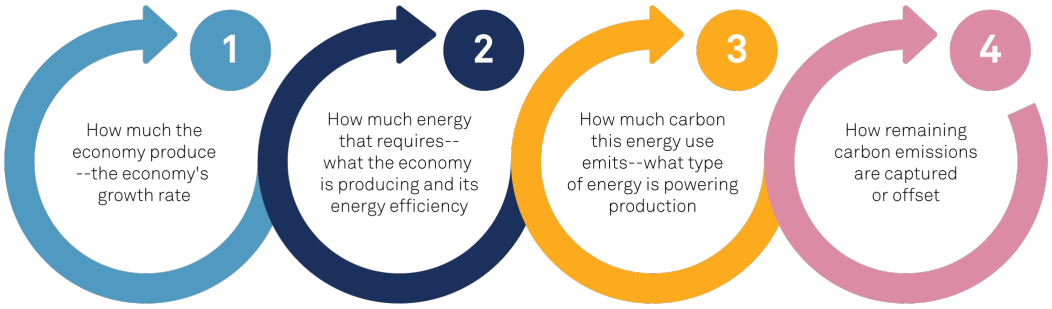
Roman Kramarchuk
S&P Global Platts
roman.kramarchuk@spglobal.com

Alan Struth
S&P Global Platts
alan.struth@spglobal.com

In this article, S&P Global economists and S&P Global Platts analysts together assess how much economic rebalancing can contribute to China's energy transition and its carbon commitment. We project China's energy profile through 2040--how much and what type of energy it will consume--by combining our economic projections with the rigorous framework provided by our global energy model (see Appendix for details on our Global Integrated Energy Model).

The Four Drivers Of Carbon Emissions

How much and what the economy produces will help determine whether China is firmly on the path to become carbon neutral by 2060. At the most basic level, net carbon emissions can be broken down into four parts:



These four parts are related. For example, the share of different industries in an economy's output will affect both total output and its energy intensity. Still, it's helpful to consider each of these separately to assess how much of a contribution each can make. This helps us understand the potential impact of different policy changes on China's energy transition.

How We Model China's Energy Transition

Start with macroeconomic projections

We model rebalancing from the expenditure side of the economy. China is an anomaly among the major economies given its low share of private consumption in total spending--in our rebalancing baseline, we expect that anomaly to vanish over the next two decades. We think this assumption is plausible if the government follows through on its commitment to raise the consumption share with policy changes. We discuss the reform roadmap in the policy section.

Shifting spending habits will ripple through supply and energy chains.

As spending changes, so must output. We model the effects of rebalanced spending on the output of 34 industries using input-output (I-O) tables that describe supply chains. We start by adjusting the shares in total spending in 2040, raising private consumption, and cutting investment. Over time, this means that spending on services rises at a faster rate than spending on capital goods falls, in real terms. This spending shift ripples through the domestic supply chain; for example, as China spends less on physical infrastructure like roads and airports, it needs less steel, which means less coal. I-O tables help us understand what this shift in spending means for all stages of the supply chain (see Appendix).

Combine with energy assumptions and a rigorous energy model

We test a scenario of rigorous decarbonization as well a more ambitious 2°C scenario.

We apply the economic rebalancing scenario outlined above to the Platts Analytics Global Integrated Energy Model (GIEM) that translates this economic shift into an energy demand outlook by sector, across all fuels. We calculate demand growth within each end-use category and assess how sensitive our results are for different assumptions about fuel switching and energy efficiency improvements in certain sectors. Details on the model are presented in the Appendix.

We also consider a "2 degrees Celsius" scenario, which models how much China would need to further reduce emissions on top of economic rebalancing in order to limit global warming to 2°C from pre-industrial levels (see Appendix). This scenario reflects an aggressive phase out of fossil fuels from China's energy mix, driven by the penetration of alternative fuels and an accelerated deployment of high-efficiency technologies, as China and other industrialized countries are assumed to severely reduce CO2 emissions to meet a long-term budget constraint.

Under the 2015 Paris Agreement, more than 200 countries agreed to meet this 2°C goal by 2100, and while China has also made individual 2030 commitments as part of this agreement, the 2°C scenario assumes that even deeper national decarbonisation efforts materialize post-2030. (see "What's the Deal with the 2-Degree Scenario?" S&P Global, Feb. 25, 2020.)

In Platts Analytics' accounting, a 2°C scenario requires China to meet a 2050 emissions constraint that is 60% lower than pre-COVID emissions in terms of absolute levels. This is a massive reduction that is modelled by changes to the availability and deployment of technologies within specific end-use sectors

Emissions Driver No. 1--How Much The Economy Produces

Demographics and reined-in credit expansions will slow China's next phase of growth.

S&P Global Ratings expects China's economy to grow at an average annualized real rate of 3.6% over the next two decades. This may seem low given the track record since 1990 but our projection is rooted in careful assumptions for the supply-side of the economy.

China's slowdown will be driven by a shrinking workforce, lower productivity growth, and less investment (see Table 1). We estimate, based on the United Nations' population projections, that demographics will exert an average drag on the economy of about negative 0.6 percentage points in our forecast period. We expect productivity to contribute 2.9 percentage points to annual growth, a halving from the previous two decades. We also expect the contribution from capital deepening--the degree to which high investment and capital accumulation drive growth--to fall as the economy relies less on credit. This assumption means that, along with many other economies, China's capital-output ratio will stabilize rather than inexorably rise.

Table 1

China's Long-Term GDP Growth Projections (Five-Year Annualized Percent Change)

	2015	2020	2025	2030	2035	2040
Real GDP	7.9	5.7	5.0	4.0	2.7	2.6
Total factor productivity	2.4	1.7	2.0	1.7	1.5	1.5
Capital depth	3.1	2.8	0.8	0.6	0.0	0.0
Human capital	1.3	1.2	1.1	1.1	1.1	1.1
Labor force	0.2	-0.2	-0.1	-0.4	-1.0	-1.0

Note: Measured as the cumulative annualized average growth rate over the five years ending in that year.
Source: National Bureau of Statistics, World Bank, Penn World Tables 9.1, and S&P Global Economics.

Emissions Driver No. 2--How Much Energy The Economy Requires

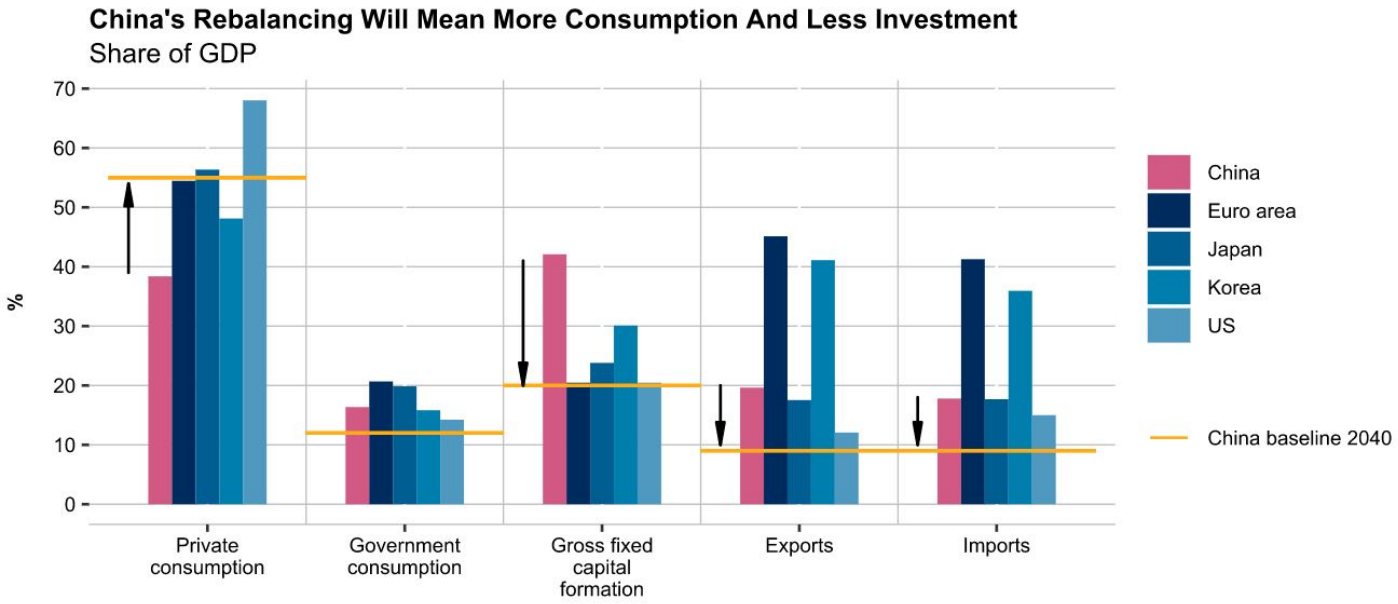
China's consumer spending to rise to 55% of total spending

We assume that the share of private consumption in total spending rises from less than 40% to 55% in 2040, with investment seeing a decline of a similar size.

We also assume that China becomes less open over time, with imports and exports falling as a share of GDP. This reflects three factors. First, as China's economy shifts to services, many of which are non-tradable, its trade share will naturally fall. Second, President Xi's "dual circulation" concept aims to have domestic supply meet most of the needs of growing domestic demand, particularly in fast growing sectors such as technology components and digital services. Third, the rest of the world will become less globalized as multilateral trade deals give way to protectionist tendencies. The recently signed Regional Comprehensive Economic Partnership (RCEP), a broad but shallow free trade agreement among 15 Asia-Pacific economies including China, may slow but not reverse these trends.

Trade will fall as a GDP component as globalization retreats.

Chart 1



Note: Average expenditure share for the last five available years, through 2019 in most cases.
Source: World Bank, CEIC, and S&P Global Ratings.

More consumer spending, more services, less industry = less energy

As consumers become richer and more important for the economy, they spend more on services like education, health, and leisure and relatively less on goods. Firms will still spend on capital goods but, spending on raw materials and investment goods will fall relative to that of consumer goods and services.

Table 2 shows how our rebalancing scenario could affect gross output growth across a set of five aggregated industries, including all the supply chains effects resulting from changes in demand for intermediate goods and services. We find that service sector output, in real terms, will grow by an annualized 5.2%, almost double the rate of industry at 2.7%.

Table 2

Rebalancing Will Mean Rapid Growth Of Services, Slower Growth Of Industry

	Share of output (%) Latest 2017	Share of output (%) Rebalancing 2040	Growth rates (%) for different industries 2020-2040
Industry	53.1	46.2	2.7
Services	28.1	39.3	5.2
Construction	9.9	6.4	1.2
Transport	2.7	2.4	2.7
Own use	2.8	2.6	3.0
Residential*	3.4	3.2	3.1

*Residential is mainly explained by the output of power utilities for final consumption.
Source: Asian Development Bank and S&P Global Economics.

Rebalancing would lower energy intensity by 20% by 2040

China's size and economic structure mean that it is the world's largest consumer of energy. Although rapid growth in travel spending explains part of this, the main driver has been industrialization. Platts Analytics data suggests that industrial demand (including chemicals and non-combusted fossil fuels) accounted for 69% of the net growth in energy consumption between 1990 and 2019.

Rebalancing lowers energy intensity--the amount of energy required per unit of real GDP--by 20% compared to the no-rebalancing scenario by 2040. This is the most direct impact of rebalancing on the energy transition. As consumption rises at the expense of investment, the relative demand for less energy-intensive goods and services rises.

As a concrete example, in 2017, the gross output of China's hotels and restaurants was about the same as that of the rubber and plastics industry, about US$600 billion. I-O tables estimate that direct energy inputs of hotels and restaurants was less than half of that for the plastics industry, even before considering other energy-intensive inputs, including chemicals.

Emissions Driver No. 3--How Much Carbon This Energy Use Emits

Coal's share in China's total primary energy supply has remained stubbornly high at 55%-60% over the past three decades, supported by demand from heavy industry. The non-fossil fuel share from renewables, hydropower, nuclear energy, and combustibles now accounts for almost 18% of total energy supply. While China is the world's largest consumer of renewable wind and solar energy, their combined share remains only 6% of total energy supply.

China is the world's biggest consumer of wind and solar energy...

Rebalancing will mean relatively more demand for electricity that can be produced from low-carbon sources like renewables. This will make it easier to break the country's dependency on coal (including imported coal), especially in sectors like steel, demand for which will grow more slowly in the rebalancing scenario. Although steelmakers are experimenting with using low-carbon fuels like hydrogen, most steel in China is still made in blast furnaces that use coke made from coal.

Even before we take account of an accelerated economic rebalancing, the Platts Analytics base case outlook on fuel switching and technological adoption across end-use sectors implies a substantial reduction in CO2 emissions versus a business-as-usual case, where China's energy intensity remains unchanged in the future.

The Platts Analytics base case is broadly aligned with Paris Agreement commitments

In the Platts Analytics base case the long-term energy mix is broadly aligned with China's nationally determined contribution as per the Paris Agreement on climate change, ratified by China in 2016. China's commitment is to achieve peak CO2 emissions by 2030 and sets a target of a 20% non-fossil share of total primary energy supply by the same year, as well as to lower the carbon intensity of China's GDP by 60%-65% compared with 2005 levels. See Appendix for more details.

...yet these renewable segments make up only 6% of total energy supply for the country.

The Platts Analytics base case does include the effects on energy demand resulting from rising income per capita. History shows that as economies become richer, their energy intensity falls. However, the base case does not account for a disappearing "China anomaly" in which policies drive private consumption substantially higher as a share of GDP.

The Platts Analytics 2°C scenario is much more ambitious

We also consider a more ambitious 2°C scenario in which China contributes to a decline in global CO2 emissions sufficient to limit global warming to 2 degrees above pre-industrial levels. This scenario reflects a large-scale rollout of low-carbon technology at the end-use level.

We assume China massively builds out its renewable power generation capacity. From 2020-2040, we assume a 10% annual increase in delivered gigawatt hours from solar, wind, and other renewable sources (tidal, geothermal). This is actually slower than the equivalent annual growth in renewable electricity in China from 2010-2020. On an absolute basis, this growth in renewable power generation over two decades is roughly equivalent to the increase in coal-fired power generation in China over the past decade.

Transport would have to change dramatically under 2°C. By 2040, we assume China's on-road passenger cars are almost all zero-emission vehicles, which would require the phase out of internal combustion engines from new car sales within the next decade. This is more aggressive than China's new energy vehicle (NEV) industry development plan, which foresees NEVs achieving a 20% market share by 2025 and even the long-term road map formulated by the Chinese Society of Automotive Engineering which foresees a 50% market share for NEVs by 2035.

China aims for 20% of primary energy supply to be fossil-free by 2030.

Table 3

The Platts Analytics 2°C Scenario Assumes Big Changes In China Transport Use

	Platts 2°C		Platts Base Case	
Shares (%)	**Fossil**	**Non-fossil**	**Fossil**	**Non-fossil**
Industry	61%	39%	65%	35%
Buildings	29%	72%	43%	57%
Transport	58%	42%	84%	16%
Power Generation	22%	78%	34%	66%

Source: S&P Global Platts Analytics.

Emissions Driver No. 4--How Remaining Carbons Emissions Are Captured Or Offset

The potential role of carbon capture utilization and storage (CCUS)

CCUS may have a key role to play in meeting China's 2060 carbon neutral goal. CCUS can capture the emissions of those hard-to-decarbonize parts of the economy like steel and coal generation sectors. However, the technology is still in its infancy, and China currently only has a handful of pilot projects in operation. China's energy technology roadmap 2016-2030 envisages that only after 2030 will CCUS technology be mature enough to be more widely applied to coal power generation plants.

Carbon capture technologies will take a while to mature.

Putting It All Together--From Economic Rebalancing To Energy Transition

Rebalancing contributes to a one-third reduction in carbon emissions by 2040

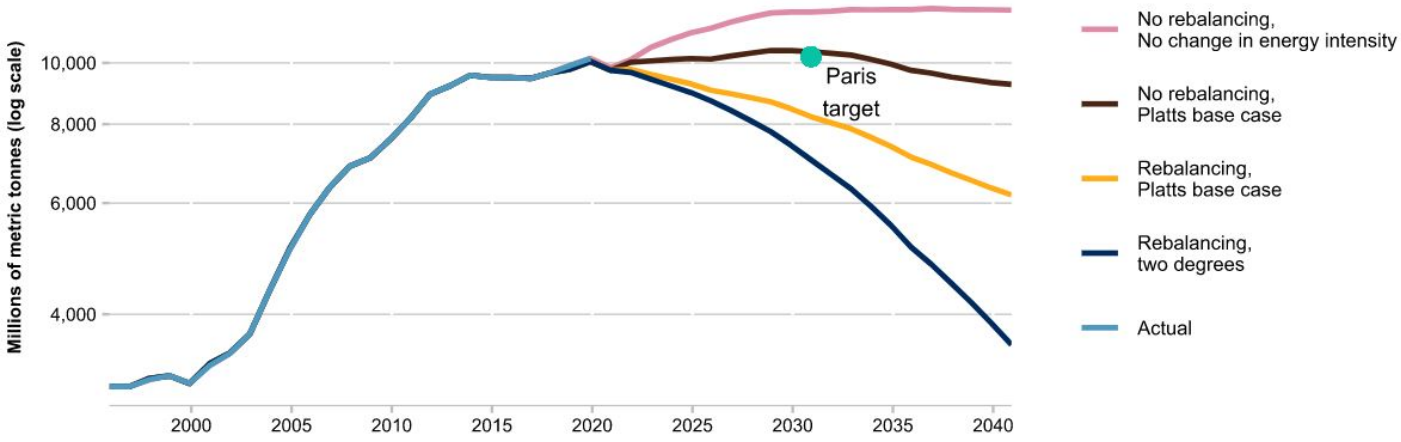
Chart 2 shows CO2 emissions for four scenarios, combining economic rebalancing and the base case and 2°C assumptions:

- Business-as-usual: no change in energy intensity.
- No economic rebalancing applied to the Platts Analytics base case.
- Economic rebalancing applied to the Platts Analytics base case.
- Economic rebalancing applied to the Platts Analytics 2°C scenario.

Chart 2

Economic Rebalancing Contributes To A Decline In China's Carbon Emissions Of One-Third

CO2 carbon emissions from all sectors of the economy



Note: Estimates from the S&P Global Platts Analytics' Global Integrated Energy Model and S&P Global Ratings economic projections.
Source: S&P Global Platts and S&P Global Ratings.

When a rebalancing scenario is compared to one with no rebalancing--i.e., the share of spending and the structure of the economy remains unchanged beyond the effects of rising income per capita--we estimate that CO2 emissions would be about one-third lower by 2040. This is a remarkable result and emphasizes the enormous contribution that economic rebalancing can make to China's path toward carbon neutrality. Layering on 2°C assumptions provides an even more dramatic 61% fall in emissions that puts China firmly on the path to a carbon neutral economy.

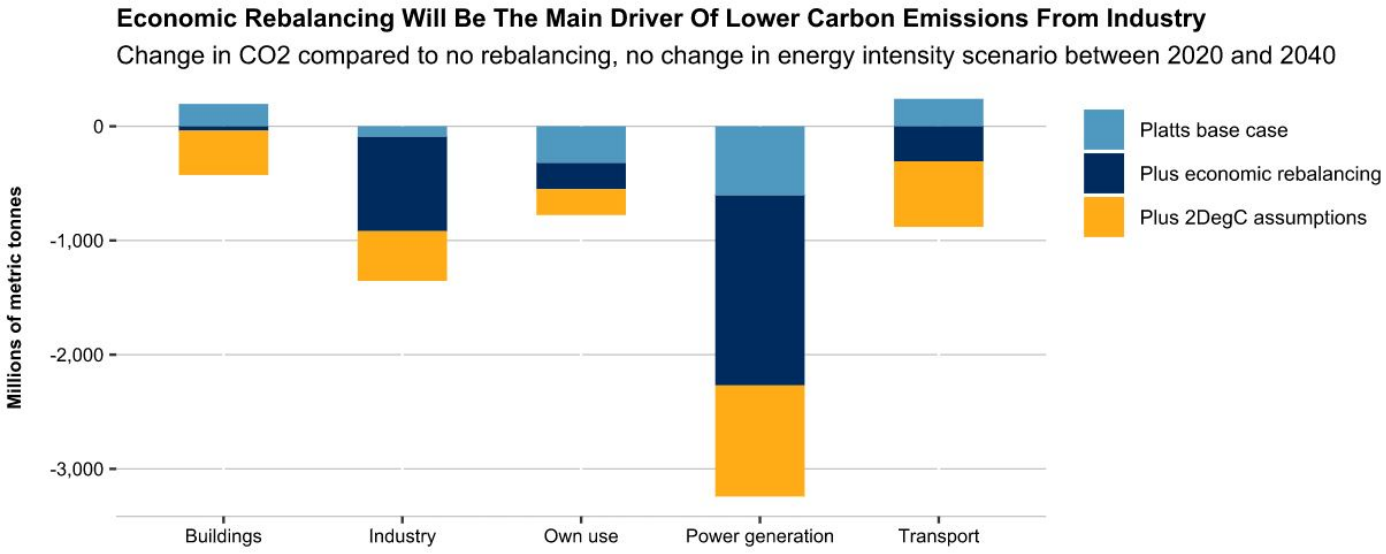
Emissions would fall a third in our base case or a more dramatic 61% under 2°C .

These dramatic falls in emissions are associated with a large increase in the share of non-fossil power generation. By 2040 this rises to over 65% in the base case and by nearly 80% in the 2°C scenario.

Rebalancing helps so much because it is hard to decarbonize end-use sectors

We can look at this through the lens of end-use sectors--see Chart 3. This chart shows how carbon emissions fall compared with "no rebalancing, no change in energy intensity" as we layer on our assumptions in sequence. We start with the Platts base case, add economic rebalancing, and finally 2°C. Each stacked bar shows the additional contribution of these assumptions.

Chart 3



Note: Estimates from the S&P Global Platts Analytics' Global Integrated Energy Model and S&P Global Ratings economic projections.
Bars represent the additional impact on CO2 emissions from cumulatively assuming economic rebalancing and two degrees (2DegC) scenarios.
Source: S&P Global Platts and S&P Global Ratings.

Rebalancing is important because, while it is hard to decarbonize end-use sectors, even under the 2°C scenario, it changes the size of these sectors. This helps reduce demand for, and emissions from, power generation, heat, and industry.

In the 2°C scenario we assume by 2040 a nearly full phase-out of petroleum-based fuels from passenger car transport and substantial progress in building out alternative fuels in commercial transport and air and marine. We also assume the broad electrification and retrofitting of the residential and commercial buildings sectors. But industry and power generation remain particularly challenging to decarbonize accounting for over 70% of total emissions.

This is because technologies to reduce emissions from industrial processes that require heat or power, like hydrogen made from renewable electricity, and carbon capture and storage, are still relatively immature and require considerable improvement before they are widely adopted. Beyond 2040, however, it is reasonable to assume that these technologies will be key to meeting China's net zero commitment by 2060.

Even in the 2°C scenario, coal-fired power continues to deliver just over 1.5 terawatt hours of annual electricity supply in the long run, suggesting that a net zero target requires either the early closure of coal plants that have not yet reached the end of their economic life or the installation of carbon capture technology at the remaining plants in operation.

How Plausible Are These Scenarios?

The pace of rebalancing needs to double

Rebalancing toward private consumption has been slow. Over the last decade, the consumption share has risen by less than 5 percentage points (ppts) and this pace will need to almost double to achieve a 55% share by 2040. On the income side, the household share of national income in 2019 was still about 15 ppts lower than the early 1990s, just before state-owned enterprise reform smashed the iron rice bowl (based on the household survey). At the same time, households are saving almost twice as much of their disposable income as they were in the early 1990s. The income share is rising, albeit slowly, but saving is stubbornly high.

Possible but tough to reduce China's reliance on coal

Much will hinge on coal. From the energy perspective, leaving aside rebalancing, a substantial policy effort will be required, addressing both supply and demand, to reduce the carbon intensity of transportation, power generation, industry, and buildings.

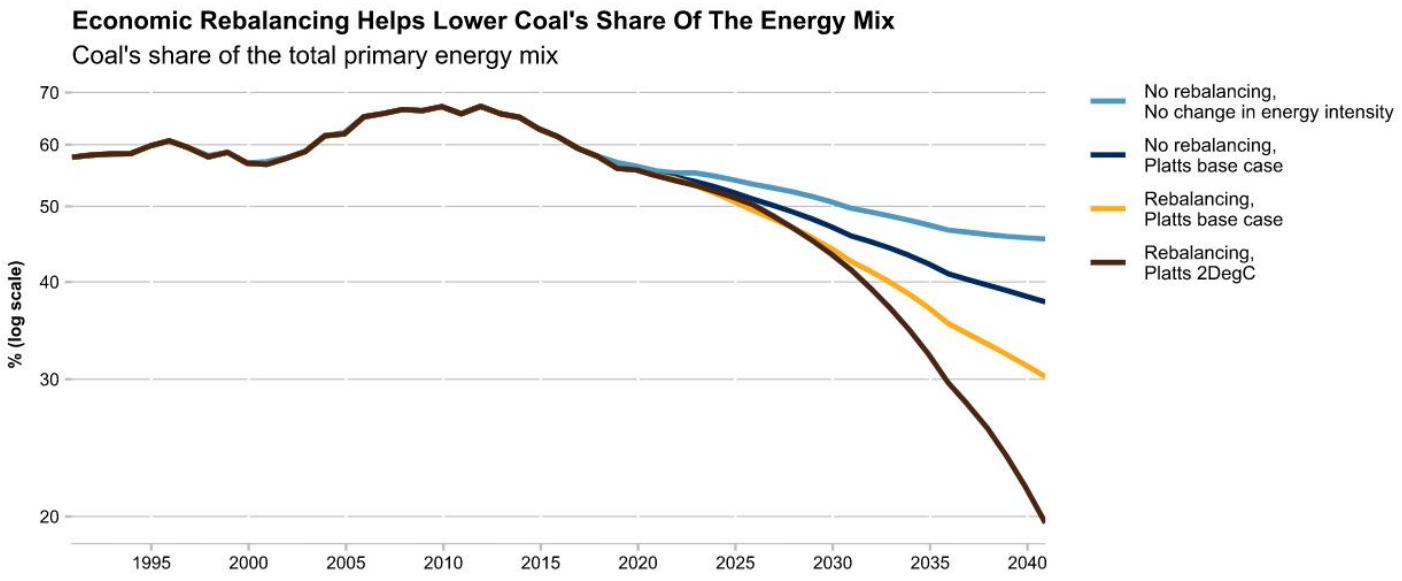
Roughly half of China's coal-fired power capacity was built in the past decade.

The 2°C scenario requires a significant increase in the supply of electricity or hydrogen produced from low carbon sources, notably renewables but also nuclear. For transport, this means more use of alternative fuels. For heating buildings and in industrial processes, this means more use of electricity (or hydrogen) rather than fossil fuels, mainly coal. The government may need to impose mandates and accelerate the natural turnover of capital stock, especially in the coal sector. However, much of China's capital stock is relativity young.

Around half of all China's coal-fired power generation capacity has been built within the past 10 years and more coal power projects were announced in the first half of 2020. With many years left before this capital reaches the end of its economic life, early retirement and replacement with low carbon alternatives or retrofitting with carbon capture technology will be expensive.

At the same time, the coal sector still employs over 2.6 million workers even after shedding more than half of all coal jobs since the peak in 2013. While this is small compared with total employment of about 770 million, many of these jobs are concentrated in economically vulnerable regions. The prospects of finding good, alternative employment locally may be hard. Rebalancing and 2°C assumptions, together, can more than halve coal's share in the energy mix, as Chart 4 shows, but this will be expensive and, potentially, economically disruptive.

Chart 4



Note: Estimates from the S&P Global Platts Analytics' Global Integrated Energy Model and S&P Global Ratings economic projections.
Source: S&P Global Platts and S&P Global Ratings.

Policies Hold The Key--What To Watch In The Next Five-Year Plan

Many of the policy prescriptions for economic rebalancing and reducing carbon emissions are not new. The government has for many years being trying to raise consumption, boost the contribution of the services sector, and control carbon emissions.

China's plan for 2035 envisages the country as an innovative and technologically advanced economy with per capita GDP at a similar level to a middle ranking developed economy. Carbon emissions are, by then, assumed to be steadily declining. Success must begin with the overarching policy framework that will guide development over the period 2021-2025, the 14th five-year plan. What will move the needle in terms of the probability of success?

Stronger social nets would boost consumer spending in China.

Economic rebalancing. Lifting consumer spending as a share of GDP will require boosting the share of national income that ends in the pockets of Chinese households and providing more assurance to them that their livelihoods will be not be wiped out by life events, such as periodic unemployment, illness, or retirement. This would help persuade households to save less and spend more. Key policies are well-known but hard to implement. These include including stronger social safety nets, property taxes to lift the revenue of local governments responsible for social expenditures, and measures to reduce income inequality, including more progressive taxes. [2, 3, 4]

Policymakers are, again, emphasizing that rebalancing toward household income is a national priority and efforts are underway. [5, 6] However, the pace of the needed reforms must accelerate to achieve a 55% consumption share by 2040.

Other measures will need to reduce excessive investment. These might include raising dividend payouts from state-owned enterprises (SOEs). Scaling back implicit credit guarantees for SOEs, a process that has already begun, and reducing other subsidies may need to accelerate to reduce over-investment in the low return projects that have in the past afflicted many of these firms.

Productivity growth. Productivity in services is almost always lower than in manufacturing. Ensuring China's economy keeps converging to its richer G-20 peers as it rebalances will rely on productivity growth. The government is likely to support indigenous innovation in frontier technologies like artificial intelligence, quantum information, integrated circuits, biotechnology, and aerospace.

Breakthroughs will underpin long term productivity. However, too much emphasis on state-driven technology independence and self-reliance could result in slower, not faster, productivity growth. (See "China's Tech Independence Will Not Come Cheaply," Nov. 2, 2020).

New infrastructure. We should see more investment in new infrastructure like 5G, data centers, the industrial internet, electric trains, and clean energy vehicle charging facilities. This should facilitate the growth of more efficient carbon-light manufacturing, the expansion of the digital services sector, and greater use of alternative transport. (See "China's Energy Transition Stalls Post-COVID," Sept. 22, 2020).

New infrastructure can help cut carbon.

Coal. Reaching net zero by 2060 will require a massive reduction in emissions from coal. In addition to ramping up renewables and nuclear capacity, a combination of closures and upgrades could make sense if cost effective. The installation of CCUS on coal-fired power plants could be combined with early retirement of the young and still growing fleet of coal plants, softening the impact on jobs in both the coal and power industries (see "S&P Global Platts Analytics Scenario Planning Special Report," Sept. 25, 2020.)

Any effort to significantly reduce the use of coal will also require measures to promote more energy efficient and lower carbon intensity construction and buildings as well as specific subsidies and policies to promote the use of renewables and electricity over coal and natural gas.

Alternative fuel vehicles (AFVs). Policies are already incentivizing a switch to AFVs, including production quota mandates and support for the creation of a hydrogen vehicle value chain. These will help improve the quality, and drive down the cost, of AFVs. Extending policies to restrict registrations of new internal combustion engine vehicles to more cities, or even an outright ban on sales to achieve a market share beyond the 2025 NEV target of 20%, would further increase the speed of the decarbonization of transport.

Carbon trading. China has been piloting emissions trading for number of years but has moved slowly in creating a national carbon market. We should see the creation of a functional emissions trading scheme covering a broad range of industries by 2025. How effective this will be in reducing emissions will likely depend on market design and how allowances are allocated, and emissions verified (see "Greenhouse Gas Emissions Special Report," S&P Global Platts Analytics, Dec. 20, 2019.)

Carbon trading markets might provide another offset.

An Inflexion Point To Compare With 1978 And 1992

Over 40 years, China's GDP per capita has risen from less than 2% to over 26% of that of the U.S. No one policy is responsible for China's ascent--as the famous saying goes, experimental reforms have allowed China to cross the river by feeling the stones. Incrementalism, not big bang. Still, the years 1978 and 1992, in our view, mark inflexion points when the entire narrative shifted. Agricultural liberalization in 1978 and Deng Xiaoping's Southern Tour in 1992 both preceded waves of reform that contributed to an acceleration of China's growth.

China's aims are now different. The focus is on safer, sustainable, more balanced and inclusive growth. The commitment to become carbon neutral is central to this idea. A similar inflexion point to 1978 and 1992 will be needed, soon. To move the needle on the four broad drivers of the carbon

budget--how much the economy produces, what it produces, what energy is used to power this production, and how remaining emissions can be captured or offset--will require an acceleration of reform touching almost every part of the economy and financial system.

Our combined base case, for economic rebalancing and energy use, is tough but plausible. Our analysis here suggests that rebalancing has an important role to play. But on its own, even a rebalancing that erodes the "China anomaly" of low private consumption over two decades will not be enough. We will see if 2021 follows 1978 and 1992 into the history books.

Appendix

Mapping Changes In Final Expenditure Shares To Gross Output By Industry

We use the Asian Development Bank's input-output table (I-O table) for China as our starting point. An I-O table shows how the output of each industry (the rows in the table) are allocated to inputs across other industries or to final demand, including private consumption, government consumption, investment, and exports. The rows sum to the gross output of each industry.

We extract three separate tables or matrices from the full I-O table. The first is the share of each of the 34 industries' output that is used as an input good elsewhere. This matrix has 34 rows and 34 columns, which we denote as A. The second is the matrix of final demand for the output of each industry divided between private consumption, government consumption, investment, and exports which we denote as z. This has 34 rows and four columns for each component of final demand. Finally, we have a matrix of total output which has 34 rows and one column which we denote as x. These matrices show the structure of the economy:

$Ax + z = x$

From these three matrices, with some algebra, we can calculate the "Leontief inverse matrix" which we denote as L. This helps us estimate how the gross output of each industry will change for a given change in final demand for any one industry:

$x = Lz$

We now project how final demand for each industry will change as the economy rebalances. We can start with the share of each industry in each type of spending--for example some percentage of consumption will be spent on agricultural produce, some percent on electrical goods and so on. This is the matrix W and each of its four rows should sum up to the five components of aggregate spending. Multiplying this matrix with the matrix which contains the output of each industry going to final demand z gives us the four components of spending, which we denote as D:

$Wz = D$

We now use our projections for D--based on the economy's overall growth rate and expenditure shares--to see how it will affect the output for final demand by industry. We make some important assumptions here, notably that price deflators are the same across different types of spending. This is unlikely to be true--historically price deflators for investment have risen much less than for consumption--but this serves as a useful benchmark. Unfortunately, this problem requires more assumptions because we have a system of four equations and 34 unknown values.

We solve this system by constraining the values of the gross output for each industry (technically, we introduce linear inequality constraints on the matrix z). These constraints take the form:

$Gz > h$

In this case, G is choosing each sector for each row (G is an identity matrix). The matrix h is determining either upper or lower bounds for the values of gross output which we determine as the starting value in 2020 and then imposing a multiple of the economy's growth rate. For example, for the output in 2040 of industries mostly serving private consumption (such as retail trade, hotels, and restaurants), we constrain output growth to be 1.1x the economy's growth rate or higher (annually at least 4%). For the output of industries mostly serving investment (such as

ferrous metals and non-metal minerals), we constrain output to grow at no more than 0.9x the economy's growth rate (annually less than 3.2%).

Once we calculate the output used to satisfy final demand, we use the Leontief inverse matrix to calculate the supply chain effect and the overall impact on gross output. The final stage is to map the ADB's I-O sectors to those used in the GIEM which are structured by energy end-use.

The S&P Global Platts Analytics Global Integrated Energy Model (GIEM)

For any given end-use sector, the GIEM uses reduced-form regression models that link income, population, and commodity prices to forecasts of economic activity. As an example, the forecast of vehicle kilometers traveled by personal vehicles in China is driven by elasticity of income (as income rises, so does car ownership), population growth (similar) and commodity prices (there is a positive link between miles driven and fuel prices).

These elasticities combine to form an S-curve describing China's evolution from a society with low personal vehicle ownership rates (and low energy demand in passenger cars) to a country with a high rate of vehicle ownership and diminishing marginal energy demand growth but high absolute levels of fuel consumption in passenger cars.

These reduced-form forecasts are then matched against sector-specific fleet models that reflect the energy conversion efficiency and fuel type of the capital stock in China's economy, whether in terms of the overall vehicle stock, building stock, or the fleet of power plants. As an integrated model, the Platts Analytics GIEM relies on factors such as cost competitiveness, technological adoption curves, and policy support to drive available fuel supply in any given sector.

Key aspects of the Platts Analytics base case scenario

Key features of the base case include: (i) By 2028, CO2 emissions in China peak at around 10.4 gigatons (GT) as 20 gigawatts (GW) of new coal-fired power generation capacity comes online over the next decade; (ii) After 2028, CO2 emissions flatline due to improved end-use efficiency as well as the deeper penetration of alternative transport and the build out of renewables; (iii) By 2030, alternative fuel vehicles (AFVs) account for over 10% of all vehicle kilometers traveled as AFVs gain a market share of over 33% of new car sales (9 million vehicles sold per annum, including hydrogen vehicles); (iv) By 2030, renewable power generation exceeds 20% of all electricity demand as policy support for solar, wind, and other non-fossil power generation remains robust.

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