Peaking by 2025: Aligning Climate and Energy Goals in China’s 14th Five-Year Plan

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Executive Summary

In its updated Nationally-Determined Contribution (NDC), the Chinese government set goals of peaking carbon dioxide (CO_2) emissions before 2030, and achieving carbon neutrality before 2060, though it did not set target years for either of these goals. This paper examines the combinations of emissions and energy targets that would be needed to peak China's energy-related CO_2 emissions by 2025, or by the end of the 14th Five-Year Plan (2021-2025).

The government's two main levers for reducing energy-related CO_2 emissions over the next five years are managing energy demand growth, captured in five-year plan energy intensity reduction targets, and increasing the supply and share of non-fossil fuel energy, captured in non-fossil fuel energy goals. Together, these two levers shape economy-wide CO_2 intensity reductions — CO_2 emissions per unit gross domestic product (GDP) — another key target in the last two five-year plans.

Our analysis suggests that the current energy intensity reduction (13.5%), non-fossil energy development, and CO_2 intensity reduction goals (18%) in China's 14th Five-Year Plan Outline are unlikely to lead to a peak in energy-related CO_2 emissions by the end of 2025, but also that these targets are not consistent with recent trends within China. Goals that would more likely lead to a 2025 CO_2 peak, and are more consistent with recent trends, include an energy intensity reduction target of greater than 16%, annual wind and solar generation capacity additions of greater than 100 GW per year, and a CO_2 intensity reduction target of greater than 21% (Table 1).

Table 1. Key Energy and Climate Goals in the 14th Five-Year Plan Outline and Goals that are Consistent with a 2025 Peak in Energy-Related CO2 Emissions

	14th Five-Year Plan Outline Goals	Goals Consistent with a 2025 CO_2 Peak
Energy intensity reduction	13.5%	> 16%
Total solar and wind generation capacity additions	76 GW per year	> 100 GW per year
CO_2 intensity reduction	18%	> 21%

Because achieving small incremental reductions in China's CO_2 intensity will require large increases in non-fossil energy supply, we argue that the key to peaking its energy-related CO_2 emissions by or before 2025 will be a more aggressive energy intensity reduction target and a continuation of three nascent trends that would support it: the shift toward services sector-driven economic growth; electrification in the transportation, buildings, and industrial sectors; and more stringent energy efficiency standards, including standards for electric vehicles, electric appliances, and electric industrial equipment.

The continued shift toward greater reliance on non-fossil fuel energy resources and a more energy-efficient economy in the 14th five-year planning period will present new opportunities for technology innovation, growth, and cleaner air in China. It also requires proactive planning and coordination, both within sectors (e.g., for coordinating investments needed to support higher levels of non-fossil generation into the power system) and between them (e.g., for coordinating electrification and power system growth). The 14th Five-Year Plan provides a forum to enable coordination at the scale and with the sectoral scope needed to manage the transitions needed to achieve an earlier peak in China's CO_2 emissions.

1 Introduction

In September 2020, President Xi Jinping pledged that China will achieve a peak in its carbon emissions (碳达峰 | tan dafeng) before 2030 and achieve carbon neutrality (碳中和 | tan zhonghe) before 2060; both goals were enshrined in China's updated (2021) Nationally-Determined Contribution (NDC). China's 14th Five-Year Plan (2021-2025) thus covers a pivotal moment for China's energy and climate policy, as it lays out initial steps in pursuit of these goals.

More specific CO_2 emissions and energy sector targets await sector-specific plans that will be released later in 2022, but the national-level targets that have been released thus far, in the Five-Year Plan Outline,[1] provide useful context for understanding the Chinese government's current level of ambition and what might be possible with additional, or even a continuation of existing, policy effort.

Five-year plans establish high-level targets that reflect the government's main levers for reducing energy-related CO_2 emissions. These include energy intensity reduction targets, which aim to reduce energy demand growth, and targets for increasing the supply and share of non-fossil fuel energy, which aim to reduce fossil fuel consumption. In tandem, energy intensity reductions and non-fossil energy development will shape the target for economy-wide CO_2 intensity reductions, which has been included in the last two five-year plans.

This paper examines proposed targets for energy intensity reductions, non-fossil fuel energy supply and share, and CO_2 intensity reductions for 2025 relative to historical trends and incipient structural changes in China's energy economy. These targets are interrelated: analytically, CO_2 and energy intensity targets and projected GDP growth rates will determine growth in non-fossil energy supply. Using relatively simple, transparent analysis, the paper estimates consistent combinations of targets for energy intensity, CO_2 intensity, and renewable energy deployment that would be necessary to peak CO_2 emissions in or before 2025.

The approach and analysis in this paper complement the growing literature on strategies for meeting China's nearer-term and longer-term greenhouse gas (GHG) emission reduction goals. These include more complex modeling to assess longer-term carbon neutrality pathways,[2] high-level analysis of China's previous 2030 carbon peaking target,[3] and analysis of detailed policy strategies to meet the nearer-term carbon peaking goal.[4] By contrast, this paper develops an analytical framework for understanding the dynamics of a peak in China's energy-related CO_2 emissions and applies the framework to the 14th five-year planning period.

The paper is organized into four thematic sections. The first three sections examine CO_2 intensity, CO_2 energy intensity and non-fossil energy, and energy intensity, respectively. The fourth section describes consistent combinations of CO_2 intensity, energy intensity, and non-fossil fuel energy development needed to peak CO_2 emissions in 2025. The final section provides concluding thoughts.

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[1] NPC (2021).

[2] Fu et al. (2020); ICCSD (2020); Jiang et al. (2018); Pan et al. (2017).

[3] Wang et al. (2016); Xu et al. (2020).

[4] Gallagher et al. (2019).

2 CO_2 Intensity Targets

For restraining CO_2 emissions, the most important target in China's five-year plans is CO_2 intensity, or CO_2 emissions per unit gross domestic product (GDP). Annual CO_2 emissions in a target year T (C_T in Equation 1) are the product of base year (subscript 0) CO_2 intensity (C_0/Y_0), a five-year CO_2 intensity reduction target (α), base year GDP (Y_0), and annual average real GDP growth (r).

$$C_T = \left(\frac{C_0}{Y_0}\right) \times (1+\alpha) \times Y_0 \times (1+r)^{T-T_0} \qquad \text{Eq. 1}$$

China's leaders declined to announce a GDP growth target in the 14th Five-Year Plan but the Chinese economy is expected to grow by 4 to 6 percent per year in real terms between 2021 and 2025.[5] The 14th Five-Year Plan Outline included a target of reducing CO_2 intensity by 18% by 2025, which was the same target set in the 13th Five-Year Plan.[6]

Based on the 14th Five-Year Plan's CO_2 intensity target and a 5-6% real GDP growth forecast, China's total annual CO_2 emissions would increase between 5% (5% GDP growth) and 10% (6% GDP growth) between 2021 and 2025, or equivalently by 1-2% per year. This is lower than the average 2.5% per year that China's annual CO_2 emissions have grown over the past decade, but an 18% CO_2 intensity target would not lead to a peak in the country's annual CO_2 emissions in or before 2025 without lower-than-expected GDP growth.[7]

Narrowly defined, peak CO_2 emissions are the year in which CO_2 emissions in the next year are lower than they were in the previous year.[8] Assuming that five-year CO_2 intensity targets can be linearly interpolated for each year (e.g., an 18% CO_2 intensity target over five years implies 3.6% annual reductions in CO_2 intensity relative to base year intensity), this statement can be written mathematically as

$$\frac{C_0}{Y_0} \times [1+\mu(t+1)] \times Y_0 \times (1+r)^{t+1} < \frac{C_0}{Y_0} \times [1+\mu t] \times Y_0 \times (1+r)^{t} \qquad \text{Eq. 2}$$

where μ is the annually interpolated CO_2 intensity target over t years

$$\mu = \frac{\alpha}{t} \qquad \text{Eq. 3}$$

Solving this equation for μ gives the minimum annual reduction in CO_2 intensity needed to peak emissions at different real GDP growth rates

$$\mu < -\frac{r}{1 + r \times (1+t)} \qquad \text{Eq. 4}$$

Multiplying μ by the planning horizon (T = 5) gives the minimum CO_2 intensity target needed to peak CO_2 emissions in 2025, shown in Figure 1 for different growth rates. At 6% GDP growth, the CO_2 intensity target needed to peak CO_2 emissions in 2025 would be 22.1%; at 5% growth it would be 19.2%; and at lower than 4.6%

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[5] For example, the OECD and IMF project that China's annual average real GDP growth will be 4.4% and 6.0% per year, respectively, between 2020 and 2025. OECD projections are from its GDP long-term forecast, https://data.oecd.org/gdp/gdp-long-term-forecast.htm. IMF projects are from the World Economic Outlook database (April 2021), https://www.imf.org/en/Publications/WEO/weo-database/2021/April.

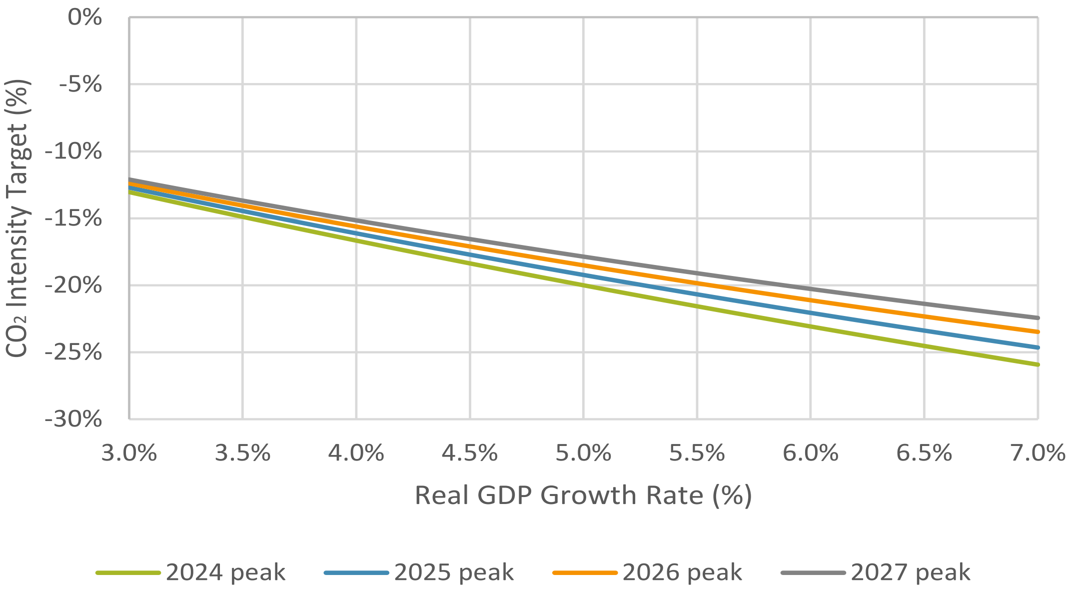
[6] NPC (2021).

[7] Annual average CO_2 emissions are based on data from the Emissions Database for Global Atmospheric Research, https://edgar.jrc.ec.europa.eu/.

[8] Assuming that CO_2 intensity declines monotonically.

growth the plan's current 18% target would be sufficient. Peaking CO_2 emissions in 2025 implies that China's CO_2 emissions continue to grow from 2021 to 2025 and peak by the end of 2025. Figure 1 also shows the CO_2 intensity targets required in 2025 to peak emissions in 2024, 2026, and 2027 (t = 4, 6, and 7 and T= 5). At 5% GDP growth, the existing target (18%) implies a 2027 CO_2 peak if annual CO_2 intensity reductions are sustained after 2025.

Figure 1. Year 2025 CO_2 Intensity Targets Required for Peaking China's Energy-Related CO_2 Emissions in 2024, 2025, 2026, and 2027 at Different Real GDP Growth Rates



Note: For 2026 and 2027, the figure assumes that (linear) annual CO_2 intensity reductions would remain constant after 2025.

3 CO_2 Energy Intensity and Non-Fossil Energy Targets

CO_2 intensity depends primarily on energy intensity, or the amount of primary energy consumed per unit GDP (E/Y), and CO_2 energy intensity, or the CO_2 released per unit of primary energy consumed (C/E)

$$\frac{C}{Y}=\frac{E}{Y}\times\frac{C}{E} \qquad \text{Eq. 5}$$

Reducing energy intensity and CO_2 energy intensity are thus the Chinese government's two main levers for reducing CO_2 intensity. We discuss energy intensity in the next section. Five-year plans do not currently set a target for CO_2 energy intensity, but CO_2 energy intensity is derivative of the CO_2 intensity and energy intensity goals by dividing the former by the latter

$$\frac{C}{E}=\frac{\left(\frac{C}{Y}\right)}{\left(\frac{E}{Y}\right)} \qquad \text{Eq. 6}$$

The 18% CO_2 intensity goal and 13.5% energy intensity goals equate to a 4% reduction in CO_2 energy intensity.[9] Reductions in CO_2 energy intensity suggest both relative and absolute growth in non-fossil fuel energy resources.

Analytically, binding CO_2 intensity and energy intensity goals, GDP growth, and the incremental fossil fuel mix will determine growth in non-fossil fuel energy resources. The CO_2 intensity goal limits the increase in CO_2 emissions from growth in fossil fuel combustion between 2021 and 2025, with higher GDP growth resulting in a higher absolute CO_2 emissions limit. Dividing this increase in CO_2 emissions by the average emission factor of new fossil fuel consumption determines growth in fossil fuel consumption between 2021 and 2025. Growth in non-fossil fuel energy (ΔNF, in exajoule (EJ) or megatons of coal equivalent (Mtce)) is the difference between the growth in primary energy consumption (ΔPE) and growth in primary fossil fuel consumption (ΔFF), which can be estimated from known quantities as

$$\Delta NF=\Delta PE-\Delta FF \qquad \text{Eq. 7}$$

where ΔPE and ΔFF are

$$\Delta PE=\frac{E_0}{Y_0}\times Y_0\times[(1+\beta)\times(1+r)^T-1] \qquad \text{Eq. 8}$$

$$\Delta FF=\frac{\frac{C_0}{Y_0}\times Y_0\times[(1+\alpha)\times(1+r)^T-1]}{\theta_C\times EF_C+\theta_O\times EF_O+\theta_G\times EF_G} \qquad \text{Eq. 9}$$

and where E_0/Y_0 is base year energy intensity, Y_0 is base year GDP, β is the energy intensity goal (-13.5%), r is the annual average real GDP growth rate, C_0/Y_0 is base year CO_2 intensity, α is the CO_2 intensity goal (-18%),

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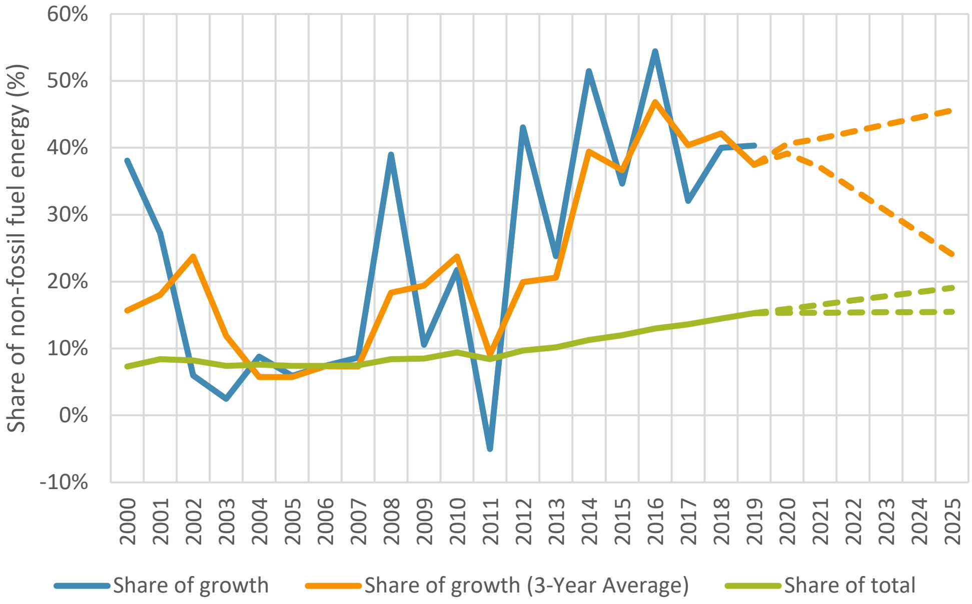
[9] The change in CO_2 energy intensity will be $\rho=1+\alpha\ 1+\beta-1$, from $CE01+\rho=CY0\times\ 1+\alpha EY0\times\ 1+\beta$, where ρ is the reduction in CO_2 energy intensity, α is the CO_2 intensity target, β is the energy intensity target, and subscript zero reflects base year values.

θ_C, θ_O, and θ_G are the shares of coal, oil, and gas in incremental primary fossil fuel energy consumption, and EF_C, EF_O, and EF_G are emission factors for coal, oil, and natural gas.

Figure 2 shows two metrics for the historical (2000-2019) share, and a low range (bottom dotted lines) and high range (top dotted lines) of estimated (2020-2025) shares, of non-fossil fuel energy in primary energy consumption in China. The first metric is the share of growth in non-fossil energy consumption in the growth of primary energy consumption (annual and three-year average). The second metric is the share of non-fossil energy consumption in primary energy consumption. The first metric reflects growth on the margin, whereas the second metric reflects more gradual changes in annual average values. The estimated low and high shares are based on the approach described above and a range of assumptions for GDP growth rates and the incremental primary fossil fuel mix (see the notes to Figure 2).

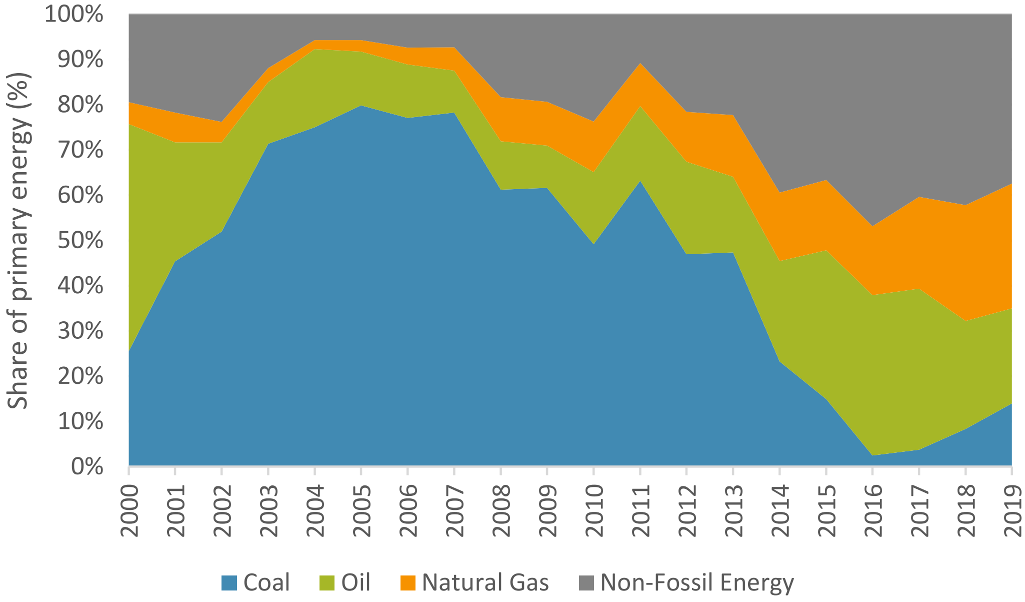
Figure 2. Shares of (a) the Growth in Non-Fossil Fuel Energy in the Growth in Primary Energy Consumption (Annual and Three-Year Average) and (b) Non-Fossil Fuel Energy in Primary Energy Consumption, Historical and Projected Based on 14th Five-Year Plan Outline Targets



Sources and notes: Shares of growth are calculated as , from Equations 7-9. Share of total is calculated as , where the base year values (subscript zero) are for 2019. C0, E0, and Y0 values in Equations 8 and 9 are for 2020. Data for E0 are from NBS (2021). Data for Y0 are from the National Bureau of Statistics' Statistical Yearbook series, accessed from China Data Online. We use a GDP deflator for China from the World Bank's World Development Indicators and a 2015 base year to convert nominal GDP to real GDP. We estimate C0 by assuming that CO2 intensity remained constant between 2019 and 2020. We estimate CO2 intensity for 2019 using historical fossil fuel consumption data and emission factors for primary coal (2.64 tons carbon dioxide per tons of coal equivalent tCO2/tce, 90 tons carbon dioxide per terajoule tCO2/TJ), oil (2.08 tCO2/tce, 71 tCO2/TJ), and natural gas (1.63 tCO2/tce, 56 tCO2/TJ) consumption from the Ministry of Ecology and Environment (MEE), https://www.xmecc.com/pic/201554112545.doc. Historical energy data (2000-2019) are from the NBS (2020). The high case assumes 30%-30%-40% shares of coal-oil-gas in incremental fossil fuel supply, consistent with 2018-2019 shares, and 5% real GDP growth. The low case assumes 0%-30%-70% shares of coal-oil-gas in incremental fossil fuel supply and 6% real GDP growth. Given concerns over air quality, we argue that these provide a realistic bound on the incremental fossil fuel mix. The share of coal in China's incremental fossil fuel supply has not exceeded 30% since 2013. The 0%-30%-70% scenarios would imply a 50% to 100% expansion of China's natural gas supply, depending on GDP growth rates, relative to 2019.

As Figure 2 illustrates, the 14th Five-Year Plan's CO_2 intensity and energy intensity goals imply lower shares of non-fossil fuel energy than occurred over the 2010s. From 2011 to 2016, non-fossil fuel energy resources grew from around 10-20% (three-year average) of China's incremental primary energy supply to around 50%, before falling back to 40% from 2017 to 2019 as an uptick in coal used for power generation and an expansion in natural gas consumption displaced non-fossil energy, illustrated in Figure 3. Growth in coal power generation coincided with policy-driven electrification efforts in 2016[10] and the central government's decision to devolve approval authority for coal power plants to the provinces in late 2014.[11]

Figure 3. Shares of the Growth of Different Energy Resources in the Growth of Primary Energy Consumption in China, Three-Year Rolling Average, 2000-2019



Source: Data are from NBS (2020). During years when coal consumption declined (1996-1997, 1997-1998, 2014-2015, 2015-2016), coal's share is set to zero.

In March 2020, China's National Energy Administration (NEA) announced a goal of meeting 25% of the country's primary energy supply with non-fossil energy by 2030, an increase of 0.9 percentage points per year from its 2019 level of 15.3% and implying a 20% share in 2025.[12] As Figure 2 illustrates, the five-year plan's CO_2 intensity and energy intensity targets are unlikely to be consistent with this goal. In our "high range" scenario (top dotted lines), the share of non-fossil fuel energy in primary energy consumption grows by 0.6 percentage points per year and reaches just over 19% by 2020.

Neither the CO_2 intensity and energy intensity targets nor the NEA's non-fossil energy goals are consistent with the recent pace of non-fossil energy supply growth in China. The high range scenario in Figure 2 implies around 360 GW of new wind and solar generation capacity by 2025 (just over 70 GW per year), assuming 42 GW of new hydropower, 20 GW of new nuclear, and no new biomass generating capacity between 2021 and

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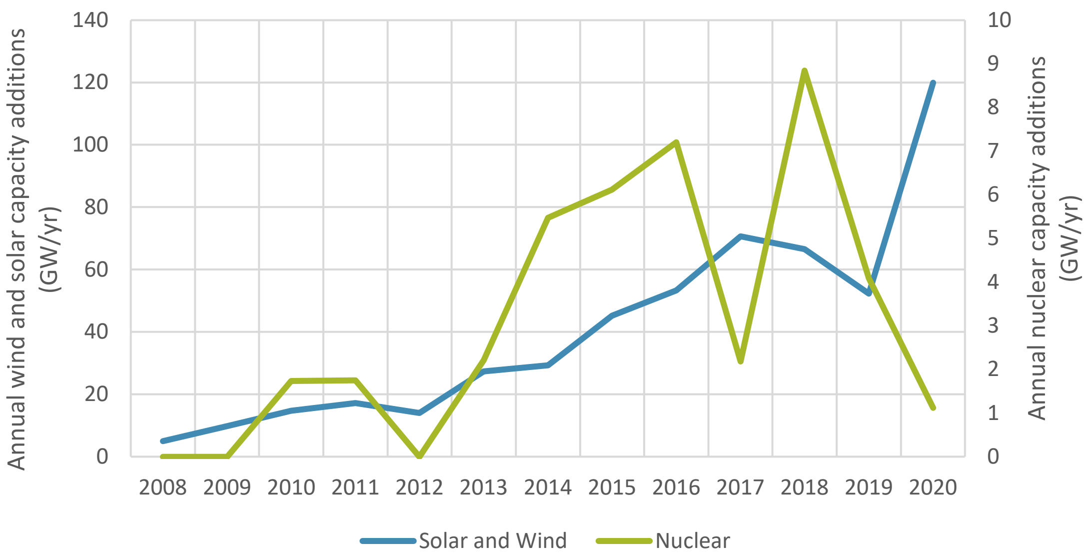
[10] In 2016, several central government agencies jointly issued Guidance on Promoting Electrification (关于推进电能替代的指导意见), as a strategy for meeting national air quality goals. From 2016 to 2018, electricity consumption grew much faster (8% annual average) than primary energy consumption (3%). Electricity and primary energy consumption data are from the Statistical Yearbook series.

[11] In 2014, the central government devolved approval authority for larger coal-fired generating units to provincial governments, which, accounting for the lead time for coal unit construction, would coincide with new units that would have begun commercial operation just after 2017. See Kahrl and Wang (2015).

[12] See, for instance, NEA (2021).

2025.[13] This wind and solar capacity expansion is on par with the 70 GW per year additions in 2017-2018 but would be less than the 120 GW additions in 2020 (Figure 4). It would be slightly higher than the 67 GW per year of wind and solar generation implied by the central government's current target of increasing solar and wind generation to 1,200 GW by 2030.[14] Wind and solar energy currently appear to be China's most scalable non-fossil energy resources, and thus we use the combined annual capacity expansion of these resources (in GW/yr) as a metric to evaluate the incremental level of effort required to meet CO_2 intensity goals.

Figure 4. Annual Wind, Solar, and Nuclear Generation Capacity Additions, 2008-2020



Source: Data are from the China Electricity Commission (CEC), https://www.cec.org.cn.

With the 14th Five-Year Plan's energy intensity goal (13.5% reduction by 2025), peaking CO_2 emissions by 2025 would require an increase in the pace of wind and solar capacity expansion. A CO_2 emissions peak at 5-6% GDP growth translates to 100-180 GW per year of wind and solar, assuming an incremental fossil fuel mix that resembles the 2018-2019 mix (30%-30%-40% coal-oil-gas).[15] This translates to total wind and solar generation capacity of 1,040-1,420 GW by 2025, which is close to or exceeds the government's 2030 goals.

Whether wind and solar can be sustainably developed at terawatt scale in China within the next five years, while managing potential land use impacts and integrating such a large amount of these resources into the power system, remains an open question. The discrepancy between small changes in CO_2 intensity and the large absolute scale of new non-fossil energy resources they imply underscores the importance of reducing energy demand growth during China's 14th five-year planning period.

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[13] We calculate installed capacity values by first converting the primary energy of non-fossil energy to electricity generation using the average net heat rate (efficiency) of coal-fired generation in 2020 (305.5 gce/kWh), consistent with energy accounting conventions in China. We then subtract hydro and nuclear generation, assuming 42 GW of hydropower and 20 GW of nuclear power and using 2020 capacity factors for nuclear (0.85, 7,453 fully loaded hours) and hydro (0.45, 3,827 hours). We assume that wind and solar generation provide all new residual non-fossil energy, using an average capacity factor for combined wind and solar generation of (0.20, 1,752 hours) based on the average 2020 capacity factor for wind (0.24, 2,073 hours) and the average 2019 capacity factor for solar (0.15, 1,291 hours); the CEC has not yet reported capacity factors for solar in 2020. The 42 GW of additional hydropower capacity is based on the NEA's projection of 380 GW of total conventional hydropower by 2025 (NEA, 2016), and 338 GW of conventional hydropower at the end of 2020 reported in CREEI (2021). The 20 GW of additional nuclear capacity is based on a 14th Five-Year Plan goal of 70 GW and a 2020 capacity of 49.89 GW. Unless otherwise noted, all data are from the CEC's 2020 and 2019 National Electric Industry Statistics Report (全国电力工业统计一览表), from www.cec.org.cn.

[14] At the end of 2020, the CEC reported that China had 535 GW of wind and solar generating capacity. Meeting the 1,200 GW goal by the end of 2030 would thus require 665 GW of new wind and solar capacity, or 67 GW per year. Data for 2020 are from the CEC's National Electric Industry Statistics Report.

[15] These estimates use the approach in Equations 7-9 and the same data sources and assumptions as used in previous estimates in this section.

4 Energy Intensity Targets

The 14th Five-Year Plan Outline sets a target to reduce energy intensity by 13.5% by 2025, which would equate to 10-16% growth (2-3% per year) in primary energy consumption between 2020 and 2025, at 5-6% per year real GDP growth rates.[16] Although this is lower than the 3.4% per year growth in China's primary energy consumption over the past decade, 10-16% growth relative to 2020 levels (146 exajoules [EJ], or 4,980 million tons of coal equivalent [Mtce]) would imply primary energy consumption growth of 15 to 23 EJ (518-785 Mtce) between 2020 and 2025.[17] For reference, total primary energy consumption in the entire African continent was 21 EJ in 2018.[18]

Analytically, economy-wide energy intensity is the product of sector-specific energy per value added (E_i/Y_i, for sector i) and the shares of each sector in total value added (Y_i/Y) and residential consumption per total value added

$$\frac{E}{Y} = \sum_i \left(\frac{E_i}{Y_i} \times \frac{Y_i}{Y}\right) + \frac{R}{Y} \qquad \text{Eq. 10}$$

To reduce economy-wide energy intensity, policymakers can (a) reduce energy intensity in individual sectors, including the residential sector, or (b) reduce the share of more energy intensive sectors. At the highest level, the three main economic sectors include the primary (agriculture), secondary (industry), and tertiary (services) sectors.

Changes in the energy intensity of China's economy over the past 30 years can be viewed through the lens of these two strategies. At the onset of China's economic reforms in the late 1970s, the energy intensity of its economy was extraordinarily high relative to other countries (Figure 5). High energy intensity was in part the result of China's "walking on two legs" economic security policies of the 1960s and 1970s and rural industrialization of the 1980s, both of which prioritized less capital-intensive, less energy efficient technologies.[19]

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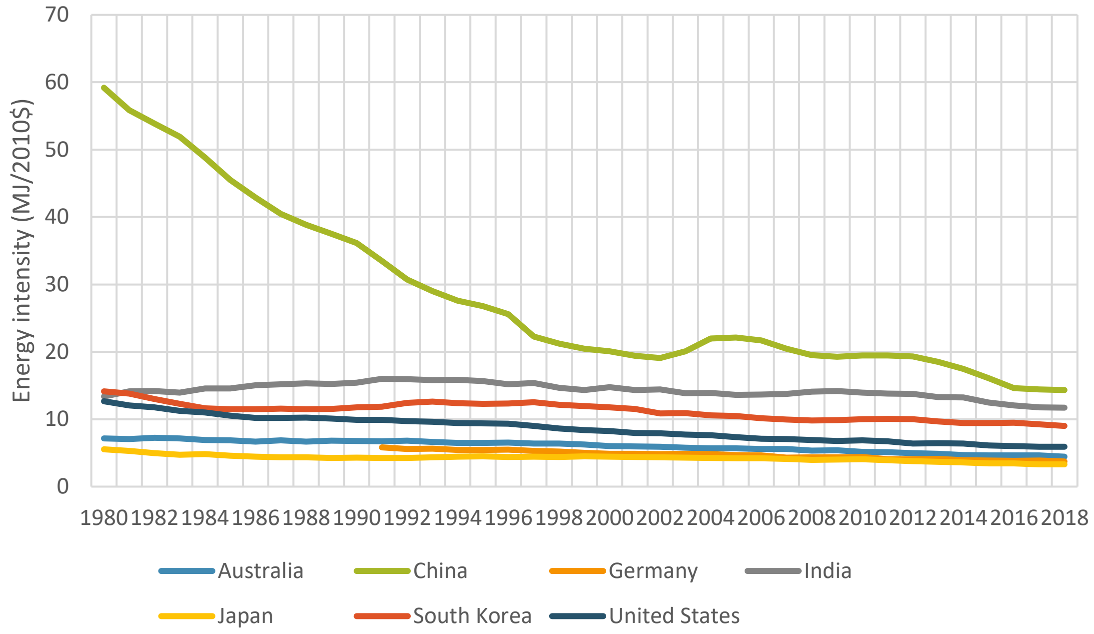
[16] The percentage change in primary energy consumption will be $1+\beta 1+r5-1$, where β is the energy intensity target and r is the annual average real GDP growth rate.

[17] One ton coal equivalent (tce) is equal to 7,000 million calories (MCal). Data for 2020 primary energy consumption in China are preliminary estimates from NBS (2021).

[18] Data for primary energy consumption in Africa are from the U.S. Energy Information Administration, https://www.eia.gov/international/data/world.

[19] For a historical overview, see Naughton (2006).

Figure 5. Energy Intensity for China, Australia, Germany, India, Japan, South Korea, and the United States, 1980-2018



Sources and notes: The selection of countries in this figure broadly captures the experience of several major industrial or industrializing countries at different stages of development but is only intended to be illustrative. Primary energy consumption data are from the U.S. Energy Information Administration, www.eia.gov. Real GDP data (2010$) are from the World Bank's World Development Indicators, https://databank.worldbank.org/. Given that China will soon become a high-income country,[20] we argue that exchange rates, rather than purchasing power parity (PPP), are a more meaningful basis for comparing energy intensities.

Efforts in the 1980s focused on upgrading the industrial sector and reducing energy use led to dramatic reductions in the energy intensity of the Chinese economy and convergence with other major economies.[21] This convergence trend began to slow for a variety of reasons — some related to energy policy and some to macroeconomics — in the 2000s and 2010s.[22]

A key driver of high energy intensity in China has been the structure of its economy. Over the last 30 years of economic reforms, China has maintained a high rate of investment and a high industrial share of GDP, reflecting continued growth in heavy industrial output to support infrastructure development. In economic, industrial, and energy policy circles, growth in industrial capacity has been closely linked with urbanization.[23]

China's urban population grew by nearly 660 million people (from 19% to 60% of total population) between 1980 and 2019, involving one of the largest migrations in human history.[24] Its urban population is expected to continue to grow to 70% (+180 million) by 2030 and 80% (+100 million) by 2050.[25] Measured over the span of the next decade, a 180 million (18 million persons per year) increase in urban population would be on par with average rates of increase over the past two decades (20 million persons per year).[26] By the logic of industrialization and

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[20] The World Bank defines high income as a GNI per capita of $12,696, calculating using its Atlas method. China's 2020 GNI per capita was $10,610, which suggests that it will become a high-income country during the 14th five-year planning period.

[21] Levine et al. (2009).

[22] Over the 1990s and 2000s, the share of industry in China's GDP grew steadily, peaking at 48% in 2006. Beginning in the 1990s, China's government also put less emphasis on energy efficiency (Levine et al., 2009).

[23] For instance, following the collapse of global demand for steel in the wake of the 2007-2009 global recession, the State Council's 2009 Plan for Restructuring and Revitalizing the Steel Industry (钢铁产业调整和振兴规划), noted that "in the current phase, with continued urbanization and industrialization, internal demand [for steel] will continue to be strong, leaving the fundamentals of steel industry growth unchanged" (现阶段，我国城镇化、工业化任务依然繁重，内需潜力巨大，钢铁产业发展的基本面没有改变). See http://www.gov.cn/zhengce/content/2009-03/20/content_8122.htm.

[24] Data are from NBS (2020).

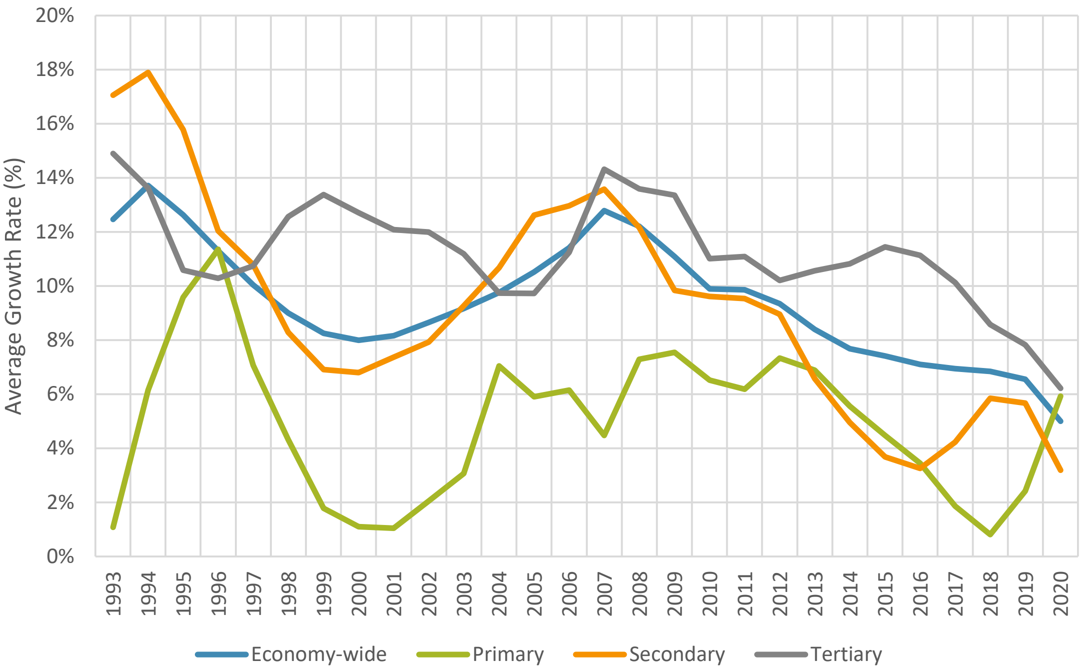
[25] Expected growth in urban population is from the Chinese Academy of Social Sciences Urban Blueprint (城市蓝皮书) series, https://www.pishu.com.cn/skwx_ps/classify?SiteID=14&classType=Book&deriesId=1450. Population forecasts are based on the UN's 2019 Revision of World Population Prospects, https://population.un.org/wpp/.

[26] Historical data are from the Statistical Yearbook series, accessed through China Data Online.

urbanization, sustained rapid growth in urban population would lead to continued growth in industrial capacity, and in particular the primary inputs to construction: steel, cement, and other energy-intensive industrial goods.

The relationship between industrialization and urbanization has, however, become more tenuous over the past decade.[27] Most notably, the structure of China's economy underwent a significant shift in the wake of the global financial recession in 2007-2009, with the secondary sector's share of GDP falling from 47% in 2011 to 38% in 2019 and the tertiary sector becoming the primary engine of GDP growth.[28] Most of the decline in the secondary sector's share of GDP was driven by a more rapid slowdown in secondary sector value added growth relative to the slowdown in tertiary sector growth, as part of an overall slowing of China's GDP growth over the late 2000s and 2010s (Figure 6).[29] The causes and dynamics of this slowdown in growth remain unexplained.

Figure 6. Economy-Wide and Sector-Specific Real GDP Growth Rates in China, Three-Year Rolling Average, 1990-2020



Source: Data are from the Statistical Yearbook series, accessed through China Data Online.

If tertiary sector value added continues to grow more rapidly than secondary sector value added over the next five years, the secondary sector's share of GDP will continue to decline. At the relative growth rates between 2015 and 2020, the secondary sector's share of GDP would further fall to 35% by 2025.[30]

The energy intensity goal in China's 14th Five-Year Plan Outline reflects assumptions about continued changes in economic structure and in sector-specific energy intensity that are consistent with changes during 2015-2020. Table 2 shows changes in energy intensity by sector and the shares of each sector in total GDP in each five-year planning period. The "2025-A" scenario, in which changes in sector-specific energy intensity are held at 2020-

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[27] The degree to which urbanization and the development of industrial capacity were ever that intimately interconnected in China remains an open question, because the expansion of urban real estate was often driven by distorted factor prices and urbanization was often incomplete. See, for instance, Tao (2014).

[28] Data are from the Statistical Yearbook series, accessed through China Data Online.

[29] Part of the relative slowdown in China's secondary sector over this time period may have been the result of falling prices for industrial commodities. Because we are calculating real value added by sector using a GDP deflator, we will not account for the shifting structure of prices within the Chinese economy.

[30] Specifically, annual average real growth rates for the primary, secondary, and tertiary sectors between 2015 and 2020 were 3.8%, 4.1%, and 7.3%, respectively. If 2014-2019 were used instead, to account for pandemic-related impacts in 2020, growth rates would be 2.7%, 4.4%, and 9.2%, respectively, and the secondary sector's share of GDP would fall to 33% by 2025. Data are from the Statistical Yearbook series.

2025 levels the changes in sector shares of GDP reflect growth relative rates during 2015-2020, has an overall decline in energy intensity of 13.2%, slightly lower than the 14th Five-Year Plan Outline's 13.5% target.

Table 2. Changes in Energy Intensity (E^n/Y^n) from the Previous Five-Year Planning Period by Sector, and Sector Shares of GDP (Y^n/Y) at the End of the Planning Period

	Total	Primary		Secondary		Tertiary		Resident
	$\Delta(E/Y)$	$\Delta(E^P/Y^P)$	Y^P/Y	$\Delta(E^S/Y^S)$	Y^S/Y	$\Delta(E^T/Y^T)$	Y^T/Y	$\Delta(E^R/Y)$
Historical								
1995	-25%	-14%	20%	-30%	47%	-28%	34%	-44%
2000	-26%	-32%	15%	-27%	46%	-6%	40%	-30%
2005	11%	28%	12%	10%	47%	3%	41%	3%
2010	-19%	-23%	9%	-17%	46%	-23%	44%	-23%
2015	-18%	-14%	8%	-12%	41%	-15%	51%	-6%
2020	-13%	4%	8%	-11%	38%	-10%	55%	-3%
Scenarios for 2025								
2025-A	-13%	4%	7%	-11%	35%	-10%	58%	-3%
2025-B	-16%	4%	7%	-11%	35%	-15%	58%	-15%
2025-C	-16%	4%	7%	-15%	35%	-10%	58%	-3%
2025-D	-19%	-10%	7%	-15%	35%	-20%	58%	-20%

Sources and Notes: Resident refers to residential energy consumption. All data is from the Statistical Yearbook series, with GDP data deflated using a GDP deflator for China from the World Bank's Development Indicators. Sector-specific energy data are only available until 2018. We calculate sector-specific energy intensity for 2020 by assuming that the energy intensity of the primary, tertiary, and residential sectors remained constant between 2018 and 2020, and then solving Equation 10 for secondary sector energy intensity (E/Y). Because economy-wide energy intensity in 2018 was less than 5% different than in 2020, this results in sector-specific energy intensities that are close to their 2018 values.

The Outline's energy intensity target may have been set at a lower level due to the fact that the 13th Five-Year Plan (2016-2020) target (15%) was ostensibly not met. However, from 2015 to 2018 China was on track to exceed this target. Annual (linear) economy-wide reductions in energy intensity were 3.6% per year from 2015 through 2018, the last year that sector-specific energy consumption data is available.[31] Had this trend continued, China's economy-wide energy intensity would have fallen by 18% by 2020, consistent with its reduction in the 12th Five-Year Plan (2011-2015). Reductions in secondary, tertiary, and residential sector energy intensity would have been 18%, 17%, and 3%, respectively. It is not clear why energy intensity reductions slowed between 2018 and 2020, or whether this might be a data anomaly that is later corrected.

Table 2 presents three alternative scenarios for economy-wide energy intensity reductions in 2025, reflecting a range of assumptions for sector-specific energy intensity reductions. With larger (15%) energy intensity reductions in the tertiary and residential sectors (Scenario 2025-B, in Table 2), or with larger (15%) reduction in the secondary sector (Scenario 2025-C), economy-wide energy intensity would fall by 16% between 2020 and 2025. With energy intensity reductions in all sectors that lie between those from 2005-2010 and 2010-2015 (Scenario 2025-D), the decline in China's economy-wide energy intensity would be 19%.

As it has been historically, the secondary (industrial) sector is pivotal to achieving larger reductions in China's economy-wide energy intensity. Holding sector-specific shares of GDP constant, the marginal change in economy-wide energy intensity (E/Y) per an additional one percentage point decline in a sector's energy intensity change in each sector will be

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[31] Data are from NBS (2020).

$$d\left(\frac{E}{Y}\right) = -0.01 \times \left(\frac{E_i}{Y_i}\right)_0 \times \left(\frac{Y_i}{Y}\right)_0 \qquad \text{Eq. 11}$$

where the zero subscripts represent values in a base year.

Table 3 shows these marginal change values, using 2020 base year values for sector-specific energy intensity (E_i/Y_i) and the share of each sector in GDP (Y_i/Y). For the residential sector, we represent Y_i/Y as 1.0 to reflect the fact that its contribution to energy intensity is based on total rather than sector-specific value added.

Table 3. Marginal Change in Economy-Wide Energy Intensity for a One Percentage Point Change in Sector Energy Intensity

Sector	A = $(E_i/Y_i)_0$	B = $(Y_i/Y)_0$	C = -0.01 x A x B
Primary	0.15	0.07	-0.0001
Secondary	0.96	0.35	-0.0035
Tertiary	0.19	0.58	-0.0011
Residential	0.07	1.00	-0.0010

Sources: Data are from the Statistical Yearbook series. See Table 2 for notes on 2020 values.

The values in Table 3 suggest that a one percentage point reduction in secondary sector energy intensity can produce reductions in economy-wide energy intensity that are more than three times higher than other sectors. While underscoring the importance of the secondary sector, the marginal values in Table 3 do not provide an indication of the potential or cost-effectiveness of energy intensity reductions across sectors. For the secondary sector, changes in aggregate energy intensity may be shaped as much by changes in within-sector structure growth — a shift in industrial output growth to less energy intensive manufacturing, for instance — as technical energy efficiency. For the tertiary and residential sectors, the two most important elements are building and transportation efficiency.

Energy accounting convention in China is to convert non-fossil electricity generation to primary energy using the average net efficiency of coal-fired power plants.[32] As a result, energy intensity can provide a misleading picture of changes in final energy consumption during periods when electricity consumption is growing faster than primary fossil fuel consumption, as has recently been the case. For instance, an energy intensity target of 13.5% and a GDP growth rate of 5% would imply primary energy consumption growth of 15.2 EJ (518 Mtce, 10% increase) between 2021 and 2025. If all of this primary energy consumption is electricity, however, final consumption growth would be around 5.7 EJ (194 Mtce, 6% increase).[33] In many sectors, electrification should lead to significant end-use efficiency improvements and a reduction in primary energy consumption.[34] Thus, continued electrification should be consistent with low growth in final energy consumption and primary energy intensity reductions.

The 14th Five-Year Plan Outline appears to reflect an understanding that, for whatever reason, the potential for

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[32] For a critique of this approach, see Lewis et al. (2015).

[33] This assumes the CEC's average 2020 net heat rate of 305.5 gce/kWh and average transmission and distribution losses of 7%. We calculate growth in final energy consumption here as $\omega \times \varphi$, where ω is the growth rate of primary energy consumption (10%), φ is the conversion factor for primary to final electricity consumption (0.37, based on the previous sentence), and τ is the average ratio between final and primary energy consumption, which we assume to be 0.65 based on IEA (2019) estimates for China.

[34] A simple illustrative example provides context. For instance, in 2019 car sales in China were approximately 20 million. Assuming a driving range of 10,000 km/veh-yr, China's 2020 average fuel economy requirement of 5 L/100 km, and an gasoline energy content of 32 MJ/L, final energy consumption from these 20 million cars would be 320 PJ/yr and primary energy consumption would be around 340 PJ/yr, assuming 10% conversion losses in gasoline refining. If these 20 million vehicles were instead EVs with an efficiency of 0.14 kWh/km and assuming 7% average losses in transmission and distribution and 40% net conversion efficiency, final energy consumption for these vehicles would be 100 PJ/yr and primary energy consumption would be 270 PJ/yr. With efficient end-use electric technologies, electrification could lead to large declines in final energy consumption growth and smaller declines in primary energy consumption growth in many sectors, depending on technology choices. The EV efficiency estimate for China is based on a mid-sized car, from Lutsey et al. (2021).

further declines in energy intensity has already begun to saturate. However, the fact that China's energy intensity remains higher than neighboring high-income countries (Figure 5) suggests that there may still be potential for more significant reductions, as China continues its transition toward a more information- and services-oriented economy. For instance, a 3% per year linear reduction in China's 2020 energy intensity (15% between 2020 and 2025) would still leave it higher than South Korea's (2020 value) until around 2029.[35]

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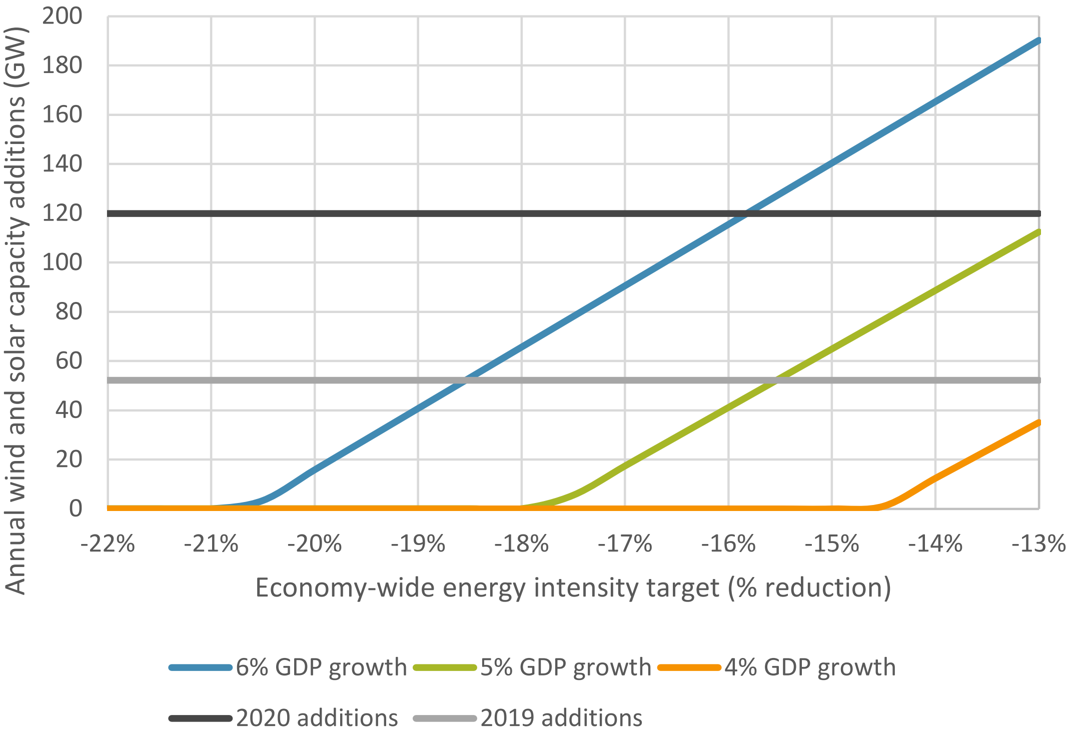
[35] Data here are from the IEA's Data browser. According to IEA estimates, China had an energy intensity of 9.7 GJ/$1,000 (2015) in 2020 and South Korea had an energy intensity of 7.1 GJ/$1000 (2015). For China, reducing energy intensity each year by 3% relative to a 2020 value (0.3 GJ/$1,000 per year), would imply just under 9 years to reach 7.1 GJ/$1,000.

5 CO_2 Intensity, Energy Intensity, and Renewable Expansion

With a fixed CO_2 intensity target, different economy-wide energy intensity targets for 2025 will imply a total amount of non-fossil fuel electricity generation, and within that an annual expansion (GW/yr) of wind and solar generation capacity. This required expansion of wind and solar generation capacity provides a useful metric for understanding the scale of change required to meet a CO_2 intensity target.

Figure 7 shows the annual average wind and solar generation capacity expansion required to meet a CO_2 intensity target that would peak CO_2 emissions in 2025, for different energy intensity targets and at different GDP growth rates. The horizontal lines show wind and solar generation capacity additions in 2020 (120 GW/yr) and 2019 (52 GW/yr), to put the annual expansion estimates in context.

Figure 7. Annual Average Wind and Solar Generation Capacity Expansion Required to Peak CO_2 Emissions in 2025, for Different Energy Intensity Targets



Notes and sources: The calculations in this figure use the CO_2 intensity calculation in Equation 2, the non-fossil energy calculations in Equations 7-9, and the same assumptions and data sources as in previous sections. As in previous sections, they assume an incremental fossil fuel mix of 30%-30%-40% coal-oil-gas (2.08 tCO_2/tce incremental emission factor), 42 GW of new hydropower, and 20 GW of new nuclear between 2021 and 2025.

Figure 7 illustrates that more ambitious energy intensity targets can moderate the pace of growth in non-fossil energy needed to meet intensity-based and absolute CO_2 emissions goals. For instance, at 6% per year real GDP growth, each one percentage point reduction in energy intensity could reduce the need for 12 GW/yr of wind and solar generation capacity (60 GW over 5 years), to meet a CO_2 intensity target that peaks CO_2

emissions in 2025. Proactive investments in technology-based energy efficiency in buildings, transportation, and industry can also reduce the risk of not meeting CO_2 goals due to higher-than-expected economic growth or lower than expected expansion of non-fossil energy resources.

Figure 7 also shows the combinations of energy intensity target and annual wind and solar expansion which would lead to a peak in CO_2 emissions earlier than 2025. These combinations will be any point above the sloped lines. For instance, with an energy intensity target of 17%, annual wind and solar expansion higher than around 90 GW will lead to a CO_2 emissions peak earlier than 2025.

6 Conclusions

China's recent energy supply and demand trends suggest that peaking energy-related CO_2 emissions in or before 2025 lies within the domain of feasibility. At 5-6% annual average real GDP growth over 2021-2025, a 2025 CO_2 peak is consistent with a CO_2 intensity goal of 19-22%, compared to the current goal of 18%. Peaking CO_2 emissions in 2025 would require expanding non-fossil fuel energy resources and reducing energy demand growth beyond existing policy targets but not at a pace that exceeds historical precedent.

Among China's non-fossil fuel energy resources, wind and solar energy are currently the most scalable. Annual wind and solar generation capacity expansion (GW/yr) provides a useful metric for considering the level of effort required to achieve CO_2 intensity goals. With a range of 5-6% annual GDP growth and the current energy intensity target (13.5%), peaking CO_2 emissions in 2025 would require 100-180 GW/yr of new wind and solar generation capacity. The lower end of this range is lower than capacity additions in 2020 (120 GW/yr), but the higher end exceeds historical precedent in any country. The discrepancy between small changes in China's CO_2 intensity goals and the large changes in absolute non-fossil fuel energy deployment required to meet them underscores the importance of reducing energy demand growth in the 14th five-year planning period.

The 13.5% energy intensity target in the 14th Five-Year Planning Outline appears to be misaligned with emerging trends: a declining share of industry in GDP; electrification in industry, transportation, and buildings; and the implementation of more stringent energy efficiency standards for vehicles and appliances. An energy intensity target of at least 16% (Scenario 2025-B or 2025-C in Table 2) is more consistent with trends from 2010 to 2018 and would help to moderate the annual wind and solar capacity additions needed to achieve an earlier peak in CO_2 emissions. It is not clear that a 16% energy intensity target would, in fact, require additional effort beyond existing economic and energy policies, aside from perhaps a greater emphasis on energy efficiency to accompany electrification in the transportation and building sectors — for instance, encouraging heat pumps rather than radiative heating or efficiency standards for electric vehicles. A higher energy intensity target would, however, likely require the political will to continue changing China's economic growth model.

The combination of an energy intensity target greater than 16% and roughly 11 EJ (365 Mtce) of new non-fossil energy supply — 100, 8, and 4 GW/yr of new wind and solar, hydropower, and nuclear generation capacity — would be consistent with a CO_2 intensity reduction of between 21-22% at 5-6% GDP growth.[36] At higher GDP growth rates (6%), these targets would imply a 2026 peak in CO_2 emissions, but at growth rates lower than around 5.5% would imply a CO_2 peak during the 14th Five-Year Plan.

For the global climate system, it likely does not matter whether China's CO_2 emissions peak in 2025, 2027, or even 2030. However, an earlier peak in China's emissions would have a galvanizing effect for the international community, providing a strong signal of the Chinese government's political will to reduce GHG emissions to net zero levels by 2060. More rapid energy intensity reductions and non-fossil energy development would also present new opportunities for technology innovation, growth, and cleaner air in China. The 14th Five-Year Plan provides a forum for the cross-sector planning and coordination needed to achieve an earlier peak in China's CO_2 emissions.

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[36] The calculations here are the same as those in Figure 7, but rather than using CO_2 intensity as a fixed input and calculating wind and solar generation expansion, they use wind and solar generation expansion as an input and calculate the change in CO_2 intensity.

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