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China's 'new normal': better growth, better climate (Appendices)

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Appendix I: NCE China Study (Summary findings)[1]

Policy and planning options for China's new development phase have been investigated in China and by New Climate Economy (NCE) project of the Global Commission on the Economy and Climate (GCEC). Stern is the Co-Chair of the Commission and Chair of its Economics Advisory Panel. This Appendix sets out the key findings of the Commission's ground-breaking study, *China and the New Climate Economy* (GCEC 2014b) (NCE China Study).

a) Background to the New Climate Economy China Study

The NCE China Study is one of the country case studies produced for the NCE project to complement and deepen the Commission's flagship Global Report, *Better Growth Better Climate: The New Climate Economy Report* (GCEC 2014a) (the NCE Global Report). The NCE China Study was produced by researchers at Qinghua University, which was also one of the eight affiliated research centres that had key input into the development of the NCE Global Report.[2] The involvement of the Qinghua research team in the Commission's work was extremely valuable and is an important example of China's growing global engagement on the issue of climate change.

The NCE Global Report provided independent and authoritative evidence on the relationship between actions that can strengthen economic performance and those that reduce the risk of dangerous climate change. The report focuses on the next two decades and shows that the coming transformation of the world economy in this period (see Part 1(a) of the Policy Paper) can be combined with action on climate change and can produce both strong, better quality growth and powerful acceleration of action on climate change.

China is a key country case study for the "better growth, better climate" concept, not only because of its size and its importance in tackling climate change, but also because other countries, less advanced in the structural transformation of their economies, will try to learn from China's experience. If China's policymakers had understood earlier the full effects of its coal-based, heavy-industrial development model, it is likely that China's development path would have taken a more sustainable path much earlier than now. There are important lessons, therefore, in both the NCE Global Report and the NCE China Study, for less developed countries and other emerging economies.

The NCE China Study demonstrates how, with the right policies, China can modernise its economy (achieving the structural change necessary to overcome the "middle-income trap" and become a high-income country) and achieve major improvements in energy security, local air pollution, and greenhouse gas emissions from the perspective of growth-climate interactions. The study was undertaken in 2013–14 and published in November 2014. The pace of change in China, even in the brief period since the study was undertaken, has been extraordinary.

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[1] The authors are grateful to the research team at Qinghua University who produced the New Climate Economy China Study, led by Professors He Jiankun and Qi Ye, and to Teng Fei for his guidance on Appendix I.

[2] See http://newclimateeconomy.net/content/research-partners.

b) Findings of the Study

i) Greenhouse gas emissions

The NCE China Study involved the modelling of scenarios for GDP growth, the energy sector (e.g. total energy consumption and energy mix), CO_2 emissions from energy, and local urban air pollution (SO_2, NOx,colatile organic compounds, and particulate matter (PM) — both primary and secondary PM).

Rather than starting with a CO_2 emissions constraint such as a peak emissions level, the Study models the emissions levels as consequences of assumptions about future economic growth and the emissions intensity of growth. These in turn depend on energy production and consumption patterns. The study thus considers the economic and energy conditions under which a 2030 CO_2 emissions peak is possible. To interpret the Study's results, it is therefore important to appreciate the relationship between economic growth, the energy intensity of growth, and the emissions intensity of energy (see Box 1 in Appendix III, below).

The Study modelled three scenarios ('high', 'middle' and 'low') for China's future GDP growth (see Table 1, below).

Table 1: Three Scenarios for China's economic growth (% Change in GDP)

Period	Low Growth Scenario (%)	Middle Growth Scenario (%)	High Growth Scenario (%)
2010–2020	6.11	7.31	7.87
2020–2030	3.28	4.77	6.02
2030–2050	2.33	3.15	4.60
2010–2050 ave.	3.51	4.60	5.78

Source: GCEC (2014b, p 52, Table 3a)

The results of these GDP growth scenarios were then put into the Study's energy sector model to analyse energy consumption and CO_2 emissions. The energy model considers two further scenarios concerning efforts to decarbonise the economy:

- a ***Continued Emissions Reduction Scenario*** (CERS), which assumes China continues to promote energy conservation and emissions reduction strategies, improve energy efficiency and develop non-fossil fuel energy sources through moderate additional policy interventions beyond what was planned at the time (i.e. somewhat beyond "business as usual"); and
- an ***Accelerated Emissions Reduction Scenario*** (AERS), which assumes significant additional policy measures beyond the CERS.

It is important to bear in mind that "accelerated effort" must be interpreted from the perspective of when the study was undertaken, in 2013–2014, and that subsequent policy developments and structural change already goes beyond the accelerated effort scenario.

The Study finds that China's ability to peak emissions in 2030 is highly sensitive to China's economic growth rate over the next 15 years. The modelling exercise found that even under the "accelerated" scenario, peak emissions in 2030 would not be possible if Chinese GDP were still growing at more than 5% per year on average over the 2020–2030 period.[3] (It must be remembered, however, that this is a modelling projection contingent on assumptions about the relationship between emissions and economic output, not a necessary truth; it is eminently possible that the Chinese economy could sustain >5% growth rates in 2020–2030 while seeing emissions peak during that decade — see Box 1 in Appendix III, below.)

Under the "middle" economic growth scenario — where the Chinese economy averages 7.31% GDP growth per year between 2010–2020, and 4.77% growth between 2020 and 2030 — the energy model's "accelerated" emissions reduction scenario causes CO_2 emissions to peak in 2030. The "middle" economic growth scenario looks plausible in light of experience over the period 2011–2015 (see World Bank 2014). Accordingly, the study focuses on this middle growth scenario as the central scenario for its energy, CO_2, and air pollution analysis, and this is reflected in the results outlined below.

Table 2, below, sets out the Study's results from its energy sector modelling exercise, showing results for total energy consumption, energy intensity of GDP, CO_2 emissions from energy, the CO_2 (from energy) intensity of GDP, and the proportion of non-fossil energy in the energy mix — in each case for both the "continued" effort and "accelerated" effort scenarios in 2020 and 2030 (2010 actual data are also shown). We also include below projections of total GHG emissions in China from all sectors, assuming that the 2010 ratio of energy CO_2 emissions to total greenhouse gas emissions (1:1.3), as recorded in the CAIT database (WRI 2014) remains constant throughout the relevant period. China's total greenhouse gas emissions, as recorded in CAIT, include emissions from all key greenhouse gases[4] and emissions sources, including energy, industrial processes, agriculture, waste, land-use change and forestry (which for China was a net sink in 2010), and bunker fuels (WRI 2014). We note, however, that this may somewhat overstate future GHG emissions projections, since it is likely that non-CO_2 emissions (especially CH_4 and N_2O from the agriculture sector, and HFCs and N_2O from industry) will not grow as fast as CO_2.[5]

[3] Assuming growth of >7% per year on average during 2010–2020.
[4] CO_2, CH_4, N_2O and F-gases.
[5] We thank Teng Fei bringing this point to our attention.

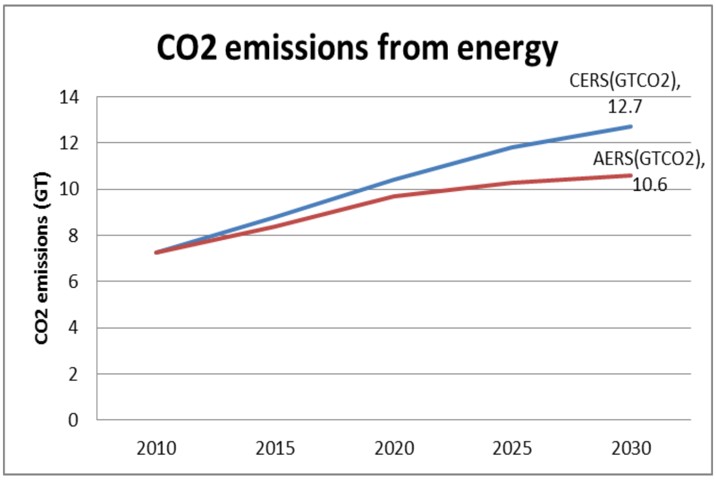
Table 2: Comparison of key results from the "continued" and "accelerated" emissions reduction scenarios in the NCE China Study's energy modelling

		Continued Emissions Reduction Scenario		Accelerated Emissions Reduction Scenario	
Variable	**2010 (actual)**	**2020**	**2030**	**2020**	**2030**
Total Energy Consumption (billion tce)	3.25	4.92	6.25	4.75	5.9
Energy Intensity of GDP (2010 = 100)	100	73.4	54.6	70.6	51.6
CO_2 emissions from energy (GT)	7.25	10.4	12.7	9.68	10.6
CO_2 intensity (energy) of GDP (2010 = 100)	100	69.6	51.1	64.8	41.5
Proportion of non-fossil energy (%)	8.6	14.5	20	15	23
Total GHG emissions (GT CO_2e)*	***9.4***	***13.5***	***16.5***	***12.6***	***13.8***

Source: GCEC (2014b, p 82, Table 4.4; does not include total GHG emissions results)
Note: All results assume economic growth averaging 7.31% between 2010–2020, and 4.77% between 2020–2030, based on the NCE China Study's "Middle" economic growth scenario.

** Total GHG emissions results calculated by authors assuming a constant ratio of CO_2 emissions from energy to total GHG emissions (including land use change and forestry) of 1:1.3, based on 2010 data from WRI (2014).*[6]

Figure 1: Projections of CO_2 emissions from energy in the NCE China Study's energy modelling



[6] This method of projecting total GHG emissions may somewhat overstate future GHG emissions projections, since it is likely that non-CO_2 emissions (especially CH_4 and N_2O from the agriculture sector, and HFCs and N_2O from industry) will not grow as fast as CO_2. On the other hand, the WRI dataset is at the lower end of the range of data for China's emissions — compare the data from IEA (2015). The model is being updated to reflect the recent revisions to China's energy statistics in light of the one in five years economic census done in 2014.

Under the CERS, the projected results are that: the energy intensity of China's GDP cumulatively falls 45.4% between 2010 and 2030, and China's total energy consumption rises to 6.25 billion tonnes (GT) of coal equivalent by 2030, with the non-fossil share of energy reaching 20% by 2030. The CO_2 emissions intensity of China's economy cumulatively falls 48.9% between 2010 and 2030,[7] at which point CO_2 emissions from energy reach 12.7GTCO_2, and keep rising until their peak in 2040. China's total net GHG emissions in 2030 under this scenario would be around 16.5GT.

By contrast, under the Study's "accelerated" scenario, China's energy consumption and emissions levels are lower than in the continued effort scenario. Specifically, the energy intensity of China's GDP cumulatively falls 48.4% between 2010 and 2030, and China's total energy consumption rises to 5.9GT of coal equivalent by 2030, with the non-fossil share of energy reaching 23% by 2030. The CO_2 emissions intensity of China's economy falls (or "carbon productivity rises") cumulatively 58.5% between 2010 and 2030, at which point CO_2 emissions from energy reach a peak of 10.6GTCO_2, implying total net GHG emissions in 2030 of 13.8GT.

The Study then considered the benefits to China's economy and society in terms of energy security and reduced air pollution under the accelerated effort scenario, and assessed the costs to the economy of this accelerated effort.

ii) Energy security

The Study finds that under this (accelerated effort) scenario, China's economy is less dependent on domestic and imported fossil fuels, significantly reducing the vulnerability of its economy to external energy price fluctuations and shocks. Under the CERS, China will be 75% dependent on imported oil in 2030 and coal consumption will go beyond the scientifically assessed domestic production capacity. Under the AERS, by contrast, total energy consumption will be 5% lower than under the CERS by 2030.

iii) Air pollution

With regard to air pollution, the Study used an air quality simulation model to model the combined effects of strict "end of pipe" technology (i.e. assuming these are mandated through regulation) and each of the two energy/emissions scenarios discussed above, focusing on the three key production regions of Beijing–Tianjin–Hebei, Pearl River Delta and Yangtze River Delta. Here, "strictness" refers to a combination of the regulated standards and implementation/enforcement of those standards (and it is important to remember that countries such as Germany have faced major challenges in implementing end-of-pipe technology, even with a very advanced economy and technology).

The Study finds that even with the strictest end of pipe technologies, these regions can only achieve Grade II Air Quality standards if China's energy consumption and energy structure are transformed as per the accelerated effort scenario in which CO_2 emissions also peak by 2030. Without such accelerated efforts consistent with CO_2 emissions peaking in 2030, about 50% of Chinese major cities will fail to meet the air quality standard (even with the most stringent end of pipe technologies). The 2030

[7] More positively, this can be expressed in terms of the carbon *productivity* of China's economy *rising* by these amounts over the relevant period.

emission peaking goal is therefore consistent with China's domestic interests to win the "war on pollution". In this way, the Study underscores the importance of the structural transformation away from coal in order to improve air quality standards.

iv) Economic costs of accelerated effort

The Study models the economic costs of the accelerated effort scenario using a computable general equilibrium (CGE) model which assumes (for simplicity) that the accelerated policy efforts take the form of a simple carbon tax, the revenue from which is "recycled" (i.e. offset) by equivalent reductions in existing, more distorting taxes (i.e. it is "revenue neutral").[8] The model projects that this scenario would result in very low costs to the economy in terms of conventionally measured GDP (under 1% of GDP to 2030).

It is important to emphasise that this figure, as with all modelling exercises, should be regarded as indicative only and is subject to a number of limitations. Most importantly, the CGE model assumes that the tax is being introduced into a perfectly efficient economy in which there are no distortions or market failures. As such, the economic benefits of the accelerated effort scenario, in the form of enhanced energy security and lower health and environmental costs (discussed above) are not factored into the model. These benefits would likely offset a large portion of the projected GDP costs. The long-term reduction in climate risks associated with such an emissions constraint, and the associated benefits to the economy, are also excluded from the CGE model.

A further limitation of the model, common to CGE models, is that it does not capture the potential for climate policies to induce innovation in green technologies, with knowledge spillovers into other sectors, which are likely to drive higher GDP growth than otherwise (Aghion et al. 2014). It is not only the endogenous, innovation-enhancing effect of the (modeled) tax itself that is left out of the model: greater innovation is likely to be induced by policies directly aimed at supporting green innovation (Aghion et al. 2014), so it is likely to be possible to achieve even greater economic benefits by applying some of the revenue from carbon taxes toward the research and development (and innovation more broadly) of clean technologies than by applying it to efficiency-enhancing tax reform.

On the other hand, the policies adopted to achieve the 2030 emissions peak will inevitably include multiple instruments and initiatives (potentially including a carbon tax, but not exclusively a carbon tax), not all of which are likely to be as economically efficient as a carbon tax. And not all of the revenue from market-based policy instruments may be recycled in an efficiency-enhancing way. Accordingly, the economic costs of the policy changes recommended in the Study could turn out higher than the Study finds. However, this argument makes a false assumption that market instruments and efficiency-enhancing tax reforms are *necessarily* more efficient than alternative policies and expenditures. In fact, there are circumstances and sectors in which regulation can induce faster innovation (and hence be more efficient) than market instruments — including energy efficiency standards for buildings, appliances and vehicles (Daley and Edis 2011).

Ultimately, the key point is that, with well-designed policy in place, GDP costs associated with the achievement of the Study's 2030 peaking target would likely be modest and — due to difficult-to-model beneficial effects on resource productivity,

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[8] On wider tax reform in China, see Ahmad et al. (2013).

infrastructure investment, innovation, energy security, and public health — could in fact be net-beneficial to GDP. And of course, these are likely to yield improvements in economic efficiency and human welfare well beyond those captured in GDP figures, for the reasons discussed above and in the NCE Global Report (GCEC 2014a).

v) Policy measures

The Study concludes that China's coal consumption should be capped so that it peaks by around 2020, followed by an absolute decline as soon as possible thereafter. In the Study's modelling, oil and gas consumption are likely to continue to expand out to 2030, therefore if total emissions are to peak by that time, coal needs to peak around ten years earlier (but see our discussion of this issue in Appendix II, below).

Additionally, the Study advocates the gradual introduction of absolute emissions targets and carbon pricing. It argues that targets should first be introduced for energy-intensive industries that are overcapacity or are located in the relatively developed economies of eastern China, and then gradually expanded to all industries and regions, and ultimately to an economy-wide emissions reduction target. With regard to carbon pricing, the Study advocates the introduction of a steadily rising carbon price signal, rising at 7–8% per year before 2030, to direct the investment towards a low carbon green development path.

Appendix II: Prospects for an early and low peak in China's greenhouse gas emissions

In this section we consider the prospects for a relatively early and low peak in China's GHG emissions from electricity generation, industry and transport. We conclude by considering the likely peak dates in the emissions from fossil fuels (which span all three of the above categories) and in overall emissions.

a) Electricity emissions

It is possible that emissions from China's electricity sector — roughly 40% of China's total GHG emissions — have already peaked. We think it likely that electricity emissions at least reached a structural peak in 2013/2014.[9] Below we explain and justify this conclusion.

During China's industrial development phase, strong growth in electricity consumption and the predominance of coal in China's electricity mix drove China's emissions from electricity to historic highs (more than 4GTCO_2 in 2011: WRI 2014[10]). During this period, electricity production experienced double digit growth (EIA 2013b), and coal use in electricity grew at over 11% per year (Garnaut 2014, 12), leading many experts and institutes to forecast continued dramatic increases in China's coal consumption and, hence, electricity emissions (see, e.g., EIA 2013a).

In the 2012–2013 period, statistics on electricity consumption and coal consumption in electricity reveal a more mixed picture, with signs of both moderation and continued strong growth in both indicators.[11] Reflecting this, a difference of opinion has emerged among experts about the extent of the shift in electricity demand and coal consumption trends. The International Energy Agency (IEA), in its latest New Policies Scenario,[12] forecasts electricity demand growth in China of 4.8% per year between 2012–2020 (IEA 2014a, 234), and continued growth in coal consumption in energy until at least 2030 (at 674). By contrast, Garnaut (2014) forecast electricity production growth of 4% p.a., and a slight *decline* (of 0.1% p.a. on average) in the absolute volume of coal use in electricity from 2013 to 2020 (he considered these to be conservatively *high* forecasts), reflecting his analysis that China's new development model is increasingly taking root, and is likely to entail more fundamental changes in the structure of Chinese demand for, and production of, electricity. Garnaut's conclusion that coal use in electricity has peaked and will fall (slightly) over the

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[9] By structural peak, we mean a peak controlling for cyclical variability in hydroelectricity output. In other words, we think any growth in electricity emissions in the near term will be due to worse than average conditions for hydroelectricity production resulting in lower than average output per unit of hydroelectric capacity, transmitted into higher than otherwise electricity generation from coal.

[10] WRI's figure (4.27GTCO_2) includes emissions from electricity and heat.

[11] Compare data from the National Bureau of Statistics in 2014 (reported in Ma 2014) with Garnaut (2014, 9, Table 1) and the most recent NBS statistics.

[12] The IEA's New Policies Scenario is a scenario in the *World Energy Outlook* that takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse gas emissions and plans to phase out fossil-energy subsidies, even if the measures to implement these commitments have yet to be identified or announced. This broadly serves as the IEA baseline scenario. See http://www.iea.org/publications/scenariosandprojections/.

remainder of the decade represents, in his view, "a turnaround of historic dimension and global importance" (at 12).

Recently-released preliminary Chinese statistics for 2014 lend strong weight to Garnaut's assessment, suggesting, if anything, that the turnaround in coal consumption in electricity is even *more* profound than he predicted.[13] According to the China Electricity Council (CEC), electricity generation output grew 3.6% in 2014 (CEC 2015b) — even lower than Garnaut's forecast[14] — and electricity demand grew only 3.8% (CEC 2015b; NEA 2015), a full percentage point lower than the IEA's forecast. Coal-fired power generation output appears to have fallen in 2014 by around 1.4%, reflecting the slower demand growth in electricity and the expansion of non-coal sources in the electricity generation mix.[15] And apparent coal use in electricity fell 3% in the first 11 months of 2014 according to data from the China Coal Industry Association,[16] reflecting (in addition to the above-mentioned factors) the increased efficiency of coal-fired power generation.

In our view, these 2014 data primarily reflect structural trends in central government policy and in the Chinese economy, including: large expansions in zero-carbon energy generation (capacity and output) and the increased use of natural gas in electricity generation (see Appendix IV, Table 3); new restrictions on coal consumption, particularly in the key economic regions, associated with China's Airborne Pollution Prevention and Control Plan (State Council 2013);[17] slower growth in heavy industrial production (and hence industrial electricity demand); and increased efficiency in the use of coal in power generation, associated with China's industrial energy conservation efforts. These structural trends are likely to continue, and if anything accelerate, as China's new development model increasingly takes hold, as the large overcapacity in China's heavy industrial sector (which accounts for 60% of China's electricity demand: CEC 2015a) presages production cuts in those sectors, and as investment more generally falls as a share of GDP.

In and of itself, the 2014 data does not conclusively show that coal use in electricity peaked in 2013; it is possible that it could rise again in future. Below we consider four possible reasons why this could be the case, and then draw our final conclusions taking these possibilities into account.

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[13] Some observers have raised the possibility of anomalies in the 2014 Chinese data on overall coal use (Wilson 2015; Wynn 2015). We address these concerns below, in the discussion of overall coal data. We think it unlikely that the electricity data for 2014 is anomalous, since electricity data is among the most reliable in China. Moreover, the electricity data are consistent with structural trends in the economy and policy; we see nothing to suggest that the 2014 electricity data are anomalous.

[14] Electricity generation output grew 4% according to China's National Bureau of Statistics (2015). This figure is consistent with Garnaut's forecast. The CEC (2015b) figures are, at the time of publication, the most recent and comprehensive (they decompose thermal capacity expansions into coal and gas), hence we use these throughout.

[15] See calculations in Appendix IV, Table 4, based on CEC (2015b) data. Compare Myllyvirta (2015b), who finds that coal-fired generation fell 1.6% in 2014.

[16] Ross Garnaut and Shenghao Feng, pers. comm. February 2015.

[17] The Plan imposes various types of restrictions on coal and heavy industry. Nationally, it sets mid- and long-term caps on coal consumption and aims to decrease the share of coal in total energy consumption to less than 65% by 2017. In the key economic regions that are heavily affected by air pollution — Beijing-Tianjin-Hebei, Yangtze River Delta and Pearl River Delta — the Plan prohibits the building of new coal-fired power plants and aims to achieve absolute reductions in coal consumption by 2017. It also aims to remove parts of heavy industry from these regions. See Slater (2014).

i) Cyclical variability in hydrological conditions and hydroelectric output

One reason coal use in electricity may increase in future has to do with cyclical variations in hydroelectric output. Hydroelectric output depends partly on hydrological conditions that vary from year to year. Since hydroelectric capacity tends to get used ahead of coal-fired power capacity, variations in hydroelectric output are transmitted inversely into thermal, including coal-fired, generation output (Garnaut 2014, 10).

Average hydroelectric running hours are 3405 hours per year of installed hydro capacity.[18] Hydrological conditions in 2014 were favourable and hydroelectric plants were utilized for 3653 hours — 248 hours more than the average — resulting in an additional 72TWh of electricity being generated.[19] Given that coal-fired power generation output fell 57TWh in 2014,[20] this implies that, controlling for the yearly variation in hydrological conditions, coal-fired power generation increased in 2014, but by a mere 15TWh compared with 2013 — or less than half of one percentage point of total coal-fired generation output in 2014.[21] Given that the coal-fired generation fleet became more efficient in 2014 (CEC 2015b), likely by somewhere between 0.6% and 1.5%,[22] we can conclude that coal use in power generation likely fell slightly in 2014, even when controlling for hydrological conditions. Since these data are subject to a degree of uncertainty, we draw the more cautious conclusion that coal use in electricity reached a peak in 2013 or 2014, controlling for hydroelectric variability, hence our phraseology of "a structural peak in 2013/14".

ii) Rates of non-coal generation capacity expansion in the next five years

A further possible reason that coal use in electricity generation could rise again in coming years is if the expansion of non-coal generation capacity slows compared with 2014 (other things being equal), such that coal-fired generation output would need to expand to fill the gap in incremental electricity demand. This seems very unlikely to us, given the ambition of the government's targets for non-coal generation capacity expansion (discussed in Appendix III). It is possible, however, that expansions in the 13th five year plan (2016–2020) could be back-loaded toward the later years of the plan, as often occurs in order to ensure targets are met, in which case the rate of expansion might be slower in the next few years (but faster in the subsequent few). However, we would consider any rise in coal use (e.g. in 2016) attributable to such a

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[18] Average running hours calculated based on yearly average running hours for the last seven years, from 2008 to 2014 (inclusive), as reported by relevant central government agencies. The average over this period is 3405 hours. See Appendix IV, Table 5.

[19] Hydroelectric capacity was 280GW in 2013 and a further 21.85GW was added in 2014 (CEC 2015a). We multiply the 248 hours of "above-average" generation by each of (i) the 280GW total capacity as at the end of 2013 and (ii) 10.925GW (reflecting the capacity at the end of June 2014 assuming capacity expansions were spread evenly over the year, so as to account for the cumulative installation of capacity throughout 2014): 248hrs x (280GW + 10.925GW) = 72,149GWh (which we round to 72TWh) of "above average" hydroelectricity generated in 2014.

[20] See Appendix IV, Table 4.

[21] On CEC (2015b) data, the additional coal-fired generation output (controlling for hydro variability) of 15TWh amounts to 0.4% of the 3957TWh of coal-fired power generated in 2014 (see Appendix IV, Table 4).

[22] China's 12th Five-Year Plan suggests that that the amount of coal per megawatt hour of coal-fired electricity generated will continue to fall by an average of 0.6% per annum; Mai and Feng (2013) suggest a rate of fall of 1.5% per annum and Garnaut (2014, 9) assumes a fall of 1% per annum. This is due to the replacement of older, less efficient capacity with newer, more efficient capacity (see, e.g., CEC 2015b).

factor as cyclical in nature, not structural; on average, over the next six years, we think the rate of non-coal capacity expansions will apply downward pressure on coal-fired generation, not upward pressure.

iii) Continued coal-fired generation capacity expansions

China added some 36GW of coal-fired power generation capacity to the electricity grid in 2014 (CEC 2015b).[23] A number of analysts have pointed to the ongoing expansion of China's fleet of coal-fired power plants as evidence that China's coal use in electricity will rise in future, or will at least plateau for a long time (Cohen and Liu 2013; Cohen 2015; Trembath 2014). But the inference that usage will follow from capacity needs to be scrutinised.

In our view, the better inference is that much of this new capacity will not be used. Already, much of China's coal capacity is underutilised: coal-fired generation capacity growth has outstripped coal-fired electricity output growth since 2011, and the utilisation rate has been falling since then, reaching a low of 54% in 2014 (Myllyvirta 2015b). The decline in coal-fired power generation is being driven by targets and policies to reduce coal consumption and expand non-coal energy sources, which are in turn driven by high-priority concerns about air pollution, energy security and climate change. The inference that coal-fired electricity generation will continue to rise runs counter to the clear direction of official Chinese policy and to structural changes in the economy. If coal-fired generation continues to fall while capacity continues to expand, then utilisation will continue to fall, meaning an increasing amount of economic value in coal-fired power generation will be "stranded".[24] This is, to be sure, a significant economic problem — unproductive capital allocation will be a drag on China's economic growth — but it would not imply an environmental/climate problem.

So what explains the continued expansion of coal-fired power plant capacity (other than to replace less efficient capacity)? Why invest if there is already an over-capacity problem? We think the two most likely explanations are as follows.

First, recent capacity expansions reflect an inevitable lag in the effect of central policy and market changes on planning, approval, investment and construction decisions in the Chinese power sector. The average time from NDRC approval to commissioning of a Chinese coal power plant is 4–5 years. Thus, capacity expansions in 2014 would reflect approval, investment and construction decisions made between 2009 and 2011 — at the end of the heavy industrial development phase, before the extent of over-capacity became clear, and well before the new development model took deep root and substantial restrictions on coal were introduced to curb air pollution. Indeed, we could expect to see a large amount of new coal-fired generation capacity come online in the next 2–4 years that simply reflects the outputs of a project pipeline that was heavily stacked in the period up to around 2013, when different economic and policy conditions prevailed.

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[23] China also closed some older, inefficient generating capacity, likely around 2GW, in 2014 based on State Grid's 2014 target. China's new coal plants are predominantly super-critical and ultra-super-critical models, which are much more efficient than the older generations of sub-critical plants that are being closed, meaning the efficiency of the coal fleet is increasing (see CEC 2015b and Garnaut 2014, 9).

[24] As Myllyvirta (2015b) notes: "A new coal-fired power plant will still generate power and revenue even if there is overcapacity, as the lower capacity utilization gets spread across the entire coal power fleet and across all power plant operators".

Second, the 2014 capacity expansions to some extent probably reflect investment decisions that were inefficient, even when viewed from the perspective of 4–5 years ago, due to subsidies and other incentives for heavy-industrial investment by state-owned enterprises, local governments and state banks, which encouraged excessive investment (Myllyvirta 2015b). These incentives, a feature of the old model of growth, persist today, which may explain why we see continued planning and investment in new capacity even in the last couple of years.

Taking the above two factors together, we would not be surprised to see considerable (inefficient) capacity expansions for much of the remainder of this decade. Clear signals and policies will be needed in order to change the expectations and practices of firms, banks and government authorities to minimise this inefficient allocation of capital, and we discuss this further in Appendix III. The key point for now is that these explanations for the continued investment seem to us more plausible than the assumption that capacity is being expanded so that total coal-fired generation will be expanded.

iv) Growth in electricity demand due to electrification of transport

A further structural trend that could increase the rate of electricity demand growth in future is the progressive electrification of passenger transport (and other processes such as heating and parts of industry). We follow Garnaut (2014) in the view that substantial electrification of transport is unlikely to occur until after 2020, however, to the extent it does occur it will increase electricity production in the electricity sector and, in turn, increase or slow the decline in coal-fired power generation output. This would raise emissions in the electricity sector, but reduce them in the transport sector, with a net effect that is likely to be beneficial for overall emissions reduction since electric vehicles are more energy efficient than combustion engine vehicles (all the more beneficial the less emissions-intensive the electricity sector is) (Garnaut 2014).[25] The earlier electrification occurs, the slower we will see emissions from electricity fall, but the faster we will see overall emissions fall. Accordingly, we acknowledge the potential for electrification to alter our conclusion about coal use in electricity, but conclude that, if anything, this eventuation would strengthen our conclusions below regarding the early peak date in overall emissions.

v) Conclusion on electricity emissions

In summary, we conclude that developments in the years ahead will likely show that coal use in electricity structurally peaked in 2013/14. The structural trends in policy and the economy that affect coal use in electricity point strongly towards continued reductions; any rise in coal use in electricity in the current or immediate future years is likely to be due to cyclical factors (in particular, worse than average hydrological conditions), which should be controlled for.

Since coal is the highest CO_2-emitting energy source, we can expect CO_2 emissions from electricity to decline as coal-use in electricity declines.

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[25] We do not consider here the second order effects, which could favour zero emissions sources. For example, expanded use of electric vehicles will raise the storage capacity on the grid, with beneficial implications for the use of zero emissions electricity sources.

b) Industrial emissions

A similar story is bearing out in China's industrial sector. Like emissions-intensive electricity generation, emissions-intensive industrial production expanded at a rapid pace throughout 2000–2011, then showed some signs of moderation in the subsequent two years.[26]

Given the disproportionate share of China's GDP constituted by investment in China's heavy industrial sectors and the extent to which they are overcapacity (CCICED 2014), the prospects for declining investment, rationalization and falling production across such sectors in the context of China's new development model look strong, with a likely favourable impact on emissions (Garnaut 2014). The extent of excess capacity in China's steel and cement industries — the largest sources of industrial emissions — and the need for a structural turnaround in these industries is now widely recognised throughout the Chinese government and the industries themselves. The chairman of the China Iron & Steel Association, for example, recently stated that "China's steel sector has already entered a period of peaking and flattening out" (Reuters 2014a). Indeed, in 2014, China's crude steel production grew at its slowest rate this century, 1.2%, and cement production grew at only 2.3% (NBS 2015).

The slower growth in steel and cement proportionately reduces the demand for coking coal and thermal coal, respectively. Moreover, the impact on coal use is compounded by trends within these industries to substitute away from emissions-intensive production processes. A declining proportion of steel, for example, is being produced from blast furnaces (which use coking coal) and an increasing proportion from methods that use recycled scrap steel (which do not use coal). In combination, these trends caused coal use in steel production to fall 1.5% in the first 11 months of 2014 according to the China Coal Industry Association.[27] Industry leaders expect steel production in China to fall in 2015, and a greatly increased proportion of production to come from recycled scrap methods, meaning China's coking coal has entered a declining trend of at least a couple of percent per annum.[28] A similar trend of levelling-off and imminent decline in output, and substitution toward lower-emissions processes, is occurring in the cement industry.[29]

While we have not analysed data on emissions from other industrial processes, the expected declines in coal use and CO_2 emissions from steel and cement in 2014, and the expected acceleration of those declines in 2015, combined with the broader structural changes associated with China's new development model, suggest it is likely China's overall industrial emissions will peak before 2020 (if they have not done so already), provided coal-to-gas plant developments are minimised through effective regulatory controls (discussed in Appendix III, below).

c) Transport emissions

After strong growth in oil consumption and CO_2 emissions from transport throughout China's heavy-industrial development phase, growth in oil consumption eased somewhat in recent years, growing at 4% in 2013 (EIA 2014). The IEA (2014a, 674)

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[26] China now accounts for over half of global production of steel and cement (Garnaut 2014, 11).
[27] Ross Garnaut and Shenghao Feng, pers. comm., February 2015.
[28] Ross Garnaut (pers. comm., March 2015).
[29] Ross Garnaut (pers. comm., March 2015).

forecasts continued growth in Chinese oil consumption[30] until 2040 at an average rate of 1.6% per year, with very strong growth maintained until 2030 (at 100). By contrast, Garnaut (2014, 13) expects oil consumption and transport emissions "to respond strongly to new incentives and opportunities to reduce emissions intensity". As oil consumption becomes more efficient in response to higher fuel efficiency standards for vehicles — at levels now in-line with developed countries — and as China's industrial structure becomes less oil intensive, there is strong potential for moderation in transport emissions. The speed with which transport emissions peak depends, significantly, on China's success in implementing its plans to build and modify cities according to a high-density, public-transport-linked model (discussed further below) and to roll-out electric vehicles at scale (Garnaut 2014).

While we cannot be confident about the timeframe of China's transport emissions peak, it seems to us unlikely, in light of the above trends, that any growth in transport emissions over the next decade will significantly counteract the tendency towards reductions in emissions from electricity and industry.[31] As noted above, the earlier the electrification of transport, the better for transport emissions and overall emissions.

d) Conclusion: peak emissions by 2020?

Another means of gauging the likely peak of China's emissions is to consider trends in the consumption of fossil fuels (across all sectors). Coal accounts for two-thirds of China's primary energy consumption,[32] and the largest source of China's emissions. In 2014, coal consumption fell 2.9% (and coal imports fell 10.9%), according to official Chinese preliminary statistics (NBS 2015).[33]

Some observers have raised the possibility of anomalies in the 2014 coal use data (Wilson 2015; Wynn 2015). However, in light of our analysis of coal use in electricity and industry above, and noting that electricity and industry each account for about 50% of coal use, we think China's coal use did fall in 2014, though perhaps by more like 1.5%. Since we conclude that coal use in both sectors has passed its structural peak, we expect a continued structural decline trend in coal in the years ahead.[34] While it is theoretically possible that the 2014 data are seriously anomalous in the way that the above-mentioned authors suggest it could be, we think this is unlikely, given that the structural trends in the economy and policy, and multiple independent lines of data, paint a compelling and consistent picture of structural peak and decline in coal

[30] Which we can take to be a rough proxy for transport emissions, at least until substantial electrification of the transport sector.

[31] The recent fall in the global oil price is not likely to have a major effect on China's oil consumption due to price controls on fuel products. The recent surge in oil imports, prompted by the lower prices, has been directed primarily toward filling strategic reserves. Meanwhile, as consumer demand moderates, China has grown its export of refined products (Hornby et al. 2015).

[32] Coal's share of energy consumption was 66% in 2014 according to official Chinese statistics (NBS 2015).

[33] See also figures from the China Coal Industry Association and the National Energy Administration, which recorded falls in Chinese coal consumption, production and net imports (Xinhua 2015a; Xinhua 2015b; CPNN 2015; Myllyvirta 2015a).

[34] This prediction is subject to the caveats mentioned above in relation to coal use in electricity (regarding seasonal variations in hydroelectric output, and the potential for increased growth in future electricity consumption from electrified transport) and industry (if significant expansions in the coal-to-gas industry occur).

use in both electricity and industry.[35] More comprehensive statistics (yet to be released at the time of publication of this paper) will provide more authoritative and precise data, however we would be surprised if they altered our qualitative conclusions.

Estimates of a peak date for China's coal have been moving ever earlier over the last few years. A 2020 peak would have seemed highly implausible five or ten years ago. Even 12 months ago, when we argued that China could peak coal by 2020 (Green and Stern 2014), this was considered a minority view. That coal may have already peaked — and has, in our view, structurally peaked — is a measure of the extraordinary pace of change in China, and reflects the many structural policy and economic shifts that we have discussed.

Furthermore, peak coal consumption is regarded as a leading indicator of peak emissions, at least of CO_2 — the question is, leading *by how long*? This is not an area where precision is possible; assumptions need to be made. The NCE China Study finds a ten-year lag between peak coal and peak CO_2 emissions. If the ten year lag is correct, we would expect a peak in Chinese emissions in 2023 (assuming our conclusion of a structural peak in coal consumption in 2013 proves to be correct).

Yet there are grounds for thinking that the peak in CO_2 emissions will come sooner. We can perhaps expect CO_2 emissions from natural gas to continue rising for another decade as gas grows its share in the energy mix (and as overall energy consumption continues to grow). However, coal emissions are roughly twice those from gas and, as we discuss in Appendix III, numerous factors are likely to limit China's continued expansion of gas beyond the medium term (5–10 years), meaning gas expansion is not likely to delay China's CO_2 emissions peak substantially. Nor, we think, is oil consumption growth. The government does not have official targets for oil consumption and the future trend in oil consumption growth is less clear, as we noted above. Garnaut (2014, 13–14) considers that trends in the Chinese transport sector and wider shifts in China's economic structure associated with the new development model hold out reasonable prospects for a peak in emissions by 2020.

Accordingly, on the whole, we consider a ten year lag between coal-peak and CO_2-peak to be too high; it is more likely that a peak in China's CO_2 emissions will occur closer to five years after the peak in coal, and thus (if we are correct about coal) closer to 2020 than to 2025. A 2030 peak in CO_2 emissions now seems highly unlikely. The fact that CO_2 emissions from fossil fuels appear to have fallen in 2014 (Evans 2015; Myllyvirta 2015c) lends weight to this view.

Trends and levels in China's land-sector and in its non-CO_2 emissions are less clear, and we have not analysed these for present purposes. But, given that many of China's biggest non-CO_2 emissions sources are from agriculture, mining and industrial processes will be increasingly disfavoured in China's new development model, it would be surprising if overall trends in these emissions departed greatly from the trend in CO_2 emissions. China's land sector is already a net sink for emissions, and China is pursuing policies that would expand that sink capacity further still (see NDRC 2013), which will also push overall emissions toward an earlier peak date.

[35] We note, however, that the most recent Chinese statistics significantly revise upwards the data for total coal consumed in 2013 — from around 3.5 billion tonnes to over 4 billion tonnes — on the basis of the one-in-five-year economic census that was carried out in 2014, which puts the 2013 data on a much firmer footing.

While further analytical work on all sources and sinks of emissions is needed to have strong confidence in these conclusions, we share Garnaut's (2014) considered opinion that such further work could well confirm the likelihood of a peak in China's GHG emissions by 2020. It is certainly the case that trends and tendencies in Chinese policy in the new development model would mean that targeting such a peak would be a realistic and prudent objective of official policy.

Were China's emissions to peak around 2020, it would be reasonable to expect a peak emissions level of around 12.5–14GT, assuming emissions in 2014 were around 12–13GT and emissions growth is slowing rapidly.[36]

[36] Precise calculations of China's emissions are not available. Leading databases, WRI (2014) and the IEA's emissions database (IEA 2015), differ in their estimations by more than 1GT for emissions in 2010, with the former at the lower end (9.4GTCO_2e, including land-use and forestry) and the latter at the higher end (10.8GTCO_2e, including land-use and forestry). More recent direct comparisons between the two datasets are not available. The assumed 2014 emissions range of 12–13GT is based on multiple data sources containing more recent (2013) estimates of CO_2 emissions (e.g. Global Carbon Project 2014) and assumptions about non-CO_2 emissions growth based on previous ratios of CO_2 to non-CO_2 emissions. See also Boyd, Stern and Ward (2015).

Appendix III: Accelerating the rate of fall of emissions after the peak

Achieving an accelerated rate of fall of GHG emissions after China's emissions peak will be crucial for the task of reducing global emissions, and hence to China's long-term development interests. Achieving the strong improvements in air quality, water security and energy security, and economic gains from increasing productivity, clean innovation and leadership in global markets for clean goods and services — all of which would accompany the efforts needed in the years ahead to enable strong reductions to occur in post-peak emissions — will be crucial for China's economic interests in the medium term (CCICED 2014; GCEC 2014b; Green and Stern 2014; Teng and Jotzo 2014).

Yet, achieving strong declines in post-peak emissions will present a particularly weighty challenge for China as it continues to grow and to urbanise. It will require, among other things, concerted efforts in the areas of cities, the energy system, and innovation, supported by wider fiscal reforms.

a) Cities

The urban form and transport infrastructure of cities are extremely long-lived assets that create very long-term "path-dependencies" with respect to land-use, transportation, resource utilisation and hence GHG emissions (Rode and Floater 2013; MGI 2009). Given the extraordinary urbanisation that will occur in China in the coming 10-15 years,[37] the urban planning decisions, and associated policy and investment choices China makes today and over the next decade will have long-lasting implications; they will determine whether China's cities are livable, attractive, competitive and energy efficient.[38] It will thus be critical that China's city planning be based on a model of spatially compact, medium/high density urban form, tightly linked by mass transit systems (Rode and Floater 2013; GCEC 2014).[39] The power of such a model can be illustrated by a comparison between Atlanta and Barcelona, two cities with roughly the same population and economic size: Atlanta's CO_2 emissions from private and public transport are 7.5 tonnes per person; Barcelona's are only 0.7 (GCEC 2014a).

Urbanising in this way will necessitate reforms to city-level fiscal and governance arrangements that provide the right incentives and revenue structures to support such a model of urban development and the social services accompanying it (Ahmad and Wang 2013; World Bank/DRC 2014; Green and Stern 2014).

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[37] China's urban population is expected to increase from around 700 million in 2013 to around 850 million in 2020, and to approach 1 billion in the late 2020s. World Bank (2015a; 2015b) data show China's urban population was 53% of China's total population of 1.36 billion in 2013. China's urbanisation plan targets an urban population of 60% by 2020 (Xinhua 2014a), implying a total of around 850 million urban residents on the assumption that China's total population at that time will be around 1.4 billion.

[38] As the effects of climate change increase, putting pressure on already scarce resources like freshwater, affecting food production, raising sea levels and worsening natural disasters, it will be critical that China's cities are also built to be resilient to these effects.

[39] Further planning elements will be needed to make China's cities "people-centred" (see Chen et al. 2008; UCI 2013). For China, this phrase connotes an emphasis on the provision of essential public services, particularly education and healthcare, and residential registration (hukou) reform (Xinhua 2014a; CCCPC 2013).

b) Transforming energy systems

Another key determinant of China's ability to achieve an accelerating rate of fall of emissions, post-peak, will be the energy efficiency, and energy mix, of China's energy system. The relationships between energy supply, energy efficiency and economic output can be considered in terms of the emissions intensity of energy, and the energy efficiency of output (see Box 1, below). We consider energy efficiency (energy intensity) and then energy supply (emissions intensity).

Box 1: Economic growth, energy and emissions — some key relationships

The relationship between an economy's economic output, energy consumption, and CO_2 emissions (from energy) can be expressed mathematically as follows:

(1) Em = (Em/En x En/y) x y

Where: Em = CO_2 emissions from energy consumption;
En = energy consumption; and
y = economic output

If Em/y is falling at b% and output is growing at c%, (1) implies that:

(2) The rate of growth of Em = (c – b)%. Hence emissions fall if b>c, and rise if c>b

This can be expressed as: The rate of growth of Em = (–b) + c

Further, the rate of fall of Em is the sum of the rate of fall of Em/En and En/y:

(3) –b = –(f + g)

Where: f = rate of growth of Em/En; and
g = rate of growth of En/y

There is also a question of whether *b* depends on *c* (or vice versa). For example, a vibrant economy with high investment and growth may carry more scope for discovery and creativity. Conversely, small falls in *b* might be an indicator of a lack of creativity/inventiveness, which could imply slower growth.

i) Energy efficiency

The energy intensity of China's economy has fallen strongly over the last three decades since opening-up. This desirable trend was reversed for a brief period during the early stage of China's heavy industrial development phase, but continued to decline steadily over the decade to 2013 thanks largely to energy conservation measures put in place during this period. The decline in energy intensity accelerated sharply in 2014, falling 4.8% on the previous year — significantly ahead of the government's target of 3.9%, and of the 2013 decline of 3.7% (NBS 2015; Reuters 2015). Slower growth in electricity demand and in overall primary energy consumption appear to be the primary causes of the decline, since overall economic output appears to have been steady (World Bank 2014; CEC 2015a). This augurs well for improvements in energy intensity, providing an indication of what we can expect as structural change associated with the new development model takes hold.

Nonetheless, the energy intensity of China's economy remains well above that of the most energy efficient advanced economies, and continued urbanization will put pressures on energy demand (Green and Stern 2014; Teng and Jotzo 2014). Strong and continuous improvements in energy efficiency will therefore need to be central to China's efforts to accelerate the rate of fall of its emissions post-peak, and reforms put in place in the near-term will lay the foundations for those improvements.

Continued expansion and implementation of mandatory energy efficiency standards for buildings, appliances and vehicles, measures to encourage the growth of the energy services industries, and the liberalization of energy prices (discussed further below) will all be important to enable continuous improvement in China's energy efficiency.[40]

ii) Transforming energy supply

There is perhaps no more important factor affecting China's future emissions trajectory than the transformation of its energy supply. Given the grave threat that coal poses to all aspects of China's "new climate economy" — to air quality and health, energy and water security, industrial modernisation, and climate change — there are strong reasons for China to scale-up non-coal energy sources, limit additional coal-based energy and industrial developments, and phase out existing coal as quickly as possible. We therefore discuss each of these in turn, below. A lower-carbon electricity sector also paves the way for radically lower emissions from transport and industry through electrification, though we do not discuss this further here.[41]

Scaling up non-coal sources

A key theme underpinning China's efforts to scale up non-coal energy sources is diversification. Having a diversity of non-coal sources of energy is important because it: enables the technical and economic potential of new energy sources to be discovered; contributes to energy security; and reflects the different roles that different sources and technologies play within an integrated energy system. A diversity of energy sources is valuable for China, not only to replace coal in incremental electricity generation, but also to displace existing coal usage.

Within the current portfolio of non-coal energy sources, some sources, such as gas and hydroelectricity, are likely to play a stronger role in the medium term but a more limited role over the longer term. Other renewables and nuclear will therefore need to be expanded at an accelerating pace if coal is to be phased out.

China has targeted an expansion of gas in primary energy consumption to 10% by 2020, and it expects much of this gas supply to be used directly in households and industry, and in transport, though with significant development of gas for electricity production, too (State Council 2014). While this expansion of gas, as a replacement for coal, should help to mitigate China's GHG emissions in the next five to ten years, if the rate of fall in China's emissions is to accelerate post-peak then the continued expansion of gas would become increasingly inconsistent with that goal.

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[40] See Green and Stern (2014) and references cited therein for further discussion of each of these measures and the mitigation potential of stronger energy efficiency improvements.
[41] Electrification is a key pathway to reducing emissions in other sectors, especially transport (through battery-powered electric vehicles, electric bikes, and rail), residential heating (through, for example, ground source and air source heat pumps), and some parts of industry (Fankhauser 2012; IDDRI/SDSN 2014).

Other factors could also constrain China's scale-up of gas consumption beyond the next 5–10 years. Over the next decade, the bulk of China's gas is likely to come from imports, through pipelines from Russia and central Asia, and in the form of seaborne LNG from various countries. While the growth in gas imports and associated infrastructure is strong, dependence on foreign sources, and associated energy security risks, could well constrain China's willingness and ability to scale-up imported gas supplies beyond this period. At home, China faces many challenges (e.g. geological, technical, regulatory, and environmental) in scaling up its domestic unconventional gas industry (Gao 2013; Gunningham 2014; Stevens 2014). The ambitious 2020 targets for shale gas production set by the government in 2012, of 60–100 billion cubic meters (bcm) were last year more than halved to 30 bcm due to technical challenges (Platts 2014). These obstacles and developments suggest that unconventional gas may not be able to make a major difference to China's energy mix within the limited, 5–10 year growth period that we envisage as being roughly appropriate in a carbon-constrained energy environment.[42]

Hydroelectric power is also likely to contribute strongly to non-coal generation in the next 5 years but be constrained beyond that, since China's capacity to increase large dam projects is limited by appropriate sites, and the best sites are increasingly being used up. While capacity continues to expand strongly, approvals for, and investment in, new dam projects have slowed in recent years, moderating expectations of future growth. Indeed, China revised down its official target for 2020 hydro capacity from 420 GW to 350 GW in its latest strategic energy plan (State Council 2014; Reuters 2014b).

Indeed, the bulk of non-coal generation expansion is expected to come from other renewable sources,[43] led by wind and solar, but with development also of geothermal, bio-energy and ocean energy. Solar and wind power capacity has expanded at astonishing rates in China in recent years, exhibiting strong technical progress and cost reductions (see Stern 2015).[44] Critically, these and other renewable technologies have the potential to scale fast enough to displace increasing amounts of existing coal from China's energy mix over the coming decades, provided strong trends in energy efficiency (see above) continue to keep electricity demand growth low. China's energy planning agency has consistently revised upwards its planning targets for wind and solar PV generation capacity: in 2006, China planned to have 30GW of wind and 2GW of solar by 2020; with those targets long since eclipsed, China's latest 2020 targets for these technologies are 200–300GW of wind and 100GW of solar by 2020 (Jiang 2014; State Council 2014)[45] — around 7–10 times and 50 times higher, respectively, than the equivalent forecasts eight years prior. With strong demand–side policies, such as feed-in-tariffs, to support expansions at scale and continued innovation, we can expect costs to fall further and targets to continue to be revised upwards (CCICED 2014).

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[42] Moreover, whether electricity provided from unconventional gas, particularly shale gas, would be beneficial on a life-cycle emissions basis depends, among other things, on the degree of methane leakage in the production process, about which data are scarce (see Gunningham 2014, 308).
[43] The IEA (2014a), in its New Policies Scenario, projects that China will install over 960GW of renewables-based capacity to 2040, and the bulk of new capacity and electricity generation will come from non-hydro renewables (2014a, 243–235, 654).
[44] China installed a record 13GW of solar in 2013 alone (Stanway 2015), a further 10.6GW in 2014 (CEC 2015b), and is targeting a further 17.8GW, more than half of existing solar capacity, in 2015 (Bloomberg 2015).
[45] Chinese Academy for Engineering concluded that China's electricity grid could adopt these renewable energy power generation capacities in the short term (Jiang 2014).

The other key source of non-coal energy with potential for significant expansion is nuclear. China currently has 19GW of nuclear capacity and is targeting an expansion to 58GW of operational capacity by 2020, and a further 30GW under construction by that time (State Council 2014).[46] Recent forecasts of Chinese nuclear capacity in 2030 range from 114–175GW.[47] On these forecasts, China would need to deploy around 100–150GW over the 15 years to 2030. France deployed 42GW in the seven years between 1980 and 1987, and the US also deployed large amounts (30GW+) in two separate 3–4 year periods (Yip 2014).[48] China is scaling up its nuclear capacity from a much larger economy and industrial base than the US and France had in the 1980s, and has two decades of experience building nuclear plants (Yip 2014). Accordingly, China's ambitions look eminently achievable.

The biggest challenge China may face in continual rapid expansion of these sources is the management of an increasingly complex energy system (IEA 2014b). In particular, an increasing proportion of intermittent (wind and solar) and non-variable (nuclear) electricity sources generates challenges for the transmission and storage of energy and for the stability of the grid. Reflecting positively on China's ability to manage these issues, Garnaut (2014, 11) explains that:

> For many regions, the presence of large hydro-electric capacity which can be varied over short periods facilitates balancing the grid and can continue to do so. Over recent years, larger investments have been made in upgrading the electricity grid than the huge investments in generation, much of it to facilitate absorption of intermittent and non-variable power … [including] large pumped hydro storage facilities (a total of 30GW capacity to be installed by 2015) adjacent to many of China's large cities. Improvements in the grid and expanded storage facilities have facilitated more complete utilization of low-emissions capacity (People's Republic of China 2011).

In future, increasing availability and lower cost of battery storage will provide further opportunities for storage, especially if China's plans for large scale electric vehicle expansion succeed. This will be essential if the expansion of renewable energy sources is to occur at the levels necessary to achieve a relatively rapid phase-out of coal. At the same time, EV expansion will increase the complexity of managing the grid. This will therefore need to be an ongoing priority for China — and indeed for the world.

<u>Limiting new coal developments</u>

The second key factor in transforming China's energy supply away from coal is to limit firmly any future coal-based developments through clear policy and planning signals and regulatory controls.

Already, China has imposed limits on coal consumption and on the development of new plants in key economic regions (see Slater 2014). Recall the problem identified earlier of overcapacity, and yet continued inefficient expansion of coal-fired generation capacity. Strictly limiting approvals for, and investments in, new coal plants — unless

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[46] China currently has 23 nuclear reactors in operation, 26 under construction, and more about to commence construction (WNA 2015).
[47] 2030 forecasts for Chinese nuclear capacity included in this figure are: IEA (2014a, New Policies Scenario) — 114GW; WNA (2015) — 150GW; Wood McKenzie (2014) — 175GW.
[48] The United States deployed a total of 112 GW of nuclear power between 1957 and 1996, though much of this total came in waves of intensely active deployment: 38GW between 1972 and 1976; 33GW between 1984 and 1987; and a total of 93GW between 1972 and 1987 (Yip 2014).

these are necessary to replace older and less efficient capacity — will likely be needed to curtail these economically inefficient expansions. Such action is strongly warranted for economic and financial reasons, let alone environmental, public health and climate reasons.

There are at least two further types of coal development being considered by China's energy planners that would alleviate air pollution in eastern cities, but which would counteract the downward trend coal consumption and related GHG emissions.

First, China could increase coal-fired electricity production in western regions — so-called "coal bases" — for export to eastern cities via ultra-high-voltage transmission lines (Slater 2014). This was one of three options for mitigating eastern air pollution presented in China's *Air Pollution Prevention and Control Action Plan* (State Council 2013).[49] However, this would have the undesirable effect of exacerbating air pollution in the west. It would be unfortunate if China decided to develop its poorer western regions along the lines of the old, heavy industrial model, given the lessons it has learned in the east. A much cleaner development path is now open to these regions. Solar conditions are much stronger in the western regions and many of China's most innovative renewable energy companies have their origins in Xinjiang,[50] suggesting a high potential for a western energy strategy based much more strongly on renewables, particularly solar (including concentrating solar power). Moreover, expansion of ultra-high-voltage transmission lines present increasing opportunities for efficient transmission of renewable energy from western regions to eastern cities.

A second type of coal development being considered in China is to build large-scale coal-to-gas plants in central and western coal-producing regions and export the resultant synthetic natural gas (SNG) to eastern cities for consumption in gas-fired electricity, heat or industrial production (Slater 2014). This would displace air-polluting coal-fired power stations with lower-polluting gas, but would add greatly to industrial coal consumption and water consumption at the SNG plants, and to the lifecycle GHG emissions of the energy ultimately consumed, since the process of converting coal to SNG is extremely energy, water and GHG intensive (Yang and Jackson 2013).[51]

Two SNG plants are currently in operation and, as of July 2014, there were 48 projects in the pipeline (Ottery 2014). According to an analysis by Greenpeace, if all 50 projects were to proceed and be operational by 2020, they would produce 225 bcm of SNG and 1.087GT of CO_2 per year (Ottery 2014). This would clearly add greatly to China's coal consumption and CO_2 and would tend against both an early emissions peak and strong emissions reductions post-peak. Even the target for the sector

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[49] The others were increased use of gas and increased use of non-fossil energy sources. The western "coal bases" strategy was promoted by President Xi during a meeting with central leaders on China's energy security strategy in June 2014, and it has been heavily promoted by prominent figures such as State Grid's CEO Liu Zhenya (Slater 2014). Already, according to Mou Dunguo at the Centre for Energy Economics at Xiamen University, "two AC and four DC UHV lines have been built to transmit electricity from these bases to loading centres in the east" (quoted in Slater 2014).

[50] We thank Ross Garnaut for bringing the latter point to our attention.

[51] A recent study by researchers from Duke University and published in *Nature* found that the lifecycle GHG emissions of SNG used to produce electricity are ~36-82% higher than for pulverised coal-fired power generation (Yang and Jackson 2013). The study also found that, compared with shale gas production, the life-cycle GHG emissions of SNG production (i.e. not including downstream uses), are seven times higher and the water used in SNG production is 50-100 times higher (Yang and Jackson 2013). See also Ding et al. (2013).

previously set by China's National Energy Administration of 50 bcm of SNG per year by 2020, which would produce around 242MT of CO_2 per year (Ottery 2014), would jeopardise those goals.

In December 2014, Chinese press reported that the government was considering adopting in its 13th Five Year Plan a policy of refusing approvals for new coal-to-SNG plants, thus limiting coal-based SNG production capacity to 15 bcm at the end of the decade (Liu 2014). This would limit emissions to 67.5MT of CO_2 per year (Liu 2014). In our view, such a moratorium would be much more consistent with the early peaking, and strong decline, of coal and emissions and therefore desirable from the perspective of climate mitigation and water security. It would also send a clear signal to the international community about the importance China places on climate change mitigation as an independent issue, distinct from mitigating local air pollution.

Phasing out unabated coal

The imperative to phase out coal leaves China with a challenge of managing its existing, large fleet of coal-fired power plants (which, as discussed above, is already highly under-utilised).

One option that may be available to some extent in the medium-term is to use carbon capture and storage (CCS) technology to abate the CO_2 emissions from coal plants. It will in large measure be the experimentation and deployment of CCS technology in China that determines its potential for application at scale and associated cost-reductions. But only if this proves successful could there be a case for maintaining coal (at least on climate mitigation grounds). The fact that CCS involves an "energy penalty", of between 10-25% depending on the type of capture technology applied (EEA 2011), means that coal plants with CCS require significantly more coal, and thus water use, than a conventional coal plant, giving rise to a trade-off between climate, energy security and water security objectives (Green and Stern 2014).

These and other potential limitations of CCS technology mean that, even with a significant roll-out of CCS, China will likely face a significant "stranded asset"[52] challenge with regard to its coal fleet.[53] It will therefore be important for all relevant stakeholders in China — central and provincial governments, financial regulators, financial institutions (and other investors in Chinese coal assets), coal companies, coal-fired power generation companies, affected workers and communities — to undertake careful analysis and planning, and implement appropriate policies and practices, to achieve an orderly phase out of China's unabated coal fleet, mitigating financial risks and social impacts (Caldecott and Robins 2014). Managing this transition well will be an important political and economic factor affecting China's ability to accelerate the rate of fall in its emissions, post-peak, and requires careful and immediate attention.

[52] "Stranded assets" can be defined as "assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities" (Caldecott 2015).
[53] To some extent, it may be possible to repurpose the thermal generation components of coal plants for use in concentrating solar thermal plants, which would mitigate the value of asset-stranding.

c) Key policies: coal taxation, wider pricing reform and energy innovation

We highlight here some additional policies that would help China to achieve a structural transition to a new climate economy along the lines envisaged in this paper.

i) Taxing coal and wider pricing reform

First, expanded resource taxes, particularly on coal, would support all aspects of China's transition, directly and indirectly. Coal is currently taxed very lightly in China, and thus fails to tax coal resource rents to a reasonable degree let alone to reflect coal's impacts on human health, the local environment and the climate (CCICED 2014).[54] It would be sound tax policy to rationalise existing ad hoc local fees and charges on coal, and to raise a centrally-administered tax on coal to reflect, at least to some extent: (a) an appropriate taxation of resource rent; (b) local environmental and health impacts from mining, transporting and burning coal; and (c) global climate impacts (Ahmad and Wang 2013; CCICED 2014).

Taxing coal in this way has a number of attractive features. First, it has lower complexity and administration costs than individual taxes or trading schemes for each component, particularly since the information needed to tax coal inputs is more easily obtainable by governments than is firm-level data on individual emissions (Ahmad and Wang 2013). As such, it could be implemented more quickly and easier to administer, reducing the likelihood of "government failure".[55] And second, the better availability of the relevant information and the upstream imposition of the tax make it harder to evade, thus it is likely to bring greater fiscal benefits when informal sectors are considered (CCICED 2014; Bento et al. 2012).

A tax on the carbon content of coal alone of US$25/t$CO_2$ would add just under US$50 to the price of a metric tonne of coal. We have previously (Green and Stern 2014, part 4) illustrated the potential incentive effects the tax could have and the revenue it could raise.[56] China's currently low coal price and industry uncertainty over its future direction means that now is a good time to implement such a measure. In order to achieve this structural adjustment in an equitable an orderly way, and ameliorate some of its distributive consequences, the tax could begin at a relatively low level and be scaled up over time, and some of the revenues could be used to assist people who are adversely affected (Green and Stern 2014). Sharing revenues with local governments could also be important to elicit local information and compliance, and support for the reform in the first place, especially where less efficient local taxes are eliminated.[57]

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[54] CCICED's Task Force on Green Transition in China (2014) finds that the unit tax on coal is set at 8–20 RMB per tonne for coking coal and just 0.3–5 RMB for other types of coal.

[55] This is not to deny that there will be significant challenges associated with introducing such a tax.

[56] The IMF has subsequently done its own analysis: it concludes that a coal tax of US$15/gigajoule would cut pollution-related deaths by two-thirds, substantially reduce CO_2 emissions and raise revenue of almost 7% of China's 2010 GDP (Parry et al. 2014, 6–7).

[57] We are grateful to Ehtisham Ahmad for helpful discussion of desirable Chinese tax reforms, including the political economy and administrative dimensions of such reforms. See further: Ahmad and Wang (2013) and Ahmad et al. (2013).

A coal tax of this nature would be an important step in the Chinese government's wider energy and resource pricing reforms (CCCPC 2013). Indeed, the full behavioural effect of such a tax on the demand side will only be felt with greater liberalisation of energy prices over time. Combined, these measures would have a significant effect on emissions reduction (CCICED 2014). Moreover, they will help to prepare China's energy markets and governance systems for more complex approaches to carbon pricing over the longer term, such as the planned national ETS.[58]

ii) Green innovation

Achieving an acceleration in the rate of fall of China's emissions post-peak will require major efforts in zero-carbon energy innovation. This will require concerted Chinese policy and financial support across the full innovation chain in China (Green and Stern 2014).

As we have discussed elsewhere,[59] China has a particularly important role to play in the middle of the innovation chain — demonstration and early-stage deployment of technologies with a high potential for emissions reductions and cost reductions. The size of China's internal market means it has a special advantage of *scale* when it comes to fostering the maturation of such technologies. The partial application of revenues raised from coal (and other environmental) taxation to finance support for green innovation is likely to be a potent policy combination for reducing emissions and fuelling economic growth.[60] Moreover, as China aspires to become a leader in zero carbon energy R&D,[61] it will need to cultivate the strategic, institutional, financial, managerial and cultural conditions required for this kind of innovation (Zhi et al. 2013; Cao et al. 2013).[62] At the same, more bottom-up, smaller-scale technology and socially-driven approaches to green innovation should not be overlooked, especially given the potential for such forms of innovation to scale in other developing country contexts — the rapid expansion of e-bikes and solar water heaters being instructive cases in point (Tyfield et al. 2015).

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[58] Combining, in an effective, efficient and equitable way, the multiple carbon and related policy instruments that China has implemented or is planning to implement will be a significant challenge, as it has been in Europe and elsewhere. This is an area where careful planning, informed by further research and analysis, is needed.

[59] See Green and Stern (2014) and Boyd, Green and Stern (2015) for a further discussion of energy innovation in China. See also GCEC (2014a, ch 7) for further discussion of low-/zero-carbon innovation globally.

[60] See Green and Stern (2014, Parts 3(d) and 4) and references cited therein.

[61] China's professed strategic ambitions to be a "world leader" in nuclear technology production and export through the engineering of "major technological breakthroughs" and "industrial upgrades" (Chen 2014) illustrate China's growing appetite for more advanced energy innovation.

[62] This is discussed further in Green and Stern (2014, part 3(d)).

Appendix IV: Electricity generation data

Table 3: Electricity generation capacity in China by source — 2014 additions and total capacity at end of 2014

Generation Source	Capacity added in 2014 (GW)	Total generation capacity at end 2014 (GW)
Thermal	47.29	920
— *Coal*	*35.55*	*830*
— *Gas*	*8.86*	*55.67*
— *Other thermal*[63]	*2.88*	*34.33*
Hydroelectricity[64]	21.85	301.83
Nuclear	5.47	19.88
Wind	20.72	95.81
Solar (mostly PV)	10.64	26.52
Total[65]	**105.97**	**1360**

Source: China Electricity Council (2015b) unless otherwise specified.

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[63] This includes biomass, cogeneration and wastes, calculated here as a residual from coal and gas capacity additions.

[64] The figure for total installed hydroelectric capacity in CEC (2015a) is 301.83GW, which is slightly greater than the figure given in CEC (2015b), namely 300GW. We assume the latter figure is rounded down (in both documents, the capacity added is 21.85GW, and earlier data for 2013 show total hydro capacity at the end of 2013 of 280GW), so we have included the slightly larger figure in the table.

[65] Total capacity added in 2014 is the aggregate of capacities added from individual sources. Total generation capacity is the aggregate of individual sources rounded to three significant figures, which reflects the CEC (2015b) stated figure of total generation capacity (1.36TW).

Table 4: Electricity generation output from thermal sources, 2013–2014

Generation Source	Generation Output 2013 (TWh)	Generation Output 2014 (TWh)	2013–14 change (TWh)	Percentage change, 2013–14 (%)
Total thermal	4199.4	4170	–29.4	–0.7
Non-coal thermal[66]	185.1	212.87	27.77	15%
Coal[67]	4014.3	3957.13	–57.17	–1.4%

Source: China Electricity Council (2015b)

Table 5: Hydroelectric utilisation rates and capacity

Year	Hydroelectric Capacity Utilisation (hours / year)	Hydroelectric Capacity Utilisation (%)	Cumulative Total Hydroelectric Capacity at end of year (GW)
2008[68]	3589	41	173
2009[69]	3264	37	197
2010[70]	3429	39	213
2011[71]	3028	35	230
2012[72]	3555	41	249
2013[73]	3318	38	280
2014[74]	3653	42	302
Average	**3405**	**39**	

Sources as per footnotes for each year.

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66 Total non-coal thermal generation capacity was 90GW in 2014, up 11.74GW compared with 2013 (from Table 3; CEC 2015b). Assuming a capacity factor of 27% for non-coal thermal generation in 2013 and 2014 (this is consistent with the IEA's calculation of the non-coal thermal capacity factor for 2012: IEA 2014a), that implies 212.87TWh of non-coal thermal generation in 2014, up 27.77TWh compared with 2013. (NBS data do not provide a breakdown of thermal generation.)

67 Calculated as a residual.

68 http://www.gov.cn/gzdt/2010-01/06/content_1504129.htm.

69 http://www.gov.cn/gzdt/2010-01/06/content_1504129.htm.

70 http://www.nea.gov.cn/2011-01/28/c_131054979.htm.

71 http://www.nea.gov.cn/2012-01/14/c_131360365.htm.

72 http://www.nea.gov.cn/2013-01/14/c_132100340.htm.

73 http://www.nea.gov.cn/2014-01/14/c_133043689.htm.

74 CEC (2015a).

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