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March 2016

Centre for Climate Change Economics and Policy
Working Paper No. 258

Grantham Research Institute on Climate Change and the Environment

Working Paper No. 228

ESRC Economic & Social Research Council

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Authors' Note

This article was accepted for publication in *Climate Policy* on 17 February 2016 and is expected to be published on the journal's website in late March 2016. This version of the article is the version submitted to *Climate Policy* on 20 December 2015, with some minor amendments.

Abstract

As China's government finalises the country's 13th Five Year Plan for economic development (2016–2020), this article takes stock of recent changes in China's economy and energy system since the turn of the century, and looks ahead to the likely trajectory of China's emissions over the next decade. The period 2000–2013, it is now clear, was a distinct and exceptional phase in China's developmental history, during which the very high levels of greenhouse gases emitted were linked closely with the energy-intensive, heavy industry-based growth model pursued at that time. China is currently undergoing another major structural transformation — towards a new development model focused on achieving better quality growth that is more sustainable and inclusive — and it is also grappling with economic challenges associated with the transition. Data from 2014 and the first three quarters of 2015 illustrate the extent of these changes. Based on analysis of this data in light of the underlying changes occurring in China's economy and policy, this article provides an updated forecast of the Kaya components of energy CO2 emissions (GDP, energy/GDP and CO2/energy) over the next decade to 2025. It concludes that China's CO2 emissions from energy, if they grow at all, are likely to grow much slower than under the old economic model and are likely to peak at some point in the decade before 2025.

Policy Relevance Statement

The article suggests a number of important areas of Chinese policy focus to mitigate risks and challenges that might otherwise prolong the peak date for CO2 emissions. Our analysis and conclusions also have more general implications for Chinese and international climate policy.

They suggest that China's international commitment to peak emissions 'around 2030' should be seen as a highly conservative upper limit from a government that prefers to under-promise and over-deliver. They also reinforce the virtue of a 'dynamic' approach to international climate cooperation, as envisaged under the Paris Agreement, whereby countries' targets and policies are regularly updated in light of new information. The importance of macroeconomic analysis for emissions projections climate policy development is also highlighted.

Acknowledgements

We are grateful to Tim Buckley, Athar Hussain, Thomas Spencer and Dimitri Zenghelis for helpful discussions on China's economy in the course of preparing the present article, to Isabella Neuweg editing assistance, to four anonymous referees who provided helpful comments and suggestions, and to members of WRI's ChinaFAQs network who provided feedback on a presentation of this material. We are also grateful to the following people for input into an earlier Grantham Research Institute Policy Brief on which the present article is partly based: Ehtisham Ahmad, Rodney Boyd, Ben Caldecott, Shenghao Feng, Ajay Gambhir, Ross Garnaut, Sam Geall, Himanshu Gupta, Karl Hallding, Guoyi Han, He Jiankun, Neil Hirst, Frank Jotzo, Lauri Myllyvirta, Felix Preston, Qi Ye, Morten Rossé, Ligang Song, Teng Fei, Shane Tomlinson, Wang Jianliang, Renfeng Zhao, and members of the Grantham Research Institute Policy Group. Any errors or omissions are our own.

Funding

Support from the Grantham Foundation for the Protection of the Environment and the UK's Economic and Social Research Council via the Centre for Climate Change Economics and Policy is gratefully acknowledged.

1. Introduction

As China's government finalises the country's 13th Five Year Plan for economic development (2016–2020), and in the wake of the successful negotiation of the Paris Agreement in December 2015, this article takes stock of recent changes in China's economy and energy system. It places these recent changes in the context of wider shifts in China's economic development pattern since the turn of the century, and looks ahead to the likely trajectory of China's emissions over the next decade.

The article primarily contributes to an ongoing debate about the likely trajectory and peaking year of China's emissions. The Chinese government has committed China internationally to 'achieve the peaking of carbon dioxide emissions around 2030' and to make 'best efforts to peak early' (People's Republic of China, 2015). Some analysts of China's economy and energy sector have argued that China's emissions are likely to peak by or before 2030 (Garnaut, 2014; Global Commission on the Economy and Climate [GCEC], 2014; Green and Stern, 2015; He, 2014; Jiang, Zhuang, Miao, & He, 2013; Teng & Jotzo, 2014). These predictions are at odds with the vast majority of energy system and economic (general equilibrium) modelling studies of China, which find that peaking by 2030 will be challenging without profound changes in climate-energy policy (see the analysis of 89 modelling scenarios by Grubb et al., 2015).

In an important recent contribution that provides a convenient point of departure for the present article, Grubb et al. (2015) illuminated the structural features of twelve of the main models used to forecast Chinese emissions to 2030 using statistical analysis of the Kaya components of these models. They found that the carbon intensity of energy is the major dependent variable affecting CO_2 emissions, implying that 'most CO_2 reductions from the models are delivered by interfuel substitution and adoption of technologies with lower CO_2 intensity', especially in the electricity sector (at S22). The vast majority of the models reviewed 'pay relatively little (or no) attention to macroeconomic structure' and its potential to change (at S31). Rather, the models tend to assume smooth continuations in economic growth rate, economic structure and energy demand based on historical trends. Accordingly, the models would do a poor job of predicting future emissions in the context of significant and rapid structural economic changes, particularly were these to affect energy demand.

The present article argues that China is in fact undergoing large-scale, rapid, and multidimensional changes in economic structure, with major implications for energy demand, at the same time as the energy supply is diversifying. Accordingly, the modelling scenarios referred to above, insofar as they fail to account for such changes, will not generate accurate forecasts of China's emissions trajectory. Moreover, it may be very difficult to capture the changes occurring in China with yet further formal modelling exercises (Grubb et al., 2015).

This article therefore takes a different approach to analyse China's emissions trajectory. Methodologically, we proceed by explaining the genesis and nature of the recent and ongoing changes in China's economy, economic strategy/policy, and energy sector (Part 2). In the light of this overview, we then synthesise relevant data from the period January 2014 to September 2015 to produce an account of what might be termed the early or transitional phase of China's 'new normal' economic strategy (Part 3). In Part 4 we explore how the dynamics of this new strategy are likely to play out over the next decade, while also identifying risks, challenges and key policy responses to these. We use a simple illustrative scenario to show how the likely trends we identify in this Part could lead to a peak in CO_2 emissions before 2025. We conclude by considering some implications of our analysis for both policy and future research.

2. 2000–2013: heavy industry growth and its implications

China has been growing very rapidly, often at double-digit rates, for more than three decades since its period of reform and opening-up took hold in the late 1970s / early 1980s. Its strategy has been centred on high savings and investment, strong export orientation and a focus on manufacturing and construction industries. Yet periods of continuity have been punctuated by major structural shifts.

One such shift came at the turn of the century, as China rapidly developed its energy-intensive, heavy industries. Over the period of roughly 2000–2013, China's growth strategy was characterised by the following features (China Council for International Cooperation on Environment and Development [CCICED], 2014; Garnaut et al., 2013; 2014):

- roughly double-digit annual GDP growth (on average);
- a very high investment share of expenditure, with exceptionally low proportions of expenditure on domestic consumption and services;
- very high levels of investment in heavy industry sectors such as steel and cement production, which require large volumes of energy (both direct fossil fuel inputs in the

production process and electricity consumption, with the latter supplied predominantly through expansions in coal-fired power generation);

- a high profit share of income;
- strong dependence on exports to external markets, albeit less so in the period following the global financial crisis of 2007/08, in which falls in net-exports were largely replaced by additional, government-stimulated domestic investment.

One consequence of this growth model was an extraordinary expansion in coal consumption. Between 2000 and 2013, China's coal consumption nearly trebled, growing at a compound rate of more than 8% per year (National Bureau of Statistics [NBS], 2015a[1]). This rapid growth saw China become a net importer of coal from 2009, and by the end of this period half of the coal consumed globally was being consumed in China.

This model brought with it many benefits. However, the Chinese people (Pew Research Centre, 2013; Wike & Parker, 2015), leading experts (International Monetary Fund [IMF], 2015; World Bank & DRC, 2013) and China's leaders[2] have increasingly come to recognise that this model of growth is not sustainable or desirable — for economic, financial, social and local environmental reasons, to say nothing of its incompatibility with global climate goals (Stern, 2015, pp. 224–225).

First, China's growth model is *environmentally* unsustainable. In particular, the economy's reliance on coal-fired power and heavy industrial production, and its growing vehicle use in urban areas, have led to acute rises in outdoor air pollution, to which China's growing urban population is exposed (CCICED, 2014; World Bank & DRC, 2014). Air pollution is exacting an immense toll on public health: in the most comprehensive study of ground monitoring data to date, particulate matter pollution measuring less than 2.5 micrometres in diameter (PM2.5) in China has been estimated to contribute to 1.6 million premature deaths per year, i.e. 4,000 deaths per day (Rohde & Muller, 2015) — or a monetary equivalent (using conventional monetisation techniques) of more than 10% of China's GDP (Hamilton, forthcoming). Other environmental impacts are mounting, too, including water pollution and water scarcity, soil pollution and solid waste (CCICED, 2014; World Bank & DRC, 2014).

[1] This data takes into account the significant statistical revision of Chinese coal data from 2000–2013 following the five-yearly economic census completed in 2014.
[2] See, e.g., remarks made by President Xi (quoted in Anonymous, 2013) and Premier Li (quoted in Anderlini, Mitchell and Wildau, 2015).

The old model of growth, while lifting hundreds of millions of Chinese out of poverty, has also produced various undesirable *social* impacts that are adding to pressures for reform (Hu, 2015; World Bank & DRC, 2014; Pew Research Centre, 2013; Wike & Parker, 2015). Most prominently, it has led to growing inequalities of different kinds. Rapid urbanisation and urban economic growth, combined with China's restrictive residential registration (*hukou*) system, have led to rising urban-rural inequality and social divisions between registered and unregistered urban residents (World Bank & DRC, 2014). There has also been growing inequality between regions as the growth was disproportionately concentrated in the eastern coastal cities, though with an increasing shift toward central regions in recent years (Hu, 2015). In addition, the low-wage/high-profit structure of the old growth model combined with the relatively low expenditure on social services contributed to rising interpersonal inequality (Garnaut et al., 2013). Meanwhile, the health impacts of pollution and environmental degradation have created deep and growing social pressures for change (Pew Research Centre, 2013; Sheehan, Cheng, English, & Sun, 2014; Wike & Parker, 2015).

Thirdly, the old model of growth is unsustainable in a conventional *economic* sense. As demand in many parts of China's construction and heavy industrial sectors passes saturation points, continued political-economic incentives to invest in these areas have resulted in widespread excess capacity and diminishing returns on capital, undermining their competitiveness and resulting in weak productivity growth (CCICED, 2014; IMF, 2015). Additionally, the working-age proportion of China's population (i.e. those between 16 and 60 years old) is shrinking (Fan, 2015), contributing to upward pressure on wages. Changing labour market conditions are, in turn, eroding China's comparative advantage in low-wage, low-value-added, export-oriented manufacturing (IMF, 2015). Moreover, natural resource constraints, environmental deterioration and high levels of dependence on imported energy are also undermining China's economic performance and imposing mounting economic costs (CCICED, 2014; GCEC 2014; World Bank & DRC, 2014).

Additionally, China faces major vulnerabilities in its financial sector that threaten long-term growth if not managed well. In the midst of the global financial crisis of 2007–08, state-owned banks engaged in a major expansion of credit that resulted in large amounts of bank debt being accumulated by local governments and commercial enterprises to finance investment, especially in property construction and infrastructure, in turn stimulating demand for heavy-industrial products like steel and cement (Guan et al., 2014, p. 1019). Total debt in the Chinese economy quadrupled from an estimated $7 trillion in 2007 to $28 trillion by mid-

2014 (Dobbs, Lund, Woetzel, & Mutafchieva, 2015). Given the extent of excess capacity in real estate and heavy industry, much of the investment was not allocated to profitable projects, leaving Chinese banks with large and rising portfolios of non-performing loans (IMF, 2015). Deeper problems with credit quality are being revealed as the economy slows (see, e.g., Bland, 2015). According to the IMF, these vulnerabilities 'have reached the point that addressing them is an urgent priority' (IMF, 2015, p. 8).

Around 2012–13, China's then-incoming generation of political leaders began articulating the need for fundamental structural change and policy reform — a 'new normal' — in order to respond to these challenges and steer China's development path onto a more sustainable and desirable course. Between late 2013 and 2015, the contours of that agenda have been articulated with increasing force and clarity at the highest levels of China's government (Central Committee of the Communist Party of China [CCCPC], 2013; State Council, 2013; Zhang, 2014; and see Kuijs, 2015).

This 'new normal' is understood by China's leadership and policy elite as embodying a shift toward economic growth of a higher quality and lower rate, with a particular emphasis on four sub-themes: *services*, *innovation*, *reduced inequality* and *environmental sustainability*.[3] 'Services' and 'innovation' can be read as proxies for the changing structure of Chinese industry and investment towards services and higher-value-added manufacturing. 'Reduced inequality' refers to rebalancing the economy toward domestic consumption and initiatives to reduce urban-rural and inter-regional inequalities. Environmental sustainability is both a product of the other measures and a distinct aim referring to changes in the energy supply and other environmental and climate policy initiatives. For example, a number of additional energy/climate plans and policies were introduced around 2013, including the National Climate Change Plan, the Energy Development Strategic Action Plan, and the Air Pollution Prevention and Control Plan. One can readily see how each of these sub-themes directly responds to the social, environmental and economic legacy of the old model of growth, discussed above.

Through a combination of emergent changes in the economy and top-down shifts in strategy and policy, deep and wide-ranging changes in China's economic structure and policy are now

[3] This summary definition of the 'new normal' concept is based on Stern's discussions with Chinese leaders and policymakers at the China Development Forum in March 2015. These four sub-themes are also apparent from key documents produced under China's new leadership over the last two years, such as those cited in the previous paragraph (cf Hu, 2015).

occurring — changes 'so comprehensive and profound that they add up to a new model of Chinese economic growth' (Garnaut et al., 2013; cf Hu, 2015). At the same time, China is experiencing shorter-term transitional challenges associated with the decline of industries that powered the old growth model and the introduction of policies needed to underpin the new model. The following section substantiates this picture of profound change by analysing recent economic data and associated dynamics.

3. 2014–2015: the early phase of China's 'new normal'

The nature, scale and pace of change occurring in China can be gleaned by recent analysis of data relating to energy consumption and energy supply, and their underlying dynamics, and contrasting these with trends from the previous growth phase.

3.1 Energy consumption

Driven by strong growth in heavy industry investment and production, China's total primary energy consumption (PEC) grew at a compound annual rate of more than 8% per year between 2000–2013 (NBS, 2015a). In a dramatic shift, PEC growth slowed to just over one quarter of that rate in 2014, growing only 2.2% compared with 2013 (NBS, 2015b), and slowed even further to less than 1% year-on-year in the first three quarters of 2015 (NBS, 2015c).

To understand why this shift has occurred, it is helpful to analyse energy consumption as the product of GDP and the energy intensity of GDP (the latter reflecting both changes in the sectoral composition of growth and changes in energy efficiency within sectors).

GDP growth in China has fallen from an average of 10.5% p.a. over the period 2000–2010, to 7–8% over 2012–2014 (World Bank, 2015; IMF, 2015). Official data record growth slowing to below 6.9% over the first three quarters of 2015 (NBS, 2015c), with unofficial forecasts using alternative methods forecasting significantly lower levels of growth for 2015.[4]

China's slowing growth rate is linked to the changing structure of its economy, which is moving away from high reliance on net exports, fixed asset investment and heavy industry, and towards greater domestic consumption and tertiary production (IMF, 2015; NBS, 2015c).

[4] See, for example, the average of forecasts by experts using alternative methods produced by Consensus Economics (cited in Wolf, 2015).

Of particular importance in this structural change is the declining share of industry in GDP. Heavy industry expanded rapidly in the 2000–2013 period, with the result that China's industry share of GDP — accounting for 44% in 2013 — has been exceptionally high compared with countries at similar levels of development (Grubb et al., 2015; Xu, Zhao, Liu & Kang, 2014). Because Chinese industry is such a high consumer of energy relative to the services, household and transport sectors, the changes in the structure of growth described above are putting strong downward pressure on PEC growth. Notably, the steel and cement industries, which are especially high energy users, have begun to decline. In 2014, these industries grew much slower than in the 2000–2013 period (NBS, 2015b), and in the first half of 2015 they declined in absolute terms: crude steel production fell by 1.3%, and cement production fell by 5.3%, compared with the same period in 2014 (NBS, 2015d).

These structural changes are occurring on top of ongoing energy conservation initiatives within industry and other sectors (see Song et al., 2015). The result of both structural change and energy efficiency improvements has been especially strong declines in the energy intensity of GDP over the last two years — 4.8% in 2014 (NBS, 2015b) and 5.7% percent year-on-year in the first three quarters of 2015 (NBS, 2015c) — at the same time as GDP growth slowed significantly.

3.2 Energy supply

At the same time as China's energy demand growth has been slowing dramatically, China's energy sector transformation has continued apace. Between 2010 and 2014, non-fossil energy generation capacity went from 256.7 gigawatts (GW) to 444 GW, an increase of 73% (Song et al., 2015). In 2014 alone, China added roughly 22 GW of hydroelectric capacity, more than 5 GW of nuclear, 21 GW of wind, and 11 GW of solar (mostly photovoltaics) (China Electricity Council 2015a; 2015b). By the end of 2014 China's non-fossil share of total PEC was 11.2% (NBS, 2015a).

The expansion of non-fossil energy sources is being driven by at least three important factors. First, it constitutes part of the government's response to the air pollution crisis by helping to reduce reliance on coal-fired power generation (Sheehan et al., 2014). Second, higher proportions of indigenous renewable energy mitigate reliance on fossil fuel imports, improving energy security (Baghat, 2010). Third, the government has strategically prioritised zero-carbon energy generation industries (nuclear and renewables) as innovative sectors in which China can move up the global value chain, capture global market share, and secure future domestic industrial growth (Energy Research Institute, 2015; Nahm & Steinfeld, 2014). These efforts have materialised in strong state support for innovation in, and the manufacturing and deployment of, zero-emissions energy sources (Frankfurt School–UNEP Centre & BNEF, 2015).

China is also rapidly expanding its supplies of gas, along with its domestic gas production and import capacity, as a key part of its plans to diversify the energy mix and reduce air pollution. Gas consumption grew at a compound rate of 14% per year from 2010 to 2014 (NBS, 2015a). Along with the expansion of other non-coal thermal sources, such as bioenergy, the expansion of gas is further eroding the share of coal in China's energy mix.

Coal consumption in industry, which accounts for about half of China's total coal consumption, also appears to be falling. The downward pressure on industrial coal use resulting from falling steel and cement output (see above section 3.1) is being compounded by trends within these industries to substitute away from emissions-intensive production processes. For example, industry experts point to a declining proportion of steel being produced from blast furnaces (which use coking coal) as these are substituted for methods that use recycled scrap steel (which do not use coal), and to similar substitutions toward lower-emissions production processes occurring in the cement industry.[5]

While the expansions of all non-coal energy sources and changing production methods in industry are increasingly displacing coal in the energy mix, the government is also taking unprecedented steps to regulate coal consumption directly to combat air pollution. In 2013, pursuant to its Air Pollution Prevent and Control Plan, the government established coal caps in nine provinces and cities that together account for 30% of China's coal consumption (Song et al., 2015).

The combined effects of all of the above measures, in the context of significantly slower PEC growth, has been a rapid turnaround in China's consumption of coal. According to estimates by the US Energy Information Administration, in 2014, there was no growth in coal consumption when measured on an energy content basis and, when measured in terms of physical tonnage, coal consumption fell by 2% (EIA, 2015).[6] After compound annual growth

[5] Ross Garnaut (personal communication, March 12, 2015).
[6] The figures cited here take into account the upward revisions to China's historical coal consumption made by China's statistical agencies following the once-in-five-year economic census, which took place in 2013. The census put China's coal data on a surer footing. China's National Bureau of Statistics (2015a) reported an increase of less than 0.06% in the consumption of coal in Standard Coal Equivalent (SCE) terms in 2014

in coal consumption of more than 8% per year in the preceding 13 years, this turnaround is remarkable. The rapid change is also reflected in coal production and import data from 2014, with production falling 2.5% and imports falling 10.9% (NBS, 2015b). In the first three quarters of 2015, coal's decline deepened, with production falling 4.3% and imports falling nearly 30% year-on-year, suggesting consumption may have fallen by as much as 5% in volumetric terms (China Shenhua Energy Company Ltd, 2015).[7]

While there has been considerable attention paid to anomalies and revisions in China's recent historic coal data up to the end of 2013 (Buckley 2015; Wilson, 2015; Wynn, 2015), the 2014 and 2015 data are likely to be relatively accurate owing to changes in calculation methods made following China's once-in-five-year economic census in 2013. The 2014–15 data, moreover, are consistent with wider market trends, most relevantly in thermal electricity generation (where data are more reliable due to metering) and in heavy industry sectors such as steel and cement, discussed above (see China Shenhua Energy Company Ltd, 2015, pp. 14–15; Green and Stern, 2015). Accordingly, it is highly unlikely that the 2014–15 coal data misrepresent the general picture over this period: flattening and then falling coal consumption, production and imports.

4. The next decade: likely trends and dynamics in China's energy demand, supply and CO_2 emissions

This final section of the article looks forward to the next decade, considering the possible evolution of China's economy and energy system over the course of the 13th and 14th Five Year Plans by focusing on key themes and issues affecting the trajectory of China's CO_2 emissions. Significant risks and challenges in relation to each theme are explored, along with suggested policy priorities to address these.

4.1 Energy consumption

GDP growth: managing structural change for slower but better quality growth

compared with 2013. This increase in SCE consumption at the same time as the fall in physical coal consumption reflects an increase in the average quality (hence energy content) of coal burned in China in 2014. Preliminary statistics from China's National Bureau of Statistics had earlier (NBS, 2015b) estimated a 2.9% decline in coal consumption in SCE terms in 2014, before changes in average energy content were factored in.

[7] This figure assumes slower growth in inventories over this period in 2015 compared with 2014. The fall may have been lower when measured in terms of energy content, depending on changes in the average quality of coal consumed.

There is widespread agreement among expert analysts of China's macroeconomy that the *long-term structural trend* in China is one of slowing economic growth (see, e.g., IMF, 2015; Hu, 2015; Johansson et al., 2013; Pritchett & Summers, 2014). That has been the historical experience of countries experiencing periods of rapid growth, 'catch up' and policy reform. China's growth path, with its past very high savings and investment rates, will likely involve a continued shift toward domestic consumption and more productive, higher-value industries, including services and clean-technology industries. This will significantly improve living standards in China, but likely come with slower GDP growth, since it will be more difficult to obtain short-term growth from productivity improvements than from the past strong driver of investment in capital stock.

Successfully transitioning to the new economic model will require domestic policy reforms to boost consumption and raise productivity. These include further fiscal reforms to ensure governments at relevant levels have sufficient revenue to provide local infrastructure and social services to the resident population (e.g. education, healthcare, welfare assistance and pensions). They also include reforms in the financial sector, land sector and State-Owned Enterprises so as to remove subsidies for resource-intensive and over-capacity industries and to improve the productivity of factors of production across the board.

While these reforms are central to the success of China's new economic model, they will entail transitional costs. Over the past few years and more prominently in 2015, the difficulties of managing that transition smoothly have become evident. The financial stimulus induced in the context of the global financial crisis (see Section 2) appears to have avoided the sharp downturn experienced in many other countries and fuelled GDP growth, but it extended the old model of growth and in key respects ran counter to underlying structural forces of change. In so doing, it added to underlying vulnerabilities that increased the risk of a subsequent sharper fall in the post-stimulus phase. This experience is instructive for those who think that China can, or should try to, return to the old model of growth; such a return would not be sustainable over the long term. Further attempts at credit-driven stimulus in real-estate and heavy industrial sectors now might maintain or boost growth in the short term, but would undermine much needed efforts toward policy reform, productivity improvement, and sustainable debt management — in turn undermining growth over the longer term (IMF, 2015).

Yet maintaining aggregate demand and low unemployment is, understandably, a central priority of China's government. Accordingly there is a risk that reform momentum might be sacrificed in a drive to maintain high aggregate demand in the short term. It will therefore be important in the years ahead that short-term stimulus measures be consistent with the long-term reform agenda. In this regard, a promising focus for policymakers is 'green stimulus' and 'green structural adjustment assistance': directing government stimulus expenditure toward decarbonising the economy — for example through energy efficiency retrofits and clean energy infrastructure construction — instead of high-carbon sectors; and retraining workers in the declining high-carbon sectors to equip them for jobs in the rapidly growing clean economy or other growing economic sectors. This strategy is likely to be particularly attractive in light of the Paris Agreement on climate change of December 2015.

In any case, in light of the long- and short-term factors discussed above, we conclude that achieving and sustaining GDP growth of 6% per year on average over the next decade should now be seen as a 'high' growth scenario, and one that is probably only achievable (in a sustained sense) if the government follows through with comprehensive reforms (cf IMF, 2015, pp. 10–11, 38). That rate of growth would be broadly consistent with projections from leading experts, which span a range of 6–7% for the period to 2020 and 3–6% throughout the 2020s (see, e.g., GCEC 2014; IMF, 2015; Johansson et al., 2013). It would, moreover, be consistent with the Chinese government's own target of 6.5% per year for the 13th Five Year Plan (Anonymous, 2015a), since we can reasonably expect the growth rate to slow further in the 2020s, in line with the logic and forecasts discussed above.

Energy intensity of GDP: capitalising on structural change to drive strong declines in energy use

As highlighted in Section 3.1, the high energy consumption of China's industry sector means that energy consumption growth can slow dramatically as China's economic structure changes in the manner described (Stern, 2011).

We expect the structural turnaround in heavy industries experienced in 2014–15 to continue into the future in response to falling demand associated with China's excess capacity in construction and heavy manufacturing sectors (China Iron and Steel Association [CISA], 2015; Ernst & Young, 2015), and to the high levels of excess capacity in the steel and cement industries themselves (CCICED, 2014). The structural nature of the turnaround in these industries is now widely recognised throughout the Chinese government and the industries themselves (Anonymous, 2015b; CISA, 2015). Accordingly, the prospects for declining investment, rationalisation and falling production across such sectors in the context of China's new development model now appear strong (on the steel sector see, e.g., Ernst & Young, 2015).

This highlights another important dynamic in China's new economic model: we are likely to see a continuation of the 2014–15 experience in which strong declines in the energy intensity of economic growth accompanied slower economic growth (see section 3.1). Accordingly, sustaining at least a 4% fall in the energy intensity of GDP over the next decade — a rate of improvement commonly assumed by other leading scholars (e.g. Teng and Jotzo, 2014) — looks very achievable in the context of China's new development model.

There are three main risks to sustaining energy intensity improvements of that order. One risk is that certain energy-intensive industries will emerge or expand. Of particular concern here are coal conversion industries (discussed below in Section 4.2).

A second risk is that the pace of intra-industry energy efficiency improvements slows within the heavy industries experiencing structural stagnation or decline. An important area of policy focus, then, is to ensure strong incentives for continued improvements in energy efficiency within those industries. Hove, Enoe and Gordon (2015) argue that there remains huge potential for efficiency upgrades in the Jing-Jin-Ji region's iron and steel sector, and that successful government energy conservation programs such as the Top 10,000 Enterprises program could be used to drive large additional reductions in CO_2 and air pollution through efficiency upgrades as the sector declines and restructures. China's slated national emissions trading scheme, which looks set to be structured as a baseline-and-credit scheme focused on intra-sectoral efficiency benchmarking, could potentially play a supportive role in this regard.

A third challenge will be to constrain growth in energy demand from buildings and transport as the residential and commercial sectors expand in line with China's changing economic structure, and as household income growth and urbanisation continue. Here, a strong focus on compact urban planning — which requires fiscal and land sector reform to address perverse incentives for urban sprawl — along with continued strengthening of energy efficiency policies (including their enforcement) for vehicles, buildings and appliances will be critical (Green and Stern 2014; World Bank & DRC, 2014).

Overall prospects for PEC: slow growth, with the potential for peak and decline

Ultimately, this trend of a slowing economic growth rate and strong declines in energy intensity suggests a medium-term future characterised by only modest growth in PEC. Taking our (if anything, high) assumption of 6% average GDP growth between 2014–2025 and assuming a decline in the energy intensity of GDP of 4% per year over the same period would imply growth in Chinese PEC of 1.8% per year to 2025. After average PEC growth of more than 8% per year between 2000–2013 this would be a monumental shift.

Yet even this PEC assumption could be considered conservatively high. The achievement of average GDP growth at around 6% over this period is likely to be contingent on successful implementation of the government's market-oriented reform agenda (IMF, 2015). Implementation of that agenda would likely accelerate the decline in energy intensity. One could therefore plausibly suggest an assumption of lower levels of PEC growth, and potentially an absolute fall in PEC alongside strongly rising incomes in the 2020s, under such a 'new normal – high-growth' scenario. This highlights an important point: one way or another (i.e. through higher GDP / lower energy intensity, or lower GDP / higher energy intensity), much lower levels of PEC growth relative to the past look set to be a stable feature of China's 'new normal'.

4.2 Energy supply

Despite expected slower PEC growth, we expect China's expansion of non-fossil energy sources to continue apace, alongside oil and gas growth, causing coal's share in the energy mix, and indeed absolute levels of coal consumption, to continue to decline significantly.

The government's official target, at the time of writing, is to achieve 15% of PEC from non-fossil sources by 2020, and 20% by 2030 (up from 11.2% as at the end of 2014: NBS, 2015a). These targets are likely to be significantly beaten, in part due to expected lower overall PEC growth than assumed by the Government when formulating its targets.

Continued strong expansions of non-fossil energy supply are rendered more likely by the three drivers identified in section 3.2: reducing air pollution; improving energy security; and promoting growth in strategic clean-technology industries. State support for innovation in, and the manufacturing and deployment of, zero-emissions energy sources appears likely to be strengthened in the forthcoming 13^{th} Five Year Plan (People's Bank of China & UNEP, 2015; Kuijs, 2015). China is also well placed to gain from further bilateral (e.g. with the US) and multilateral cooperation (e.g. through the G20) in this area, especially following the successful Paris climate conference in 2015.

Moreover, renewable energy capacity expansions continue to be guided by technology-specific targets (which are not expressed as a share of total PEC), including 200–300 GW of wind by 2020 and a solar target that was increased in October 2015 by 50% to 150 GW by 2020 (Mancheva, 2015). Indeed, such targets have been consistently revised upwards by China's energy planning agencies as costs have plummeted and the industries have grown (Jiang, 2014) — forces that are only likely to continue as China and the world move increasingly decisively away from fossil fuels. While China's highly ambitious 2020 target for operational nuclear capacity (58 GW) is unlikely to be met, more than 40 GW of nuclear power is expected to be operational by this time, and more than 100 GW by 2030 — a build-out considered ambitious but feasible (see Green and Stern, 2015, pp. 38–39, for discussion). While increasing proportions of variable (wind and solar) and non-variable (nuclear) electricity generation pose challenges for the stability of the grid, necessary grid augmentations and increases in electricity storage capacity are occurring at great scale and pace, and this is likely to continue (Garnaut, 2014).

Large gains in the efficiency of China's coal-fired power generation fleet have been made already, as older and less-efficient plants have been replaced by high-efficiency plants, meaning the rate of efficiency improvement may slow in future. Yet there remains considerable potential for further efficiency gains, and the central government has increased the efficiency standards that existing and new coal plants must meet by 2020, which it expects will save around 100 million tonnes of raw coal and reduce CO_2 emissions by 180 million tonnes annually (Anonymous, 2015c; Wei, 2015).

Beyond the electricity sector, there is great scope for improving industrial efficiency and continued substitution away from coal-intensive production processes in the steel and cement industries, discussed in Section 3.2, which will likely continue to put downward pressure on coal's share in the overall energy mix.

Oil and gas consumption in China are likely to grow significantly over at least the next decade, however, there is considerable uncertainty as to the pace of growth and the expected peak year for their consumption. Oil consumption growth will be driven by rising demand from private and commercial transportation, associated with rising household incomes and economic growth. A major determinant will be the size and composition of China's vehicle stock. However, projections of the future vehicle stock vary enormously as there are so many relevant supply and demand side variables; the sector will be the subject of both disruptive technological innovation and strong policy intervention over the coming decade and beyond, making forecasting difficult (see Gambhir et al., 2015). China has targeted an expansion of its share of gas in PEC to 10% by 2020 (State Council, 2014), which looks feasible (see Green and Stern 2015, p. 37).

In sum, while there are many variables at play, it appears likely that the transformation of China's energy sector will continue and indeed strengthen, to the disadvantage of coal.

However, there are two significant risks that could slow the transformation of China's energy mix over the next decade. In the 'new normal' context of low (and potentially even falling) electricity demand, continued strong expansions in non-fossil (and gas) generation will reduce the market share of existing coal-fired generation. China's energy supply challenge thus shifts from ensuring that all incremental capital stock in the electricity sector is zero-/low-carbon to also reducing, retiring or refurbishing existing, high-carbon stock. This will complicate the political economy of electricity decarbonisation. The slower electricity demand growth and high non-coal capacity expansions of 2014–15 illustrate this challenging new dynamic. As coal-fired generation output fell (see Section 3.2) while coal-fired power capacity expanded, the utilisation of the coal-fired power fleet has plummeted to less than 50% (National Energy Administration, 2015). The falling utilisation of coal plants has inflamed disputes among generators and grid operators about which sources should be given priority to dispatch electricity (and therefore receive payments for electricity supplied). Coal-fired power generators were often given priority over wind and solar generators, leading to high rates of wind and solar 'curtailment' and more coal being consumed than needed to be (Anonymous, 2014).

These disputes over dispatch priority will likely intensify in future, due not only to flat energy demand and increased non-fossil supply, but also to the expansion of China's coal-fired generation capacity, which has continued — in fact, it has accelerated — in 2014–15 despite already enormous amounts of excess capacity. The main causal factor behind the most recent expansions appears to be the devolution of authority over environmental approvals from the centre to provincial governments, many of which have welcomed the opportunity for short-term economic growth from the construction of new plants with little regard for the long-term productivity of the investment (Myllyvirta, Shen & Lammi, 2015). Amid low coal prices and growing numbers of new coal plants expecting returns on investment, there is a risk of a resurgence in coal-fired power generation and a slowdown in non-fossil expansion.

A second risk is the expansion of coal conversion industries — which produce, for example, synthetic natural gas or chemicals from coal using highly energy- and emissions-intensive processes. The central government is unlikely to approve a large expansion of coal conversion industries, especially the coal-to gas-industry, in light of China's climate change commitments, the dubious economic case for their expansion and the extremely high impacts on local water consumption and air pollution (Ding et al. 2013; Ottery, 2014; Sheehan et al., 2014; Yang & Jackson, 2013). Nonetheless, there is a risk that enterprises and local governments might expand these industries contrary to central government policy.

These risks suggest the need for various policy responses. First, a range of measures would help to rein in the expansion of new coal infrastructure in electricity and industry, including a ban or at least tight restrictions on new coal-fired power stations and coal conversion projects, (re-)centralised control over approvals and financing, and stringent caps on overall coal consumption (see also comments by Zhou Dadi, quoted in Zhao, 2015). Such moves would also free up capital in the energy sector that could be reallocated to expanding non-fossil energy deployment.

A second priority is to reform the operation of the electricity sector to ensure that the lowest-carbon and most efficient electricity generation sources are given priority to dispatch electricity into the grid — so-called 'green dispatch'. This would help to ensure non-fossil generation sources are prioritised over fossil generation, and that gas and more efficient coal-fired generators are prioritised over less efficient coal generators.

Third is to increase effective carbon prices on fossil fuel energy sources, especially coal. Even while generators cannot pass through carbon price costs onto consumers, effective carbon pricing would alter the economics on the supply-side in ways that would disadvantage high-carbon generators and support green dispatch. A rising coal tax would be a highly efficient and administratively effective measure, well-suited to China's institutional context (Green and Stern, 2014; 2015), though a well-designed and implemented emissions trading scheme operating in the electricity sector could in theory achieve similar results (Baron et al., 2012).

Promisingly, the Government has signalled at the highest levels its intention to move strongly in each of these policy directions in the September 2015 U.S.–China Joint Presidential Statement on Climate Change. As ever in China, local implementation will be critical, which means incentives for local governments and SOEs in the fossil fuel and electricity sector to cooperate may be necessary. A financial strategy for managing stranded coal assets and a labour market strategy for supporting and retraining workers for a transition to new growth industries would complement the other measures suggested above.

4.3 Implications for China's CO_2 emissions trajectory and peaking

Combining the above analysis, we can readily see how the trajectory of China's CO_2 emissions over the next decade is likely to be radically different from that during 2000–2013. It is quite possible that emissions will fall modestly from now on, implying that 2014 was the peak. If emissions do grow above 2014 levels — if, say, a number of the risks identified earlier manifest — that growth trajectory is likely to be relatively flat, and a peak would still be highly likely by 2025. More likely it will occur at some point between 2014 and 2025, depending on how the above factors play out.

This potential can be illustrated via a simple scenario that uses a Kaya decomposition, similar to Teng and Jotzo (2014), as per Table 1, below. We adopt the same approach and historical values/assumptions as those authors, albeit with some updated forward-looking assumptions broadly in line with the likely trends we identify in this article: GDP growth from 2014–2020 is assumed to correspond roughly to the official target of 6.5% per year on average, slowing to 5.5% per year on average over the subsequent five years; energy intensity is assumed to decline at 4% per year over the decade; CO_2 intensity of energy is assumed to decline at 1% per year over the next five years, ramping to 1.5% per year in the 2020s. The result is a peak in CO_2 emissions between 2020 and 2025.

Table 1: Illustrative peak CO_2 scenario under 'new normal' conditions

	2005-2013 (actual)		2014-2020		2021-2025		2026-2030*	
	Annual growth (%)	Index (2005 = 1) at 2013	Annual growth (%)	Index (2005 = 1) at 2020	Annual growth (%)	Index (2005 = 1) at 2025	Annual growth (%)	Index (2005 = 1) at 2030
GDP	10.1	2.16	6.5	3.36	5.5	4.39	4.5	5.46
Energy/GDP	-3.8	0.73	-4	0.55	-4	0.45	-4	0.37

CO_2/energy	-0.5	0.96	-1	0.9	-1.5	0.83	-1.5	0.77
CO_2/GDP	-4.3	0.7	-4.9	0.49	-5.44	0.37	-5.44	0.28
Energy	6	1.58	2.24	1.85	1.28	1.97	0.32	2
CO_2	5.4	1.52	1.24	1.66	-0.24	1.64	-1.18	1.54

* hypothetical - included to illustrate peak (not discussed in text)

Under this scenario, China's GDP would double between 2010 and 2020 — consistent with the Government's goal for China to be a 'moderately well-off society' by 2020 (Anonymous, 2015a) — and China's pledged commitments to peak CO_2 and reduce the CO_2 intensity of GDP by 60–65% by 2030 (People's Republic of China, 2015) would be achieved more than five years early.

5. Conclusion

This article has provided a synthetic overview of trends and dynamics in China's economic development, energy demand and energy supply during the heavy industry-based growth period of 2000–13 and the beginning of the 'new normal' period 2014–15. It has been argued that China is undergoing large-scale, rapid, and multidimensional changes in economic structure, with major implications for energy demand, at the same time as the energy supply is diversifying. Based on our analysis of likely future trends, we concluded that China's CO_2 emissions from energy — if they grow at all — are likely to grow much more slowly than under the old economic model and are likely to peak at some point in the decade before 2025.

Our analysis could usefully be applied and extended in future research in at least two ways. First, our findings reinforce the call by Grubb et al. (2015) for a new generation of models that better represent the range of possible outcomes from slowing GDP growth and structural economic change away from heavy industry. When combined with recent improvements in understanding baseline historical data (e.g. Liu et al., 2015), our analysis of recent data and likely trends could help inform new models and modelling assumptions that yield a much more realistic range of China's future emissions scenarios than at present. Second, whereas this article focused on energy CO_2 emissions, the analysis of structural change in China's economy could usefully inform analysis and projections of China's non-energy CO_2 emissions and non-CO_2 greenhouse gases. Developments in both of these directions would, in turn, help improve understanding of the size of, and dynamics affecting, the remaining global carbon budget.

Our analysis and conclusions have a number of important implications for policy. First, they suggest that China's international commitment to peak emissions 'around 2030' should be seen as a highly conservative upper limit from a government that prefers to under-promise and over-deliver. Better global understanding of the extent and pace of change occurring in China should spur a reassessment of likely future global emissions, trends in the relative prices of commodities and technologies affected by structural change in China, and market opportunities for low-/zero-carbon technologies and services. The more governments and businesses understand the shift in China, the more they should see risks in the high-carbon economy and opportunities in the low-/zero-carbon economy, and should adjust their investments, innovation priorities, and institutional arrangements accordingly.

This also suggests the value of including transparent economic information in the Nationally Determined Contributions communicated by countries to the UNFCCC pursuant to the Paris Agreement negotiated in December 2015. In particular, countries that have adopted emissions intensity targets (including China) should clarify the assumptions on growth and structural change that underpin those targets.

Second, this article underscores the importance of macroeconomic analysis for emissions projections. Structural economic change has been shown to be a major determinant of China's emissions over the last 15 years — under the old model of growth, it was a driver of emissions growth; under the new model, it is and will continue to be a driver of emissions reductions. Accordingly, macroeconomic analysis agencies, both within China and internationally, have an important role to play in analysing factors affecting future emissions trajectories. The onus is on both the traditional climate community (not least those who model emissions scenarios) and the macroeconomic community to better engage one another in the course of undertaking such analysis and forecasting.

The third policy implication of our analysis, following on from the second, is that macroeconomic policy and planning organisations, both domestically and internationally, have a key role to play in shaping climate policy to achieve and accelerate decarbonisation. While policies targeting greenhouse gas emissions explicitly (e.g. carbon pricing) and energy consumption explicitly (e.g. energy conservation programs) are clearly essential, our analysis suggests that sound macroeconomic policy and planning are also highly important to decarbonisation. This is especially the case in China and other rapidly developing economies, given the greater range of growth and development pathways open to them in the years and decades ahead compared with developed countries. Those growth pathways will be highly influenced by fiscal, financial, trade and labour market policies. It will therefore be important for international economic institutions such as the G20 to be highly engaged with processes of decarbonisation, especially in regard to infrastructure financing. China is ideally placed to advance this agenda as Chair of the G20 in 2016, and given its central involvement in the Asian Infrastructure Investment Bank, the New Development Bank, and the Silk Road Fund.

Finally, the pace and scale of change in China, and the many uncertainties attending projections of its future emissions, reinforce the virtue of a dynamic approach to international climate cooperation, as envisaged under the Paris Agreement, whereby countries' targets, plans and policies are regularly updated in light of new information, opportunities and risks. In this way, countries will (individually and collectively) be better equipped to capitalise on the extraordinary opportunities, and respond to emerging risks, associated with the energy-industrial revolution that is underway, the completion of which is essential to avoiding catastrophic climate change.

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