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Article (Accepted version) (Refereed)

Original citation: Qi, Ye, Stern, Nicholas, Wu, Tong, Lu, Jiaqi and Green, Fergus (2016) *China's post-coal growth.* Nature Geoscience, 9 (8). pp. 564-566. ISSN 1752-0894

DOI: 10.1038/ngeo2777

China's Post-Coal Growth

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A combination of slowing GDP growth and a structural shift away from heavy industry, along with more proactive policies on air pollution and clean energy, has caused China's coal use to peak. It appears that economic growth has decoupled from growth in coal consumption.

China is the world's largest consumer of coal – at present accounting for 50% of global demand, thus having a worldwide impact economically and environmentally[1]. Between 2000 and 2013, consumption rose from 1.36 billion tons to over 4.24 billion tons, at an average annual rate of 12% (Figure 1)[2]. This prodigious consumption has fueled China's economic growth over the past three decades. Since coal use is also a significant source of CO_2 emissions and air pollution, China has come under increasing international and domestic pressures to reach peak emissions[3]. Consequently, moving the economy away from coal dependency – which remains China's primary energy source – has become an important development strategy.

The timing of China's peak coal consumption has been disputed, with a majority of recent projections placing it between 2020 and 2040[4]. Yet China's coal use dropped to 4.12 billion tons, a decrease of 2.9%, in 2014, with another 3.6% decrease in 2015, all while GDP continued to grow by 7.3% and 6.9% respectively. As Liu et al. (2015) and Korsbakken et al. (2016) discuss, there are ambiguities in the accuracy of China's coal use data, which have implications in China's energy and emissions policy. However, the government has retrospectively revised statistics on the basis of more accurate accounting (which are used here).

These values refer to the raw volume of coal use; calorific value data, released later in 2013, shows that consumption growth was roughly flat. If the volume figures take into account the fact that higher quality coal was burned, 2014 is more likely to be the year of peak coal consumption. Whether the peak year was in 2013 or 2014, the essential trend is clear.

This decoupling of economic growth and growth in coal use has raised important questions: Is this just a temporary dip? Or is it a turning point, indicating that peak coal consumption has already arrived? In this article, we argue that China's coal consumption has indeed reached an inflection point much sooner than expected, and will decline henceforth (even though it will remain the primary source of energy for the coming decades). China has entered the era of post-coal growth.

Economic Structure, Environmental Policy, and Coal Consumption

During the high tide of Britain's Industrial Revolution, the economist William Stanley Jevons wrote that coal was the "universal aid – the factor in everything we do." This is certainly true of China, a country where coal is 97% of the energy endowment[5,6]. In particular, China's rapid economic growth over the past thirty-five years has been fired by coal: it has, on average, constituted three-quarters of the overall energy mix. And despite gradual declines, owing mainly to rising oil consumption by transportation and petrochemicals, it has still managed to occupy a 70% share in 2003. The pattern of the economic growth has followed that of coal use: Figure 1 shows consistent growth in the latter over the last three-and-half decades of China's industrialization. Coal consumption during the 12th Five-Year Plan (FYP) period (2011-2015) was 5.6-times that of the 6th FYP Plan period (1981-1985)[2]. It is unlikely economic growth would have been as fast without such high levels of coal use.

However, in 2015, the share of coal in the energy mix fell to 64.4%. This has been part of a fundamental shift in the Chinese economy's relationship with coal, one that has been largely unnoticed until the recent peak in consumption. Even before the 2013 peak, the growth of coal consumption had been much slower than that of the economy, indicating rising efficiency. During the 6th FYP, it burned 1.7 kg of coal-equivalent to produce one dollar (2005-level) of GDP, but this ratio dropped to 0.56 kg three decades later – a roughly two-thirds decline. In the two years after the peak, China has been able to increase the value of its economic activity even as it burns less coal.

Two forces are driving this trend. The first is the ongoing economic slowdown, especially in the construction and manufacturing industries. China's economy averaged double-digit growth from 1981 to 2010. However, growth has slowed significantly since then: the five-year average from 2011 to 2015 was lower than any FYP period since the onset of economic reforms in the late 1970s. The growth rate in 2015 dropped to 6.9%, the lowest since 1991. Construction and manufacturing have taken an even harder hit. Combined, the two industries averaged 12.6% growth from 1991 to 2010, forming the engine of China's economic ascendency. This rapid expansion corresponded with the development of the world's largest export sector.

Since the global financial crisis, however, exports have declined significantly, and, domestically, real estate development has reached over-capacity. Consequently, growth in the construction and manufacturing sector fell by 8% during the 12th FYP period. These two industries accounted for approximately 80% of coal combustion over this period, including indirect use from electricity[7]. Through 2015, coal use in thermoelectric power, iron and steel, and cement production decreased by 6.2%, 3.2%, and 8.2%, respectively: this has significantly lowered national demand for energy[5,6]. Concomitant to this decline is the growth of service industry, which has much lower energy intensity (roughly one-quarter of that of construction and manufacturing). This shift is attributable in large part to rising labor costs in China, which has caused a corresponding loss of comparative advantage in the global economy, as low-value added manufacturing moves to less affluent developing countries[8].

The second force driving the new trend is strengthened policies on air pollution and clean energy. Policy efforts have reinforced economic shifts by reducing the share of coal in the energy mix. Over the past decade, China has faced increasing pressure to reduce air pollution and mitigate global climate change. The 11th FYP, initiated in 2006, placed an emphasis on the control of major air pollutants and greenhouse gases, mandating a decrease of SO_2 and COD by 10% each, and energy intensity by 20%. In 2011, these policy objectives were strengthened by the inclusion of targets for NOx, ammonia, and carbon intensity. Lowering coal use has been integral to meeting these goals, as coal combustion is a major source for many of the targeted pollutants and greenhouse gases.

Furthermore, a limit on the amount of total coal consumption was set for 10 eastern provinces. According to this policy, Beijing, Tianjin, Hebei and Shandong – which are four of the most manufacturing-intensive provinces – are together required to cut their coal consumption

by 83 million tons from 2012 to 2017, a reduction greater than the total coal consumption of the UK. Substitution of coal by non-fossil fuels has proceeded rapidly in the power-generation sector. In 2007, 83% of electricity was generated with coal, but that share fell to 72% in 2015. At the same time, there has been a rapid growth of solar, wind, nuclear, and hydropower generation. Today, it takes 320 grams of coal to provide one-kilowatt hour of electricity, compared to 370 grams 10 years ago and 412 grams 20 years ago.

But there are still be valid concerns regarding the sustainability of the current trend. If rising coal consumption is so closely tied to economic growth, why is the current drop a turning point towards a long-term trend of stabilization and reduction, and not merely a temporary dip due to economic fluctuations? There are three answers to this concern. First, the economic slowdown and the decline of construction and manufacturing are long-term trends characterizing China's new phase of economic development[5,6]. All developed economies have experienced periods of rapid expansion followed by a phase of slower growth. Far from being a surprise, there has been an informed consensus that China's growth rate would gradually fall to 5% per cent or even lower by 2030[9]. The period of slower economic growth is here to stay, and so is the correlative softening of energy demand.

Second, current policies on air pollution and clean energy are parts of a long-term strategy. For the government, curbing air pollution is an important aspect of maintaining political legitimacy[10]. And the government's recent Energy Development Strategic Action Plan explicitly outlines the progressive substitution of coal with clean energy: by 2020 coal's share of the energy mix will decrease from 66% to less than 62%, and non-fossil fuels will rise from 11% to a minimum of 15%. Third, China is consciously making technological innovation in energy, communications and manufacturing a priority[11,12]. In particular, industrial policies and macroeconomic planning have emphasized opportunities for new energy technologies to enhance long-term economic growth [13]. A decade ago, China's renewable energy industry was negligible; today, China is the world's leader, accounting for one-third of global investments in clean energy[5,6].

The End of Coal-Fired Growth

Historically, peak coal consumption has been an important milestone in the process of economic development. In transitioning to post-coal growth, China is following the path of affluent

industrial economies: coal consumption grew with per-capita income before peaking and then declining (see Figure 2). The transitions of the UK and the US, for instance, have been gradual, taking place over a long timeframe and predicated on shifts in the energy mix from coal to oil and gas. China has followed this trend, but its shift away from coal-fired growth has been more sudden and proactive; in particular, its policy emphasis on renewable energy is likely to help make the phase of oil-and-gas substitution shorter.

China has also reached peak coal consumption at a lower level of development than the US and the UK. Using a purchasing power parity measure of per-capita GDP, China was approximately only a quarter as affluent as the US and 10% less affluent than the UK at the time of the latter two countries' respective coal use peaks, or plateaus. These are admittedly rough indicators, but taking into account the intensity of China's catch-up industrialization, its much larger demographic scale, and the vast share of its energy endowment taken up by coal (especially compared to the US, where large, accessible stocks of natural gas are being utilized) the speed of its peaking and the shift towards non-fossil fuel energy, is noteworthy. It also suggests the efficacy of China's policymaking.

Nevertheless, the renewable energy and emissions policies underlying this nascent trend should continue to be strengthened, not least to avoid the Green Paradox, whereby well-intentioned, and even well-implemented, environmental policies lead to resource overexploitation. In the case of coal, lower prices may stimulate greater demand and extraction. Additional supply-side climate policy may be required to avoid this perverse outcome[14,15]. In addition to the region-specific coal caps mentioned above, the government has announced a three-year moratorium on new production. Other supply-side policies could include direct taxes on fossil fuel production, as well as regulations limiting the kinds of fuels that may be used. Indeed, such policies are consonant with the Chinese government's broader emphasis on supply-side economic reforms, as announced recently in the 13th FYP.

The end of coal-fired growth in China does not mean that coal will cease to be a major energy source; it means that it is entering a phase of development when it ceases to be the primary one. In other words, China's economic growth – and the improving living standards of its population – will not depend on rising coal consumption. China's particular experience is also relevant to the rest of the world. As the world's largest GHG emitter, a peak in China's coal consumption is not only a necessary condition for a global peak, but may well be a major

milestone in the Anthropocene, a turning point in international efforts to mitigate the emissions of climate-altering greenhouse gases.

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Author Contributions

Y.Q., T.W., J.L., N.S., and F.G. contributed to the research, writing, and editing of this manuscript.

Competing Financial Interests statement

The authors of this manuscript declare no financial conflicts of interest.

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Figures

Figure 1. China's economy, primary energy, and coal consumption (setting 1980 values as 100), and their respective growth rates. China reached peak coal consumption (in terms of heat value) in 2014, as consumption in 2015 recorded a 2.12% decline. Note the divergence of coal consumption and primary energy consumption from 2011 onwards. (Source: National Bureau of Statistics, China.)

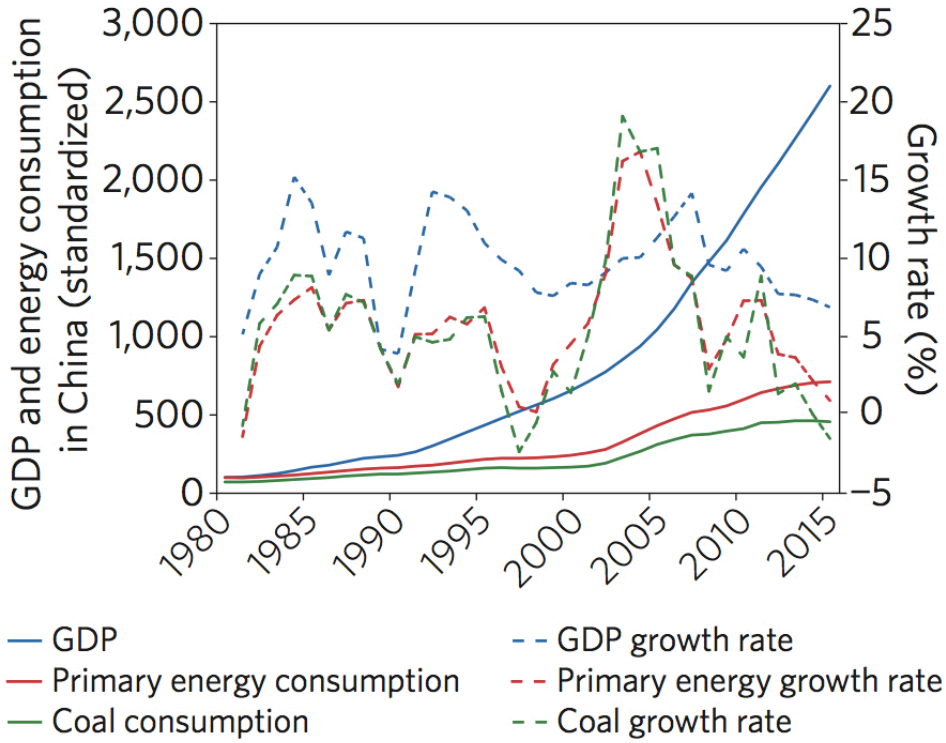

Figure 2. Historical trajectories of economic development and coal consumption for the United Kingdom, the United States, and China (data normalized for comparison). The X-axis shows the logarithm of per-capita GDP and the Y-axis the logarithm of national coal consumption. (*Annual data for China is available from 1991 through 2015 and only available at 5-year intervals between 1965 and 1980.)