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Additional information
Supplementary information is available in the online version of the paper.

COMMENTARY:

China's response to the air pollution shock

Peter Sheehan, Enjiang Cheng, Alex English and Fanghong Sun

Faced with serious air pollution, China is aggressively reshaping its energy system, building on recent progress with renewables and on available supplies of gas. This should help contain global warming and provide new impetus to climate change negotiations.

Over the past decade China accounted for over two-thirds of the growth in global CO_2 emissions from energy use. In 2012, its emissions far surpassed those of other major countries and regions[1] (Fig. 1). This reflects rapid economic growth in a massive country whose energy system remains largely based on fossil fuels, despite strong progress in renewable energy. This emissions growth has long spelt danger for the global climate. A gradual process to halt the rise in China's emissions by 2030 will alone add over 10% to the already high global level of CO_2 emissions from energy use in 2012. China's response to the air pollution crisis suggests that its government is taking action that will bring emissions under control much more abruptly than previously evisaged. Such a rapid process of emissions control could improve prospects of holding global warming to less than 2°C and have important implications for both climate modelling and international climate negotiations.

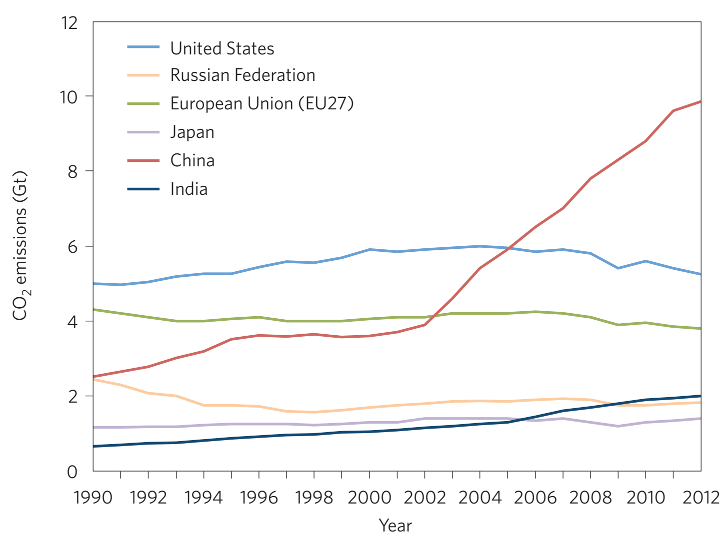

Figure 1 | CO_2 emissions from fossil-fuel use and cement production for selected countries and regions. Figure reproduced from ref. 1.

China's pollution shock
During 2013, air pollution in China became a major economic and social issue across the country ('the pollution shock'). In January 2013, thick smog blanketed Beijing and northern China, covering 2.7 million square kilometres and affecting more than 600 million people. Although varying with weather and other factors, air pollution remained high in many parts of China throughout 2013. It reached extreme levels in Harbin in October 2013 and in

Shanghai, normally a city with fairly good air quality, in December 2013. Many cities, including Beijing and Shanghai, experienced a return of heavy air pollution in January and February 2014.

The central concern is with fine particles less than 2.5 micrometres in diameter ($PM_{2.5}$). These pose the greatest health risks, lodging deeply in the lungs and leading to increased risk of pulmonary and cardiovascular disease and cancer. $PM_{2.5}$ levels are measured in micrograms per cubic metre (μg m^{-3}). The WHO guideline for the maximum safe level is 25 μg m^{-3} for a 24 hour period and 10 μg m^{-3} on an annual basis[2]. Readings in excess of 500 μg m^{-3}, twenty times the recommended WHO 24 hour level, have become common in many Chinese cities in periods of heavy pollution, with higher spikes occuring on some days. According to official data, average $PM_{2.5}$ levels for 2013 were more than five times the WHO annual maximum level in 58 Chinese cities[3].

Several factors contributed to increasing concern within China. One is the growing realization of the health threat from fine particles, especially at the levels being seen in China. Another is the evident impact of air pollution on people's lives — schools and factories were closed, warnings were issued for the young and elderly to stay indoors, flights were cancelled and so on. A third is the open availability of data, with most cities now collecting and publishing real-time data. On 12 February 2014, the State Council Executive Committee acknowledged the "grave situation" generated by air pollution, which is "cumulative for a long period of time"[4]. Air pollution has become a national emergency.

The Government's response

The Government's response to this crisis started with the 'Action Plan for Air Pollution Prevention and Control (2013–17)', issued by the State Council on 10 September 2013[5]. The plan targets marked improvement in air quality over the five years to 2017, focusing on three regions that account for 40% of China's GDP: the Beijing–Tianjin–Hebei region, the Yangtze River Delta and the Pearl River Delta. The plan includes mandatory 25% reductions in annual average concentrations of $PM_{2.5}$ by 2017 in Beijing, 20% in the Yangtze River Delta, 15% in the Pearl River Delta and 10% in other key cities.

Crucially, the plan recognizes that achieving these targets requires a transformation of the energy system. For the first time, there is a ban in these regions on new coal power plants and sharp cutbacks in coal consumption and steel production. For example, steel-making capacity in Hebei province, producing one quarter of China's steel, will be reduced by 80 million tonnes by 2017. Heavily polluting vehicles are to be removed from the regions by 2015 and nationally by 2017. The Euro V equivalent fuel standards (petrol and diesel) will be introduced in the regions in 2015 and nationally by 2017. Non-fossil energy resources will rise from 9.4% of total energy consumption in 2012 to 13% by 2017, and there will be increased emphasis on natural gas.

The implementation of this plan is continuing, through detailed local plans and through penalties for cities and officials failing to reach targets. For example, in September 2013 the Beijing government announced that the share of gas in total energy consumption would rise from 14% to 35% over the period 2012–2017, with the share of coal falling from 24% to 10%[6]. In January 2014, the Guangdong provincial government

Table1 | Energy consumption by fuel source in China.

	Coal	Crude oil	Natural gas	Renewables	Total	Memorandum item — Natural gas (billion m^3)
Actual						
1990	752	164	21	50	987	16
2000	1,007	323	32	93	1,455	24
2005	1,671	467	61	160	2,360	46
2010	2,210	616	142	280	3,249	106
2012	2,409	680	188	340	3,617	141
Scenario						
2015	2,580	664	300	456	4,000	226
2020	2,820	615	565	700	4,700	425
Target						
2030	2,616	545	930	1,364	5,455	700

Values are in millions of tonnes of standard coal equivalent, unless otherwise stated. Here, renewables include nuclear energy. Data taken from ref. 9 and from estimates made by the authors.

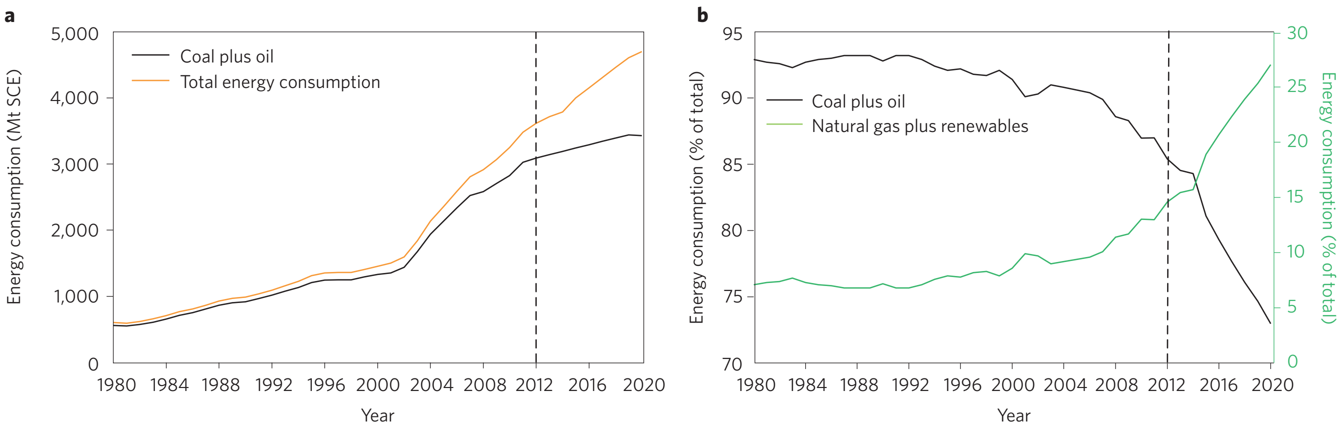

Figure 2 | China's actual and projected energy consumption by fuel type during the period 1980–2020. **a**, Energy consumption by fuel type in China, for the years 1980–2012 (actual) and, to the right of the dashed line, 2012–2020 (scenario). Energy consumption is measured in millions of tonnes of standard coal equivalents (Mt SCE), as defined in the official Chinese statistics. **b**, Share of total energy consumption (%) by fuel type for the years 1980–2012 (actual) and 2012–2020 (scenario). Here, renewables include nuclear energy. Data taken from ref. 9 and from estimates made by the authors.

Figure 3 | Natural gas infrastructure in China. This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area. Reproduced with permission from ref. 11.

announced that the coal and oil share would fall from 72.2% in 2010 to 60.6% in 2015, with the gas share more than doubling to 13.2%[7].

On 12 February 2014, the Director of the Development Research Center (DRC) of China's State Council provided an unusually frank insight into the Government's objectives[8]. In addition to slower growth in overall energy use, he indicated specific targets: the coal share to be reduced from 66.6% in 2012 to 60% in 2020 and below 50% in 2030; renewables to rise from 9.4% in 2012 to 15% in 2020 and 25% in 2030 and gas to rise from 5.2% in 2012 to 10% in 2020 and 15% in 2030. He also outlined plans for a new, low-carbon approach to urbanization.

Achieving abrupt change

We test whether these abrupt changes are achievable by examining one illustrative scenario through 2020, largely based on the DRC targets but with an earlier shift to natural gas (Table 1 and Fig. 2). This scenario involves a slower growth rate in energy use, a fall in the coal and oil shares in total energy use to 60% and 13% respectively by 2020, and a rise in the renewables and gas shares to 15% and 12% by 2020 respectively. Figure 2a shows that the absolute level of combined coal and oil use peaks by 2020, while Fig. 2b illustrates the abrupt nature of the shift in the structure of energy use. Table 1 also shows a projection of this path to 2030, based on the DRC indications.

The key question is whether the shift to renewables and natural gas can be achieved. Strong growth continues in China in the four low-carbon energy sources — solar, wind, hydro and nuclear — particularly wind and solar power. In 2013, installed wind capacity grew by 24.5% and solar capacity more than trebled[9]. Hydro-power capacity is rising strongly, increasing by 12.3% in 2013[9]. Approval of new nuclear plants was suspended in early 2011 after the Fukushima accident, but recommenced in October 2012. After no growth in 2012, installed nuclear capacity rose by 16.2% in 2013[9]. A recent review concludes that, provided specific issues such as grid connection and congestion are addressed, China can readily achieve or exceed its renewable energy targets[10].

China is also well placed to expand gas usage, both through domestic production and by taking advantage of the transformation of the world gas market resulting from the explosion of shale gas in the US and increased production of liquified natural gas (LNG) in Australia and elsewhere. Figure 3 shows China's actual and planned gas infrastructure, with a central pipeline structure linking the major markets to domestic gas fields, to providers of gas in East and Central Asia and to a growing network of LNG import terminals along the coast[11].

China's conventional gas production should continue to rise, especially in tight gas, although large-scale production from its substantial reserves of non-conventional gas — shale gas and coal-bed methane — may only occur after 2020. From 2015, China can draw on increased supplies of imported

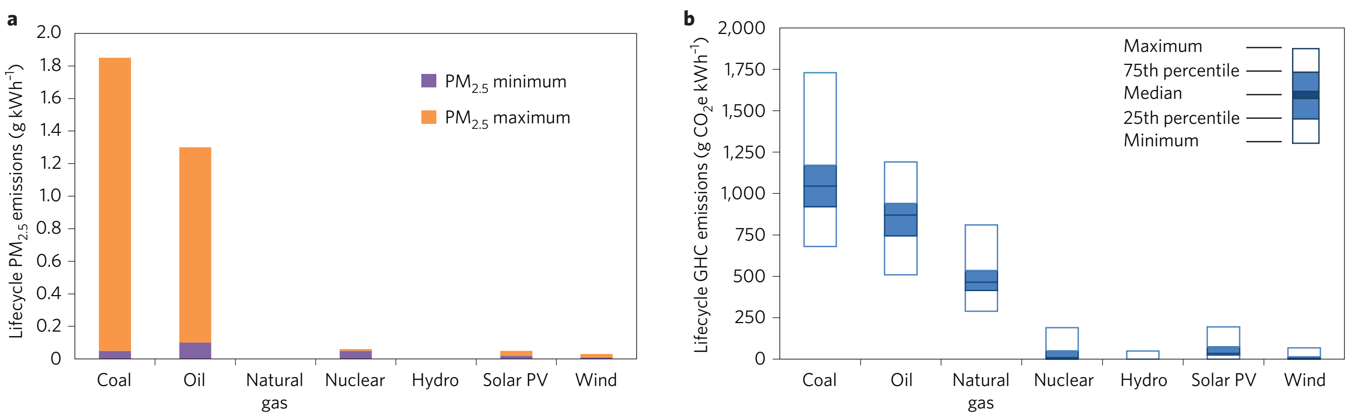

Figure 4 | Lifecycle $PM_{2.5}$ emissions and greenhouse gas (GHG) emissions for selected fuel sources used in power generation. **a**, Lifecycle $PM_{2.5}$ emissions per unit of energy generated (g kWh^{-1}). **b**, Lifecycle GHG emissions per unit of energy generated (g CO_2e kWh^{-1}). Data taken from ref. 12.

gas, both pipeline imports from countries such as Turkmenistan and Russia and LNG imports from Australia, Russia and Qatar. These imports should be at acceptable prices, as global supply options increase and as US exports of LNG impact on traded gas prices in East Asia. This combination of factors provides China with the opportunity to rapidly expand the use of gas — in areas such as power generation, combined heat and power systems, industry, transport and residential use — to meet the targets outlined in Table 1.

Implications for climate change

China's new energy strategy is primarily a response to the air pollution crisis, but will have major implications for greenhouse gas emissions (GHG). There is a large overlap between the sources of $PM_{2.5}$ and GHG emissions[12] (Fig. 4). The primary sources of $PM_{2.5}$ emissions are coal and oil use, while gas and non-fossil fuels generate few $PM_{2.5}$ emissions (Fig. 4a). Coal and oil are the dominant sources of GHG emissions, with gas occupying an intermediate position between these and renewable sources, which have low life-cyle GHG emissions.

If China achieves the 2020 energy scenario in Table 1, CO_2 emissions from energy use should peak by about 2020 and then decline. The transition from coal and oil to gas and renewables will involve many older, highly polluting plants, heating systems and vehicles being replaced by state-of-the-art combined cycle gas power plants, combined heat and power systems and natural gas vehicles as well as by non-fossil energy sources. The gains from eliminating the older coal and oil facilities, in favour of state-of-the-art facilities, should offset the rising emissions from increased natural gas use.

Such an emissions outcome for China would enhance the chances that the world can hold global warming to less than 2°C, and demonstrate an alternative path for countries, such as India, that face rising pollution from development based on coal and oil. China's new energy strategy will also impact on negotiations underway in the United Nations Framework Convention on Climate Change to establish by 2015 a legally binding emissions agreement to apply from 2020.

The main risk to this emissions path would be extensive use of coal-based synthetic natural gas (SNG). With large coal reserves and low coal prices, many see SNG as an important option for China. Many SNG projects have been proposed, some have been approved and a few are operating. But for electricity generation, SNG has lifetime GHG emissions well above coal and, for vehicle use, emissions are well above oil[13,14]. SNG plants are also water intensive, requiring more than six litres of water per cubic metre of gas produced[14]. A big SNG push would undo some of the GHG emissions benefits resulting from the Action Plan[5]. However, the Plan was notably cool on SNG plants, requiring strict enforcement of environmental controls and tight monitoring of water resources. China's severe water shortages might prevent a major expansion of SNG. ❐

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COMMENTARY:

Enabling food security by verifying agricultural carbon

H. Kahiluoto, P. Smith, D. Moran and J. E. Olesen

Rewarding smallholders for sequestering carbon in agricultural land can improve food security while mitigating climate change. Verification of carbon offsets in food-insecure regions is possible and achievable through rigorously controlled monitoring.

Global food demand is projected to double by the middle of this century, but greenhouse gas emissions from food production must be reduced. Mitigation and adaptation are often regarded as separate, though complementary, objectives in climate policy. Possible trade-offs can, in some cases, be reversed for synergy[1–3] with the potential to make smallholder farmers in food-insecure regions the main beneficiaries. Providing incentives for the adoption of carbon-sequestering agricultural practices to increase crop productivity in the developing world could enhance food security and contribute to climate equity while mitigating climate change[4]. Such a productivity increase would also reduce the pressure