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The effects of the China–Russia gas deal on energy consumption, carbon emission, and particulate matter pollution in China

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After more than two decades of negotiation, the China–Russia gas deal represents a new era of energy cooperation between China and Russia. In total, this is a win–win deal for both sides. For China, the deal will decrease energy consumption and carbon emission but will not significantly influence air quality; for Russia, it will provide a new market for its gas resources. In this study, we calculated the energy consumption, carbon emission, and particulate matter pollution ($PM_{2.5}$ and PM_{10}) in China in 2020, 2030, 2040, and 2050 under four IPCC representative concentration pathways (RCPs 8.5, 6.0, 4.5, and 2.6). We found that energy consumption and carbon emission decreased under the gas deal in RCPs 8.5, 6.0, and 4.5, although the rate of decrease slowed over time; however, in RCP 2.6, the rate of decrease of energy consumption and emission increased over time. $PM_{2.5}$ and PM_{10} emission showed similar trends but with increasing rate, although the gas deal would mitigate air pollution in the short term. Although China's government hopes to reduce carbon and pollutant emission under the deal, our results suggest that additional mitigation measures will be necessary to achieve this goal. Nonetheless, the reduction in carbon emission suggests that the China–Russia gas deal provides a model that other countries can follow to slow climate change.

npj Climate and Atmospheric Science (2018)1:8 ; doi:10.1038/s41612-018-0018-8

INTRODUCTION

On 21 May 2014, Russian energy giant Gazprom and the China National Petroleum Corporation signed a historic gas supply agreement in the presence of President Vladimir Putin of Russia and President Xi Jinping of China.[1] By 2020, Russia intends to export 38×10^9 m^3 of gas annually to China from untapped fields in East Siberia, with an economic value of US\$$400 \times 10^9$; the deal is intended to last for 30 years.[2] This agreement has many implications for both sides. Russia is aiming to diversify its export destinations in Asia to decrease its dependence on European markets, particularly after the imposition of sanctions in response to Russia's involvement in the Ukraine crisis.[2] At the same time, China is eager to improve its energy structure to incorporate more clean fuels and reduce greenhouse gas emission, since natural gas produces lower emission than coal or petroleum.[3] The increasing role of gas in China's energy structure is supposed to contribute to mitigating global climate change. This agreement is also supposed to be a good example of the importance of cross-boundary energy treaties for mitigating climate change.[4]

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "adjustment in natural or human systems to a new or changing environment".[5] In contrast, IPCC defines mitigation as "technological change and substitution that reduce resource inputs and emission per unit of output with respect to climate change".[5] It should be understood if the China–Russia gas deal can be estimated as an adaptation or mitigation measure to climate change in the future and if this agreement is a good example of cross-boundary treaties for mitigating climate change.

The Chinese economy has developed rapidly in the last three decades, and became the second-largest economy in the world in 2010, overtaking Japan's position. In 2007, China became the world's largest emitter of greenhouse gases.[6] This occurred both because China's rapid economic development dramatically increased energy consumption and because China depends heavily on coal consumption to supply this energy. Unfortunately, coal combustion emits large amounts of CO_2. Per unit of heat energy generated, coal combustion emits almost twice as much CO_2 as the combustion of natural gas.[7] In 2014, coal consumption accounted for 69.8% of China's total energy consumption (around 4×10^9 tce (standard tons of coal equivalent; NBS, 1996–2015).[8] China is the world's leading coal producer and consumer, accounting for 50% of the global coal consumption in 2015.[9] More than 400×10^6 people in China use coal to meet their daily domestic energy needs, such as energy for heating and cooking.[10] Many researchers have predicted that China's coal-based, relatively cheap energy structure last for the foreseeable future.[11–13] However, the China–Russia gas deal offers the potential to make China's energy structure cleaner while also decreasing greenhouse gas emission, but in practice, it is not yet clear how the gas deal will affect energy consumption and greenhouse gas emission. Dong et al.[4] estimated that it would take up 16–26% of natural gas imports and reduce million tons of coal usage by 50 Mt annually, thereby reducing CO_2 emission by 46 Mt per year, which is comparable to the 2020 CO_2 reduction target of many developed countries.

However, CO_2 emission is not the only problem created by coal: before mining, during mining, during storage, during combustion,

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Received: 14 September 2017 Revised: 13 January 2018 Accepted: 19 January 2018
Published online: 14 May 2018

and after combustion, coal generates many different kinds of pollutants, including inhalable particulate matter, organic compounds, and SO_2, NO_x, CO_2, and other harmful gases. Coal production and use therefore cause many environmental problems. Toxins contained in coal exacerbate these problems. Coal contains significant amounts of arsenic, fluorine, selenium, and sometimes mercury, all of which adversely affect human health.[14] When the China–Russia gas deal is implemented, it will reduce SO_2 emission by 1.1 Mt $year^{-1}$, which is equal to 5.4% of China's 2011 SO_2 emission.[4] This will also have a positive effect on air pollution.

China has among the highest particulate matter (PM) levels in the world.[15] PM is mainly composed of organic carbon (OC), sulfate and crustal species in China.[16] The NO_{3-}/SO_{2-} ratios are 0.43 ± 0.26 in PM 2.5 and 0.56 ± 0.29 in PM10, and the OC/EC ratios are 3.63 ± 1.73 in PM 2.5 and 4.17 ± 2.09 in PM10, representing that the stationary emissions from coal combustion remain the main PM source.[16] In Beijing, the combustion of coal contributed 15–20% to fine particulates, remaining the most important source of primary particulate matters.[17] According to the 2010 Global Burden of Disease study, particulate matter pollution was the fourth leading risk factor for a reduction in disability-adjusted life-years (DALYs), after next to diet risk, high blood pressure, and smoking, resulting in an annual cost of 25.2×10^6 DALYs; air pollution is included in the top-ten risks in the world and is ranked fifth or sixth in Asia.[18] Since 2000, particles with a diameter of less than 10 μm (PM10) had become the primary air pollutant in China, according to the Environmental Quality Report (http://jcs.mep.gov.cn/hjzl/zkgb/2000/200211/t20021125_83818.htm), and reducing their level has become an urgent task for national and local governments.[19,20] PM10 has been monitored in nearly all Chinese county cities by MEP (Ministry of Environmental Protection), with around one third of these cities exceeding the 100 μg/m^3.[16,17] Compared to PM10, PM2.5 (annual mean concentrations of particulate matter smaller than 2.5 μm in diameter) is of more concern owing to its smaller size, longer atmospheric lifetime and greater health risks.[21] Large variations in China in sources, energy structures, climatic conditions, and living habits across the nation make the PM2.5 distribution even more complicated.[22] $PM_{2.5}$ exceeded 80 μg/m^3 in Eastern China;[15] this is nearly three times the restrictive maximum (35 μg/m^3) according to Chinese national ambient air quality standard (NAAQS).[23] In 2013, 92% of Chinese cities failed to meet national ambient air-quality standards, and three major megalopolises (the Yangtze River Delta, Pearl River Delta, and Beijing–Tianjin–Hebei region) experienced more than 100 days with $PM_{2.5}$ concentrations at least twice the World Health Organization maximum exposure guidelines.[24] Both $PM_{2.5}$ and PM_{10} can stay in the air for long periods, thereby increasing inhalation, with adverse effects such as increased risk of cardiovascular disease, and decreasing atmospheric visibility. Researchers estimate that increasing the PM_{10} concentration by 10 μg/m^3 would increase mortality risk by 23–67%.[25] Chen et al.[26] calculated that a 10-μg/m^3 increase in the 2-day moving-average PM_{10} would increase total mortality by 0.35%, cardiovascular mortality by 0.44% and respiratory mortality by 0.56%. Liu et al.[27] estimated that PM 2.5 nationwide resulted in 1.37 million of premature mortalities in China, comparing to 0.69, 0.38, 0.13, and 0.17 million resulting from stroke, ischemic heart disease, lung cancer, and chronic obstructive pulmonary disease, respectively.

China's government hopes that the China–Russia gas deal will improve the Chinese energy structure, mitigate environmental pollution, improve human well-being, and reduce economic losses.

China is the world's largest emitter of greenhouse gases, and thus faces growing pressure to decrease its emission, both to protect its international image and to protect its citizens. China is now strengthening strategies to cut its emission, including limiting coal use by putting three year moratorium for new coal mines in 2016, gradually implementing carbon trading, limiting transportation emissions by building high-speed railways and providing incentives for buying electric and hybrid cars, making an aggressive program to make natural gas available for household use and large investments in technologies such as passive solar water heaters and renewable energy. In 2014, China pledged to cap its rapidly growing carbon emission by 2030, or earlier if possible.[28] It also sets a daunting goal of increasing the share of non-fossil fuels to 20% of the country's energy mix by 2030 when China struck a deal with the United States.[28] At the 2015 UN Climate Change Conference in Paris, President Xi Jinping declared that in 2016, China would launch 10 low-carbon demonstration zones in developing countries, 100 climate change adaptation and mitigation projects, and 1000 cooperative projects for training in adaptation to climate change.

The China–Russia gas deal is one major effort by China to cut its carbon and particulate matter emission, and is supposed to be an example of how energy treaties could promote cooperation among other countries. Nevertheless, current estimates of environmental impact of China–Russia gas deal are practically absent, except of mentioned study of Dong et al.[4]

In the present study, we examined China's historical energy structure, then predicted the impacts of the China–Russia gas deal (an increase of 8×10^9 m^3 $year^{-1}$ of gas consumption and decrease of coal consumption by 50 Mt $year^{-1}$) in 2020, 2030, 2040, and 2050 (i.e., during the proposed 30-year life of the deal) under four IPCC Representative Concentration Pathway (RCP) scenarios (http://tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=about) upon energy consumption, carbon emissions, and air quality.

RESULTS

Energy consumption and carbon emission in China under RCPs with the gas deal

Based on historical data and the results of our regression analysis, the percentage of total energy accounted for by coal consumption should decline from 74.2% in 1980 to 48.3% in 2050, although coal will still be the dominant energy source (Fig. 1). In contrast, the percentage of energy accounted for by natural gas consumption would climb to 20% in 2050 without the gas deal. The percentage for petroleum fluctuated over time, but remained close to 19%. For renewable energy, the percentage will increase from 1.2% at the beginning of the study period to 13.6% by 2050.

Predicted future Chinese energy consumption with the gas deal will always be 0.03×10^9 tce less than that without the gas deal in all RCP scenarios. This is because we assumed the same increase in gas consumption (8×10^9 m^3 $year^{-1}$) and the same reduction of coal consumption (50 Mt $year^{-1}$) in each scenario.

Figure 2 shows that in RCPs 8.5, 6.0, and 4.5, energy consumption with the gas deal will continue to decrease over time, but at a progressively slower rate. In contrast, energy consumption in RCP 2.6 will decrease at an accelerating rate; this is because RCP 2.6 assumes that radiative forcing would peak at 3.1 W/m^2 by 2050, then decrease to 2.6 W/m^2 by 2100.[29] When energy consumption decreases under the RCPs with the gas deal, this also means that carbon emission related to energy consumption would decrease. Predicted future Chinese carbon emission with the gas deal will always be 0.02 PgC less than that without the gas deal in all RCP scenarios. Figure 3 shows that carbon emission continued to decrease under RCPs 8.5, 6.0, and 4.5, but that the rate of decrease will slow over time, whereas under RCP 2.6, the decrease will accelerate over time.

Relationship between energy consumption and particulate matter pollution from 2006 to 2015

We obtained statistically significant log-linear regressions for the relationships between the two particulate matter categories (for

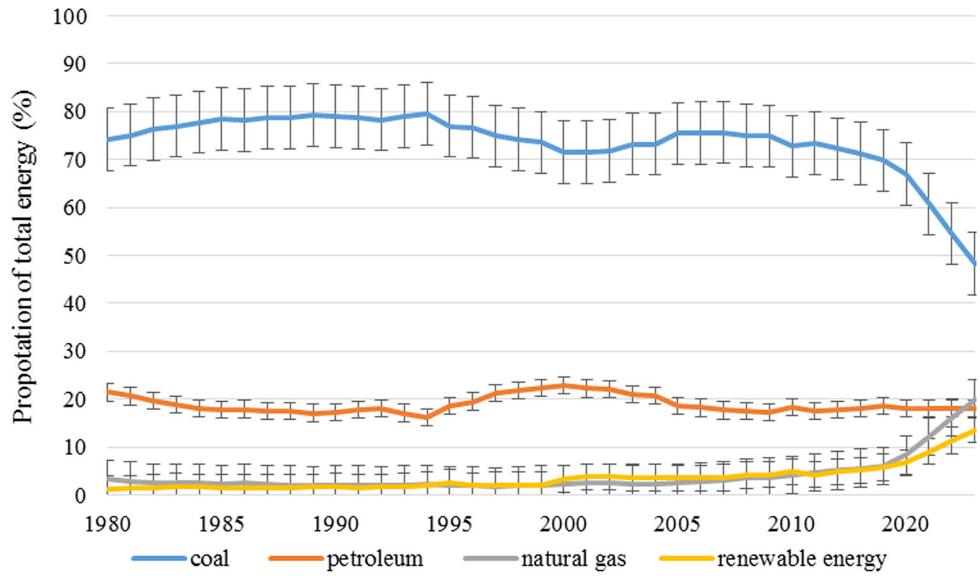

Fig. 1 Historical and predicted structure of Chinese energy consumption without the China–Russia gas deal (1980–2014; 2020, 2030, 2040, 2050)

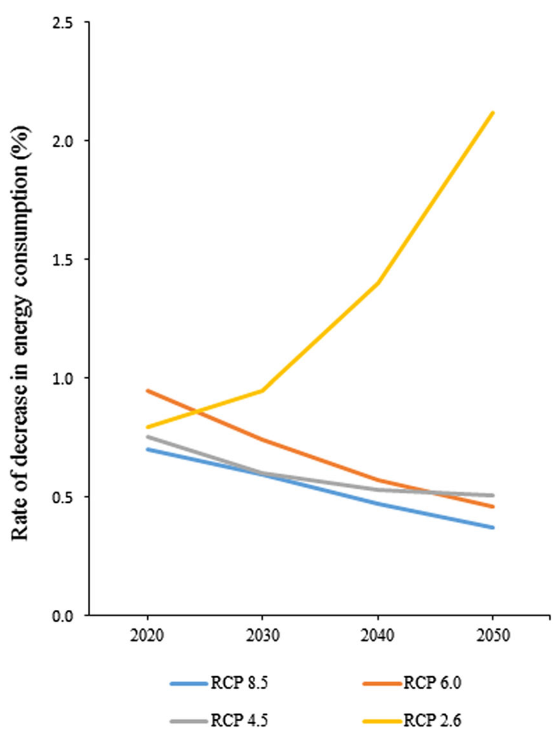

Fig. 2 Rates of change of energy consumption in China (positive numbers represent an increase) under the four RCPs with the gas deal

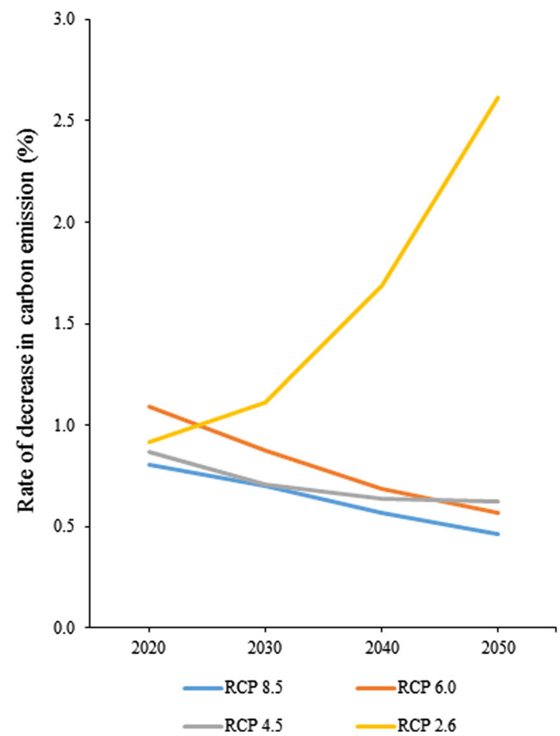

Fig. 3 Rate of change in carbon emission in China (positive values represent an increase) under the four RCPs with the gas deal

$PM_{2.5}$, $R^2 = 0.78$ and $p < 0.01$; for PM_{10}, $R^2 = 0.60$ and $p < 0.05$) and energy consumption:

$$\ln PM_{2.5\,t} = 23.14818 - 1.274523 \ln E_t \tag{1}$$

$$\ln PM_{10,t} = 17.47281 - 0.826158 \ln E_t \tag{2}$$

Both $PM_{2.5}$ and PM_{10} decreased with increasing energy consumption from 2006 to 2014. This suggests that the government's promotion of clean energy has begun to produce positive results. As clean energy technology matures and its cost decreases, particulate matter pollution should continue to decrease.

$PM_{2.5}$ responded more strongly than PM_{10}. This is because most of $PM_{2.5}$ results from fuel combustion and the production of secondary particles, whereas PM_{10} has a strong contribution from road dust.[30]

Comparison of $PM_{2.5}$ and PM_{10} in China with and without the gas deal

As Fig. 4a represents, the emissions of $PM_{2.5}$ under RCPs 8.5, 6.0, and 4.5 with the gas deal are more than those under RCPs without

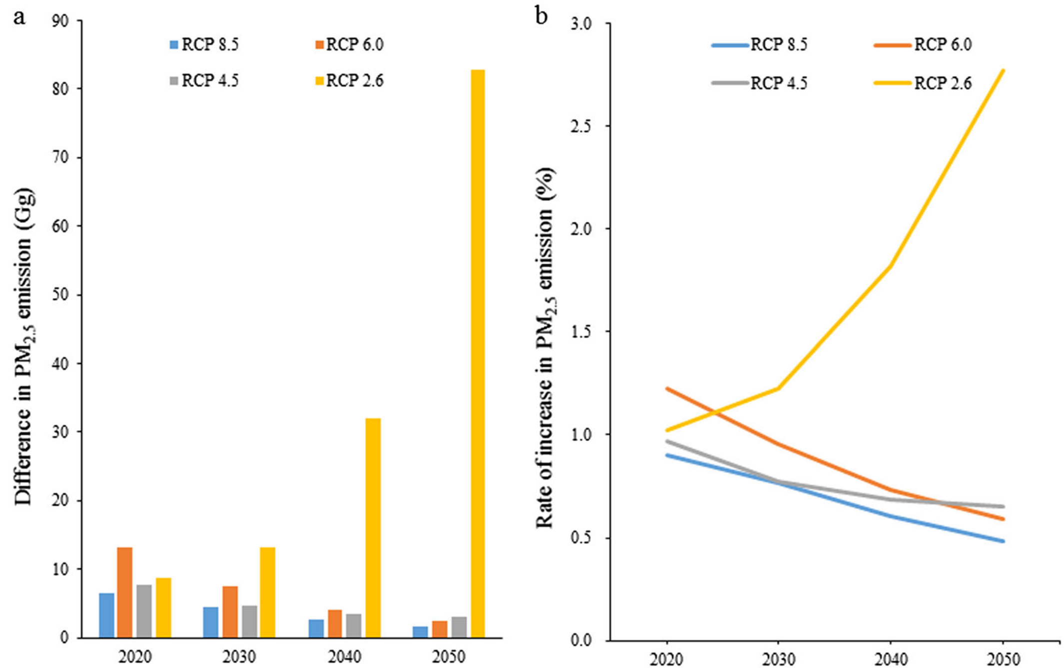

Fig. 4 **a** Difference of $PM_{2.5}$ between the situations with and without the gas deal (negative values represent a decrease compared to the scenario without a deal) and **b** change of $PM_{2.5}$ in China under the four RCPs (positive values represent an increase compared to the scenariowith no deal)

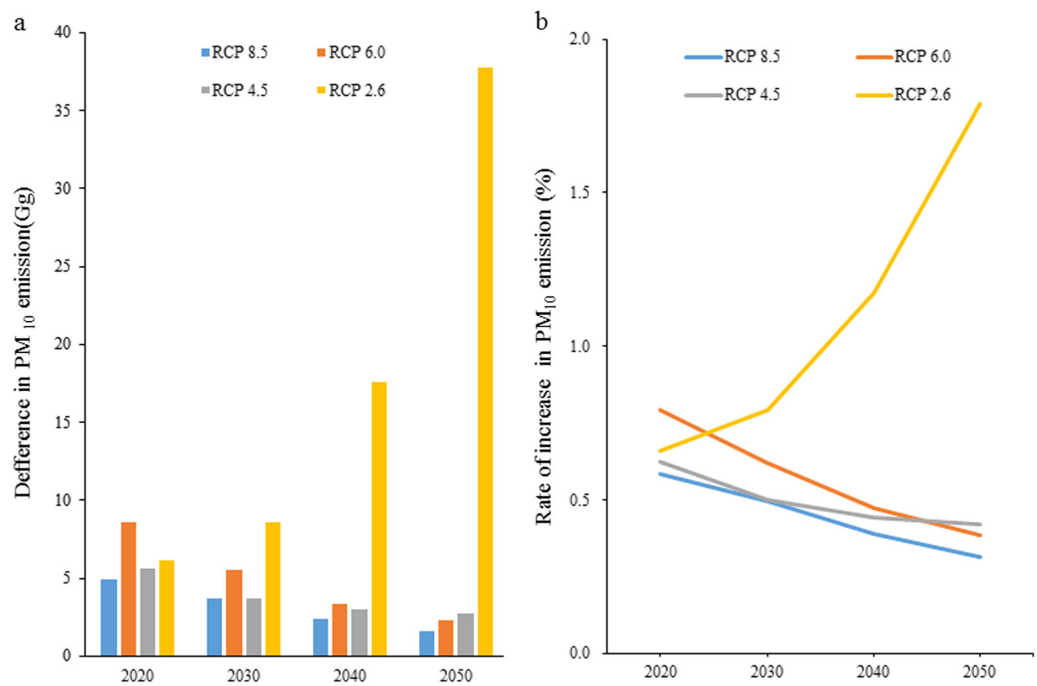

Fig. 5 **a** Difference of PM_{10} between the situations with and without the gas deal (negative values represent a decrease compared to the scenario without a deal) and **b** change of PM_{10} in China under the four RCPs

the gas in the future, but with the time their differences get less. So, the difference decreased from an average of 9.13 Gg in 2020 to an average of 2.42 Gg in 2050 for three RCPs 8.5, 6.0, and 4.5. This contrasts to RCP 2.6, where the difference increases by time. Figure 4b shows that under RCPs 8.5, 6.0, and 4.5, percentage difference "gas deal/no gas deal" for $PM_{2.5}$ emissions would decrease to 0.48, 0.59, and 0.65%, respectively, by 2050. However, the percentage difference for $PM_{2.5}$ emission would continue to rise under RCP 2.6, increasing from 1.0% in 2020 to 2.8% in 2050.

Future PM_{10} emission would increase more with the gas deal than without the deal, similarly to $PM_{2.5}$ emission (Fig. 5a, b). Figure 5b shows that the temporal dynamics format of increase of PM_{10} is similar to that for $PM_{2.5}$ (it will decrease over time in RCPs 8.5, 6.0, and 4.5, but increase in RCP 2.6). However, the rates of increase are all lower than those for $PM_{2.5}$ emissions. This means that the predicted change of the energy consumption structure will have a greater effect on $PM_{2.5}$ emission, which is reflected in the coefficients of Eqs. (1) and (2).

DISCUSSION

Because natural gas is a relatively clean energy, it has attracted increasing attention in the context of environmental protection issues and it will play a vital role in China's future energy structure. With the new gas deal, China can improve its energy structure by reducing the dominance of coal, thereby reducing greenhouse gas emission. As our results demonstrate, the gas deal will decrease energy consumption under the four RCPs because the efficiency of energy production will improve, even though continuing socioeconomic development would increase the total energy consumption. This process will also decrease future carbon emission. CO_2 is a major greenhouse gas and also has a relatively long lifespan. Thus, reducing carbon emission early will have a better payback than taking measures to increase carbon sinks (e.g., planting vegetation) or technological solutions such as carbon capture and sequestration. However, over time, the differences between the RCP scenarios with and without the gas deal will gradually decrease. For example, under RCP 8.5, the difference will be −0.02 PgC (a decrease due to the gas deal) in 2020, but by 2050, the difference will be only −0.01 PgC (i.e., a smaller decrease). The increasing demand for energy would offset the benefits of the gas deal, even though natural gas is a cleaner fuel. Under all of the RCPs except RCP 2.6, the effect of the China–Russia gas deal on energy consumption and carbon emission would gradually fade away.

According to Eqs. (1) and (2), increasing energy consumption will actually decrease emission of $PM_{2.5}$ and PM_{10}, as part of consumed energy will be directed to cleaning from particulate matter technologies. Thus with the gas deal, $PM_{2.5}$ and PM_{10} emission will increase due to reduction of energy. This has an important implication: if China only takes measures to import more gas or make the domestic energy structure cleaner rather than adopting cleaner technology, then future $PM_{2.5}$ and PM_{10} emission may remain serious. Despite this risk, the China–Russia gas deal can still improve environmental quality in the short term.

Under RCPs 8.5, 6.0, and 4.5, the carbon emission will show only small differences by 2050, suggesting that the gas deal alone cannot mitigate air pollution. This suggests that the China–Russia gas deal can be best described as an adaptation strategy. Therefore, for China, the gas deal does not eliminate the need to develop strong policies to mitigate climate change and encourage technology updates and innovations in the energy sector.

The cooperation between China and Russia will have implications for other countries. The agreement is a good example of the importance of cross-boundary energy treaties for adapting to climate change.[4] Although adaptation measures may be limited to the region that includes China, such energy cooperation could be implemented elsewhere as an adaptation to climate change and profitable deal. For example, in 2014, China's National Offshore Oil Corporation signed a 20-year deal with BP to supply liquefied natural gas to China, in a deal worth around US$20 × 10^9.[4] From this perspective, energy cooperation clearly has high market value in addition to its benefits for the environment and human health.

There are several limitations of the present study. In this paper, we only calculated the effects of the gas deal on China, although given China's high and growing consumption of energy, there will also be clear benefits for the rest of the world. Second, we did not examine the costs of this deal for Russia (in terms of infrastructure construction, energy consumption, and pollution emission), so we cannot say whether these costs will outweigh the benefits for Russia and China together. While increasing energy consumption now leads to reduction of particulate matter according to our study, projected future reduction of energy consumption leads to increase of $PM_{2.5}$ and PM_{10} emissions. However, substitution of coal by gas will also lead to decrease in particulate matter due to difference in chemical and physical characteristics of coal and gas. Decrease of particulate matter emissions, related to difference of chemical and physical characteristics of the fuels, and effects of changes in particulate matter emissions of the China–Russia gas deal to human health will be subject of following up study.

METHODS

Historical energy structure in form of proportions of energy production from four fuel types (coal, petroleum, natural gas, and renewable energy) from 2005 to 2014 was used to predict by linear regression future percentages of China's energy (see Supplementary Methods: predicted future proportions of coal, petroleum, natural gas, and renewable energy). China's carbon emission under the four RCPs were calculated from Asia's total carbon emission (see Fig. 6), extracted from the RCPs database (see Supplementary Methods: Carbon emission in China under the four RCPs). China's carbon emission from the RCPs was used recalculate future energy production by fuel types for decades from 2020 till 2050 using predicted China's energy percentages and conversion emission coefficients in situation "no gas deal". Afterwards actual mass values of fuels were calculated for future energy production by RCPs. The future mass values for gas and coal were modified according to China–Russia gas deal plan. Energy production by RCPs in situation "gas deal" was calculated and compared with the situation "no gas deal" (see Supplementary Methods: Comparison of energy consumption in China under the RCPs with and without the gas deal). Carbon emissions in situation "no gas deal" and "gas

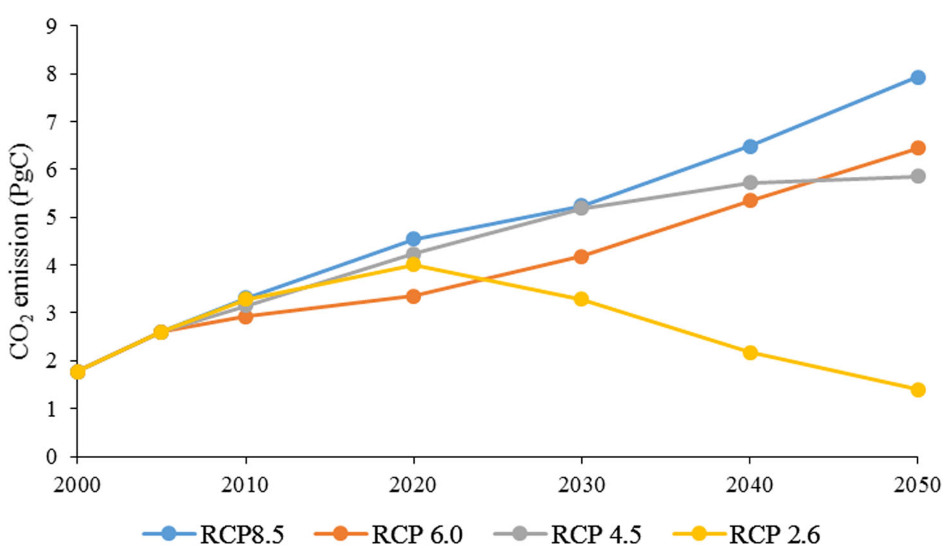

Fig. 6 Asian CO_2 emission from 2000 to 2050 under the fourselected RCPs (Data extracted from the RCP database)

deal" were calculated using conversion emission coefficients and compared (see Supplementary Methods: Comparison of carbon emission under the RCPs with and without the gas deal). To predict effect of the gas deal to China's air quality, we modeled the relationship between national energy consumption and PM2.5 and PM10 emissions using data from 2006 to 2015 (see Supplementary Methods: The linkage between energy consumption and PM2.5 and PM10 emissions in China). This log-linear regression model was used to predict the changed energy structure's effect on particulate matter pollution until 2050 (see Supplementary Methods: Comparison of PM2.5 and PM10 emissions under the RCPs with and without the gas deal).

Data availability

The authors declare that [the/all other] data supporting the findings of this study are available within the paper [and its supplementary information files].

ACKNOWLEDGEMENTS

This work was supported by the National Key Technology R & D Program (No. 2016YFC0501002) and the National Natural Science Foundation of China (31570475). We thank Geoffrey Hart of Montréal, Canada, for his help in writing this paper. We are also grateful for the comments and criticisms of an early version of this manuscript by our colleagues and by the journal's reviewers. We thanks Qiang Zhang for providing particulate matter pollution data.

AUTHOR CONTRIBUTIONS

S.V. suggested the story line and using of RCPs to estimate China–Russia gas deal and developed a methodology of calculations. C.L. made calculations and refined methodology. C.L., S.V., and S.C. are equally contributed in writing of the paper.

ADDITIONAL INFORMATION

Supplementary information accompanies the paper on the *npj Climate and Atmospheric Science* website (https://doi.org/10.1038/s41612-018-0018-8).

Competing interests: The authors declare no competing interests.

Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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