Double Impact: Why China Needs Coordinated Air Quality and Climate Strategies

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Cover Photo/David Gray Reuters

Introduction

Despite the Chinese government's redoubled efforts to curb air pollution, the air quality index in Beijing continues to spike above 300, well into the hazardous range. Cleaning up the air has climbed to near the top of the government's policy priorities, especially since record air pollution levels in January 2013 in Beijing triggered unprecedented public outrage. This and other episodes prompted pledges to take swift and significant action at the highest levels of the Chinese government, which went so far as to declare a "war on pollution."[1]

> *Air pollution control efforts, while essential, will only take China part of the way toward its stated carbon reduction goals.*

The urgency with which Beijing is tackling air pollution is certainly positive, and these efforts will also have concomitant benefits in curtailing carbon dioxide (CO2) emissions—to a certain extent. But it would be a mistake to view the current initiatives on air pollution, which are primarily aimed at scrubbing coal-related pollutants or reducing coal use, as perfectly aligned with carbon reduction.

This is, in fact, not the case. Air pollution reduction is only partly aligned with CO2 reduction, and vice versa. In addition to air pollution efforts, effective co-control requires a more significant step: a meaningful price on carbon. This is especially so if Beijing is to realize its pledge to reach "peak carbon" by 2030. In other words, air pollution control efforts, while essential, will only take China part of the way toward its stated carbon reduction goals.

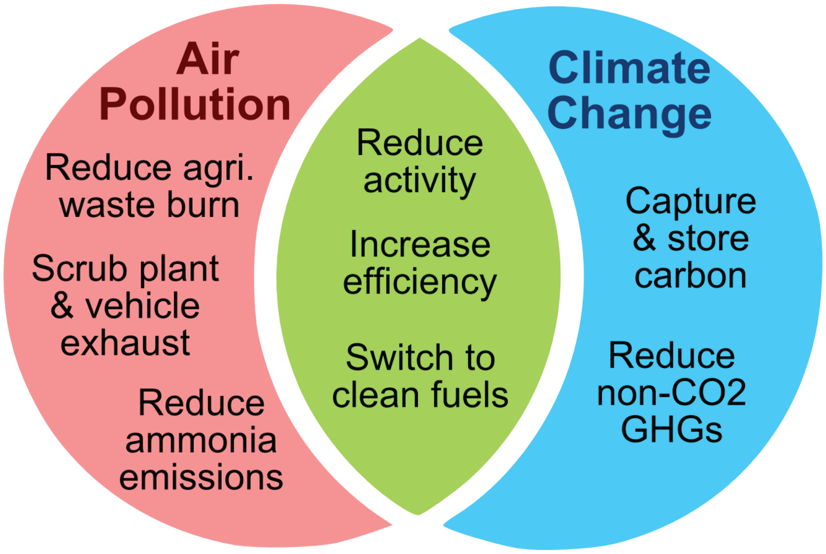
First, let us be clear why countries need a dual approach that explicitly considers both air pollution and carbon. While low-cost solutions for air pollution and carbon reduction can overlap, the reality is that co-benefits run out after low-cost opportunities to reduce or displace the fuel(s) responsible for both CO2 and air pollution emissions—in China's case, mainly coal—are exhausted.[2] Work from our team at MIT and Tsinghua University has found that air pollution control efforts can help China reach its near-term CO2 reduction goals, and vice versa, but co-benefits diminish over time as ever-greater reductions are required.[3]

In China, immediate and deep reductions in coal use would address both problems initially. However, the marginal cost of displacing coal rises as coal is squeezed out of the energy system. Because coal is the cheapest and most domestically abundant source of energy available, reducing its use and replacing it with other fuels will inevitably increase direct costs to the economy, even as it offers health and environmental benefits. Beyond this point, the strategies that make the most economic sense for carbon and air pollution control diverge (see Figure 1 for an overview of how strategies for addressing carbon and air pollution overlap).

Various options for reducing coal use—such as reducing coal-intensive activities, increasing efficiency, and promoting fuel switching—will have different associated costs. In general, curtailing coal-intensive activities altogether is costly to economic growth (but may be economically viable in industries with overcapacity). Some efficiency improvements—via equipment upgrading or improved process management—offer economic benefits for adopters and are therefore considered relatively low cost, while other strategies are trickier to exploit. In fact, efficiency improvements have driven much of China's reductions in energy intensity achieved since the beginning of economic reforms in 1978.[4] As for fuel switching, costs differ by fuel—nuclear is estimated to be less expensive than natural gas as a source of electricity, for example—and will be limited by the substitutability of alternative fuels in different end uses.[5]

Once low-cost opportunities to reduce coal are exhausted, if the focus continues to remain narrowly on air quality, other options—such

Figure 1. Overlapping and Divergent Strategies for Addressing Air Pollution and Climate



Source: Dr. Li Chiao-Ting, MIT-Tsinghua China Energy and Climate Project.

as scrubbing pollutants from the exhaust stream of coal power plants—will either already be more cost-effective or will quickly become so as the marginal cost of displacing coal surpasses that of installing and operating pollution treatment systems. Because these latter options are relatively inexpensive, policymakers and industry will be more predisposed to stick with such end-of-pipe solutions. But here is the rub: simply scrubbing end-of-pipe emissions does next to nothing to reduce CO2.

Moreover, to the extent that cleanup equipment is applied to (and is powered by) carbon-intensive energy, it could actually increase CO2 emissions even as air quality improves. These dynamics make climate change—which lacks the immediate social and environmental burden that poor air quality imposes—the tougher and more costly challenge. Indeed, carbon capture and storage would be the only viable way to "scrub" CO2, but it ranks among the most costly options for CO2 reduction.

This paper begins by examining how China's policymakers have hitherto approached air pollution and climate change management. It discusses potential actions required under goals set for each challenge, and their implications for energy, CO2 emissions, pollutant emissions, and air quality. The paper then details the shortcomings of China's current combined approach, which places more emphasis on near-term air quality improvement than CO2 emissions reduction, although nascent efforts to address CO2 through emissions trading are very promising.

Specifically, the paper makes the case for establishing a national CO2 price in China as soon as possible. End-of-pipe pollution control technologies—a core component of China's Air Pollution Action Plan (APAP)—can address local air pollution but not CO2 emissions. It concludes by emphasizing how the introduction of a CO2 price could ensure air pollution control does not come at the expense of sound, long-term climate change management. By putting early pressure on carbon-intensive energy sources also responsible for air pollution, a CO2 price would reduce the extent of end-of-pipe air pollution controls needed to achieve air quality goals, thereby preventing carbon lock-in.

China’s Current Coal-Centric Approach

Beijing’s current policy approach to air quality and climate change involves a patchwork of national and local regulations, many of which require cutting energy (or CO2 emissions) intensity as well as installing pollution control equipment. Targets for energy intensity—energy use indexed to economic output—have historically been achieved primarily by reducing incremental energy demand through efficiency measures and shutting down outdated, inefficient production capacity. Directives on air pollution have required the installation of sulfur dioxide (SO2) and nitrogen oxide (NOX) removal equipment. Pressure to tighten enforcement of the targets has increased as air quality problems have worsened in recent decades. This section reviews current approaches to air quality and climate change management in China.

China’s pollution reduction effort has mainly centered on reducing, displacing, relocating, or scrubbing emissions from coal-based electric power.

Cleaning the Air

Take air quality first: China’s pollution reduction effort has mainly centered on reducing, displacing, relocating, or scrubbing emissions from coal-based electric power, given that it is a major contributor to poor air quality nationwide. In September 2013, China set targets for 2017 (relative to 2012) in the APAP. It called for a 10 percent reduction in China’s inhalable particulate matter (PM10) levels and corresponding reductions in PM2.5 in three major urban regions along the coast: Beijing-Tianjin-Hebei (25 percent) (also known as the “JJJ” region), the Yangtze River Delta (20 percent), and the Pearl River Delta (15 percent).[6]

The plan targets reductions in coal use as central to achieving air quality goals, including a 20 percent reduction in energy intensity between 2012 and 2017 [consistent with the 12th Five-Year Plan (FYP, 2011-2015) goal of reducing energy intensity by 16 percent]. It calls for limiting coal to 65 percent of primary energy mix and prohibiting any increase in coal use in the three major urban regions listed above.

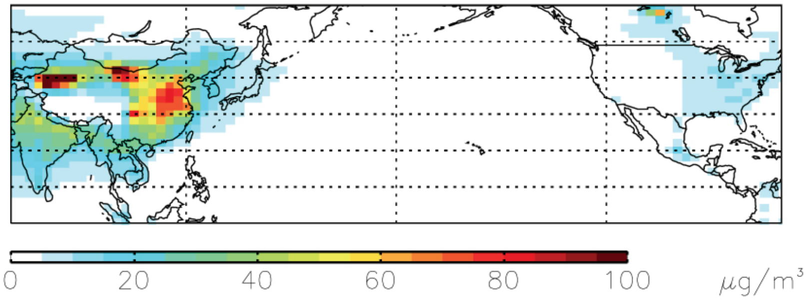
In addition to these targets focused on coal displacement, a core element of the ten-point action plan includes specific measures for limiting emissions by mandating a shift to larger scale facilities and installing pollution control equipment. District heating systems are targeted for retrofits to use electricity or cleaner fuels (e.g. natural gas). Installation and operation of desulfurization, denitrification, and dust removal equipment is required for industrial boilers and furnaces, especially those in close proximity to cities.

The last category includes precisely the end-of-pipe measures—listed in the action plan before optimizing industrial structure, accelerating energy structure adjustment, and increasing clean energy supplies—that will make progress on cleaning up the air but do little to bring down CO2 emissions. In fact, to the extent that the equipment requires coal-based energy to run, it could actually make CO2 emissions worse at the margin.

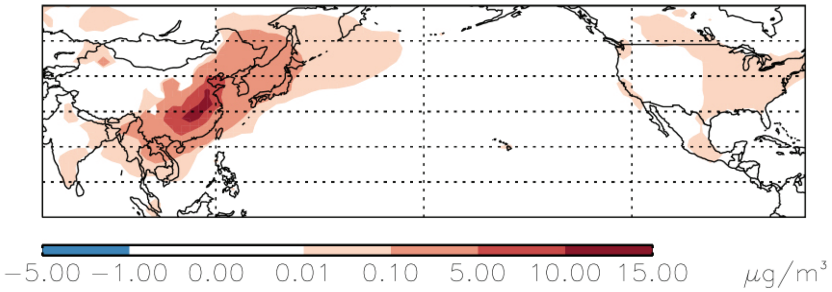
Moreover, addressing China's smoggy skies is not as easy as simply identifying the major contributing sources and

Figure 2. Effect of Ammonia Emissions on Simulated Future Air Quality

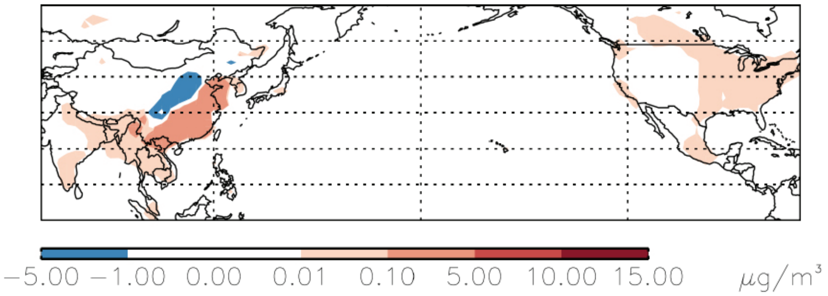
2a. Simulated spatial distribution of annual PM2.5 concentrations in 2010.



2b. Change in PM2.5 concentrations in 2030 compared to 2010.



2c. Change in PM2.5 concentrations in 2030 compared to 2010 if ammonia is held at 2010 level.



Source: Li, M., Selin, N. E., Karplus, V. J., Li, C.-T., Zhang, D., Luo, X., and Zhang, X. (2014).

focusing on reducing them. The problem is complicated by the fact that various air pollutants combine in non-linear ways to affect observed air quality or come from hard-to-control sources unrelated to the energy system specifically, such as agriculture. This means that the relative amount of multiple air pollutants must be regulated simultaneously.

Indeed, this complex chemistry means that reducing the emissions of one or more pollutants will not necessarily lead to air quality improvements, and may perversely make air quality worse. For example, under certain conditions, if NOX emissions are reduced without simultaneously curtailing emissions of volatile organics, the concentrations of ozone—a hazardous form of urban pollution that causes adverse cardiorespiratory effects—may actually rise. Similarly, according to our research, if PM2.5 precursors such as SO2 and NOX (largely byproducts of coal combustion) are reduced but ammonia (emitted from hard-to-control agricultural sources) is not, levels of PM2.5 will fall far less than if ammonia had been controlled at the same time (see Figures 2a, 2b and 2c).

Carbon Cleanup

At the Copenhagen climate talks in 2009, China made the commitment to reduce its carbon intensity by 40-45 percent per unit of GDP in 2020 relative to 2005 levels. To meet this target, China introduced an explicit and politically binding carbon-intensity reduction target during the 12th FYP, supplementing its energy-intensity reduction target (a longstanding feature of China's energy policy that was strengthened during the 11th FYP).

More recently, during the Asia-Pacific Economic Cooperation (APEC) summit in Beijing in November 2014, China's leaders announced their post-2020 climate goal jointly with the United States.

The core components of China's climate plan are to reach peak carbon and to increase the share of non-fossil fuels in its primary energy mix to 20 percent (a significant jump compared to the 2015 goal of 11.4 percent), both by 2030. More significant policies targeting carbon are likely to be part of the 13th FYP (2016-2020). For instance, China has been experimenting with carbon pricing in seven pilot areas (five cities and two provinces), which are to form the basis of a national carbon pricing system, expected to be launched during the 13th FYP period.

Our team's research has investigated how the combination of future climate and energy policies (including additional measures mandated by the APAP) could affect China's energy system through 2050. We find that a carbon price will be needed to achieve continued reductions in carbon intensity and reach the 2030 "peak carbon" goal. In an Accelerated Policy scenario, we model a carbon emissions trajectory consistent with a reduction in carbon intensity of around 4 percent per year, which is implemented via an emissions trading system (ETS) that results in a carbon price rising to $38/ton by 2030.[7]

Given expectations of continued economic growth over the same period, this Accelerated Policy scenario is at the aggressive end of potentially feasible CO2 trajectories under discussion in China. Projections in this scenario anticipate that coal use will peak as early as 2020, while CO2 emissions will peak in the 2025 to 2035 timeframe. (This time lag between the coal and CO2 peaks occurs because fossil fuel consumption continues to increase even as coal use levels off.) While this would be consistent with China's climate pledge, additional measures will be needed to improve air quality in the near term to meet the APAP targets.

Benefits of a Co-Control Strategy

So how should China's policymakers approach the coordinated regulation of both air pollution and greenhouse gas (GHGs) emissions? Economics would suggest that pollution and carbon targets should be set separately and supported by emissions pricing to encourage reduction of both air pollution and CO2 simultaneously and in the most cost effective way.

Climate Co-Benefits of Addressing Air Quality

Setting up a pricing system is more challenging for air pollution than for CO2, given the complex localized chemistry that contributes to air quality (measured in terms of ozone and PM 2.5 concentrations). In fact, since this complex chemistry means that increased pollutant emissions can in some cases translate into decreases in ambient pollutant concentrations, a price instrument targeting air quality that reflects these spatial and temporal effects would be difficult—although not impossible—to design. Moreover, the emissions contributing to local air quality by fuel and by sector vary depending on the time-of-day, season, local environment, and other factors that require additional research to more fully understand and address.

> *Air pollution measures, as they are currently being pursued in China, will quickly discrouage further reduction in the absolute level of coal consumption.*

Given the difficulty of pricing air pollution emissions in a coordinated fashion, targeting coal reduction is often seen as a viable alternative. Reducing coal throughout China's energy system means lower emissions of SO2, NOX, and other particulates. However, as mentioned, impacts can be limited if other pollutants, such as ammonia, rise unabated.

Once low-cost opportunities to reduce coal are exhausted, the continued displacement of coal from China's energy mix becomes expensive. It would be especially so if coal becomes cheaper relative to the fuels displacing it, which is likely to happen if coal demand drops significantly, providing an incentive to continue using it in the long run.

This scenario will quickly lead to a situation where it becomes less expensive at the margin to use and scrub coal than to reduce its use, displace it with another fuel, or capture carbon. For example, installing a selective catalytic reduction (SCR) NOX removal system on a coal-fired power plant in China is relatively inexpensive—about 150 yuan ($25) per kilowatt[8]—which means operating a coal plant is still cheaper than displacing it with a wind or natural gas power plant.

At this point, the co-benefits of air pollution control for climate mitigation end abruptly, as air pollution mitigation measures lock in continued reliance on a carbon-intensive fuel. By contrast, adding carbon capture and storage (CCS), an end-of-pipe solution to scrub CO2, is estimated to increase the levelized cost of generating power from coal in China by at least 50 percent, making it prohibitively expensive for large-scale use at present.[9]

Other opportunities for cleaning up the air besides reducing coal will be extremely important and necessary, but are often overlooked. One is the reduction of biomass burning to clear agricultural land, which contributes significantly to total emissions and poor air quality. Recently, real-time monitoring of land clearing has been critical to reducing the scope of biomass burning. Controlling particulate emissions from diesel trucks and other vehicles also offers an effective and relatively low-cost step to improving air quality in urban clusters and industrial corridors. Yet again, while these are economical ways to improve air quality, they hold little to no potential to meaningfully mitigate climate change.

To summarize, air pollution measures, as they are currently being pursued in China, will quickly discourage further reduction in the absolute level of coal consumption, thereby stalling progress on carbon reduction. This alone makes a strong case for pricing CO2 emissions.

Air Quality Co-Benefits of Addressing Climate Change

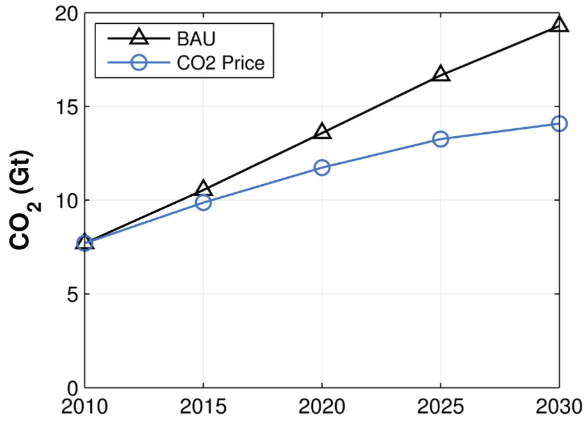
The effect of climate change, by contrast, depends on the total cumulative GHG emissions, regardless of where and when they originated. This feature makes controlling CO2 and other GHG emissions by pricing them much more straightforward, because the marginal cost of emissions is neither spatially nor temporally differentiated, nor is it mutually dependent on other species emitted.

In terms of co-benefits, a price on CO2 emissions will result in direct reductions of some, but not all, air pollutant emissions (see Figure 3). Panel A shows the CO2 emissions trajectory under the same CO2 price as was used in the Accelerated Policy scenario mentioned above (it is compared to the No Policy business-as-usual scenario). Panels B through E show the impact on the various precursors of PM2.5, the tiny particulate matter that contributes to degraded air quality and some of its worst health effects. In fact, CO2 reduction will primarily affect SO2 and NOX by reducing emissions from combustion, but do little to affect volatile organic compounds (VOCs) or ammonia, limiting the total air quality improvement.

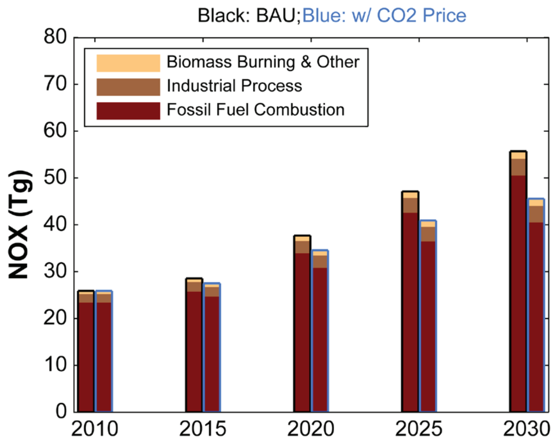
While a plausible CO2 emissions price is not sufficient to improve air quality, present air quality measures in China are insufficient to address CO2 emissions. Neither China’s APAP, nor

Figure 3. Impacts of a CO2 Price on Emissions of PM2.5 Precursors, 2010-2030

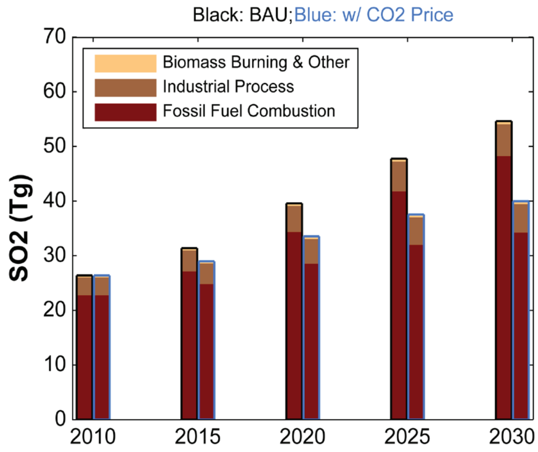
3a. Simulated CO2 Emissions Based on Carbon Price Compared to BAU Scenario.



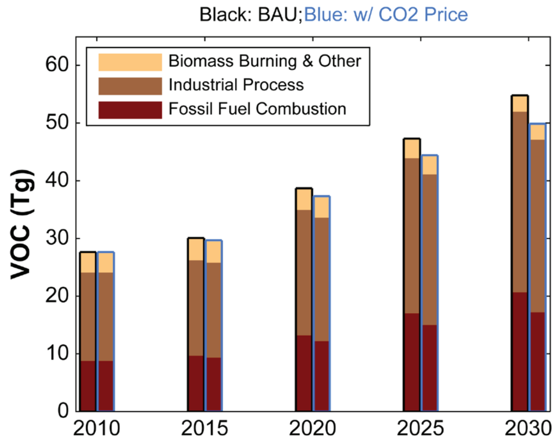
3b. Emissions of NOX, a PM 2.5 Precursor.



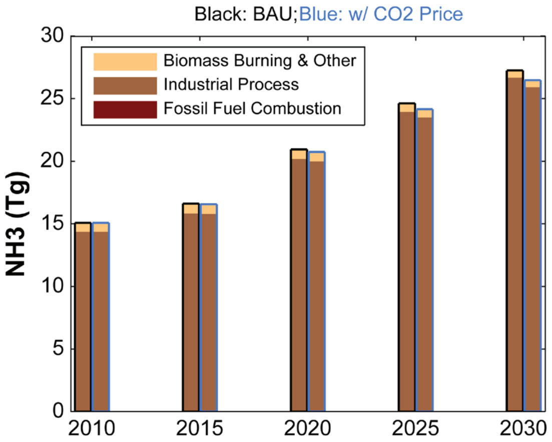
3c. Emissions of SO2, a PM2.5 Precursor.



3d. Emissions of Volatile Organic Compounds (VOCs), a PM2.5 Precursor.



3e. Emissions of Ammonia (NH3), a PM2.5 Precursor.



Source: Li, C.-T., Karplus, V. J., Selin, N. E., and Li, M. (2014).

any of its existing climate or energy policy pledges, would reverse the upward trajectory of aggregate coal use nationwide before 2020. This means that addressing air quality will need to rely extensively on end-of-pipe solutions in the near term.

For instance, assuming the recently introduced, more aggressive policies under the APAP are implemented, along with a modest CO2 price, coal use in China is expected to peak around 2020.[10] Even if coal use in the three large urban regions remains flat through 2017, coal use in the surrounding areas is expected to increase without additional policy constraints because the APAP limits the share, not the absolute amount, of coal use nationally.[11]

Still, achieving and sustaining reduction in coal demand prior to 2020 would deliver both air pollution and carbon reduction. Over the long term, addressing climate change requires displacing ever more coal, especially if end-of-pipe solutions like CCS remain relatively costly. A price on carbon is needed to continue to incentivize coal use reduction, and if designed well, could be complementary to China's air pollution control efforts. In short, a well-designed policy could allow China to achieve what most developed countries have not—air quality improvement *and* significant CO2 reduction at the same time.

The bottom line is this: if China's leaders are willing to take aggressive steps to address climate change specifically by pricing CO2 emissions, they could make meaningful progress on air quality too. Such a prioritization can also help the government avoid part of an otherwise substantial investment in technology to scrub pollutants and emissions from coal-fired power that will, over time, end up locking in a high-carbon energy system.

Conclusion

A serious commitment to reducing carbon across the energy system requires the right incentives to encourage a shift from fossil fuels to low or zero carbon energy sources. Energy and carbon intensity targets, as well as the 65 percent target of coal as a share of primary energy, will help curtail energy-related carbon emissions. But additional incentives will be needed if China wants to meet the peak carbon goal it announced at the APEC summit.

Climate Change Needs Its Own Policy

Putting a price on CO2 emissions, either through an ETS or tax, is the best way to translate China's climate pledge into clear, price-based incentives to decarbonize the economy through 2030 and beyond. It will limit the expansion of coal and other fossil fuels in favor of low-carbon alternatives and demand reduction. And it is also a robust way to ensure that carbon management goals remain binding amid the broad range of environmental priorities, including air quality improvement, which will shape China's energy and economic policy agenda in the coming years.

Additional incentives will be needed if China wants to meet the peak carbon goal it announced at the APEC summit.

Introducing a price on carbon both within and across regions will be an important tool to ensure that reductions are undertaken in the most cost effective way. Beijing is currently in the early stages of building a national ETS for CO2, a critical step in galvanizing the energy system's evolution toward a low-carbon path. Choices made in the design of the system will determine its cost effectiveness.

For instance, will electricity prices—currently managed by the government—be allowed to adjust to fully reflect CO2 emissions charges? What share of CO2 emissions sources will be covered? And if China sticks with targeting CO2 intensity, rather than absolute CO2 emissions, can the system be designed to keep CO2 emissions within an "acceptable band" while acknowledging uncertainties?

Once policymakers have settled on an acceptable band for CO2 emissions consistent with China's recent climate pledge, it will be critical to let the price signal that emerges from the ETS serve as the primary incentive driving CO2 emissions reductions. A market-based approach to emissions control follows the spirit of commitments made at China's Third Plenum in November 2013 to deepen market reforms and establish markets for environmental protection.

A carbon price will adjust automatically to policy changes (such as pollution control measures or energy price reforms), some of which will inadvertently reinforce or accelerate the reduction of CO2 and air pollution emissions through changes in the country's energy system. Moreover, if technology mandates to install pollution control equipment raise the cost of electricity and industrial activity, the carbon price would reflect any ancillary reduction in CO2 that resulted from the decrease in pollution-intensive activities (due to higher costs).

In this way, a CO2 price becomes a "backstop" that ensures that broader future transition in the energy system will be consistent with CO2 reduction goals. Its implementation requires monitoring energy use and CO2 emissions at the company level alongside conventional air pollution. For the CO2 price to work effectively, any national ETS should cover as many CO2-generating activities as possible. Otherwise, any reductions could be offset by increases in the use of fossil fuels in exempt sectors, where their use becomes less costly due to a drop in total energy demand resulting from the imposition of a CO2 price.

In addition to establishing a price on CO2 emissions through an ETS, the approval process for large, energy-intensive projects needs to be consistent in how it applies environmental impact assessments and should include CO2 alongside broader measures of pollution reduction.

Given the vast extent of new construction slated for the coming decades, setting aggressive environmental targets and monitoring energy-intensive investment activity offer a substantial opportunity to accelerate a low-carbon transition. Moreover, the project approval process can be one way to gauge whether investment decisions are responding to incentives such as a carbon price, pollution control costs, and energy price reforms.

Co-Control More Effective in Achieving China's Goals

Effective co-control of CO2 and air pollution first and foremost requires acceptable limits for each. Next, policymakers and others involved should recognize the sources of opportunity to address each problem individually, with attention to the relative cost of the various options and their outcomes.

To tackle air quality, end-of-pipe solutions on existing facilities are inexpensive, but need to be effectively coordinated with reduction of other pollutants in order to ensure an overall improvement in air quality. Depending on how high the CO2 price is, some amount of end-of-pipe controls may be needed to bring air pollutant emissions down faster than CO2 to meet the ambient air quality goals stated in the APAP. Achieving these targets will require attention to hard-to-control air pollutants such as ammonia, which significantly contribute to PM 2.5 formation.

It will also require controlling emissions associated with biomass burning in rural areas, which are not directly connected to energy use and CO2 emissions. Finally, and perhaps most challenging, will be determining how much coal-linked emissions of NOX and SO2 to scrub and how much to reduce through fuel switching, since the latter could have direct climate benefits.

Establishing a CO2 emissions price through a national ETS sooner rather than later will help to ensure that cleaning the air does not come at the expense of prolonging a carbon-intensive energy system. Furthermore, coordinated action led by the National Development and Reform Commission—the government agency responsible for developing the nation's carbon ETS—and the Ministry of Environmental Protection—in charge of air pollution control—will be critical to ensuring that China's energy/carbon and environmental policies do not work at cross purposes.

Ultimately, a price on carbon is needed to reinforce and guide the strong initial steps being taken to address China's air pollution and realize CO2 reductions over the longer term. Separate but coordinated policies for air pollution and carbon reduction are expected to lead to earlier and more enduring long-term reduction in coal use than might have been achieved otherwise. An immediate start down this path will ensure that China's 2030 peak carbon goal is achieved at least cost, while delivering significant benefits for air quality improvement.

Endnotes

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中国治理大气污染和应对气候变化为什么需要单独但要协调的政策

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THE PAULSON INSTITUTE

作者简介

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Valerie J. Karplus是麻省理工学院斯隆管理学院（MIT Sloan School of Management）全球经济和管理团队（Global Economics and Management Group）的助理教授。作为清华–麻省理工中国能源与气候变化研究项目的项目主任，她同时也在领导一个由麻省理工学院和清华大学的研究人员组成的国际合作团队，重点研究中国在全球能源市场和应对气候变化中作用。此前，Karplus博士曾在德国柏林作为博世学者（Robert Bosch Foundation Fellow）在德国联邦外交部发展政策司工作，在中国北京作为卢斯学者（Luce Scholar）和北京生命科学研究所研究员从事中国生物技术产业研究。她的研究兴趣包括不同国家和行业背景下企业经营中的资源和环境管理，特别是与新兴市场和政策影响有关的问题。Karplus博士是一位中国能源系统研究专家。她对能源技术发展趋势、能源系统管理以及商业决策对可持续发展的影响有深入的见解。Karplus博士拥有耶鲁大学生物化学和政治学学士学位和麻省理工学院工程系统博士学位。

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Cover Photo/David Gray Reuters

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引言

尽管中国政府正加倍努力治理空气污染，北京的空气质量指数仍时常飙升至300以上，给公众健康带来极大的威胁。特别是在2013年1月，北京异常严重的空气污染状况引发了公众的强烈反应。因此，治理空气污染已成为目前政府工作的重中之重。中央承诺将采取快速有力的行动“向污染宣战”。[1]

政府治理空气污染的态度和行动无疑是积极的，这些努力同时也将在一定程度上削减二氧化碳排放。虽然治理大气污染和碳减排的重点都包括降低煤炭使用量，但两者并不完全等同。

加强大气污染治理虽然十分重要，但实现中国既定的二氧化碳减排目标需要更有力的行动。

在治理空气污染政策之外，要做到对大气污染物和温室气体进行有效的“联合控制”需要更进一步：对碳排放进行严格定价。这对实现中国政府承诺的到2030年达到碳排放峰值的目标非常关键。换句话说，加强大气污染治理虽然十分重要，但实现中国既定的二氧化碳减排目标需要更有力的行动。

我们首先说明为什么政府同时需要大气污染治理政策和温室气体减排政策。虽然一些低成本的减排手段（如减少燃煤使用）能同时降低空气污染物和温室气体的排放，但当这些低成本减排机会耗尽后，实现污染物和温室气体同时减排的协同效益将十分困难。[2]我们的研究发现，治理空气污染在短期内可以同时减少相当的温室气体排放，反之亦然。然而，随时间推移当减排要求更加严格时，协同效益将越来越有限。[3]

对于中国而言，近期内大幅削减煤炭使用能够同时实现大气污染物和温室气体的减排，但在煤炭被不断挤出能源系统后，取代煤炭的边际成本将会逐渐上升。煤炭在中国仍是最便宜和最丰富的能源，即使考虑减少煤炭使用的健康效益，大量推广替代能源仍将大幅增加能源的使用成本。因此，经过一定阶段后，减少大气污染物和温室气体排放的最为经济有效的手段将会存在显著差异（参见图1，大气污染物和温室气体减排手段的异同）。

减少煤炭使用的各种途径(如控制煤炭消费密集型工业、提高燃煤效率、改用清洁燃料等)之间存在显著的成本差异。一般说来，控制煤炭消费密集型工业虽然对于一些产能过剩行业或许可行，但是其总体代价十分高昂；而通过更新设备或改进生产过程从而提升生产效率的措施能给企业带来一定的经济收益，成本相对低廉，更具有推广潜力。事实上，自1978年改革开放以来，能源使用效率的提升已经让中国成功实现了能源强度的大幅下降。[4]至于清洁燃料替代这一途径，它受不同燃料的成本差异影响（例如

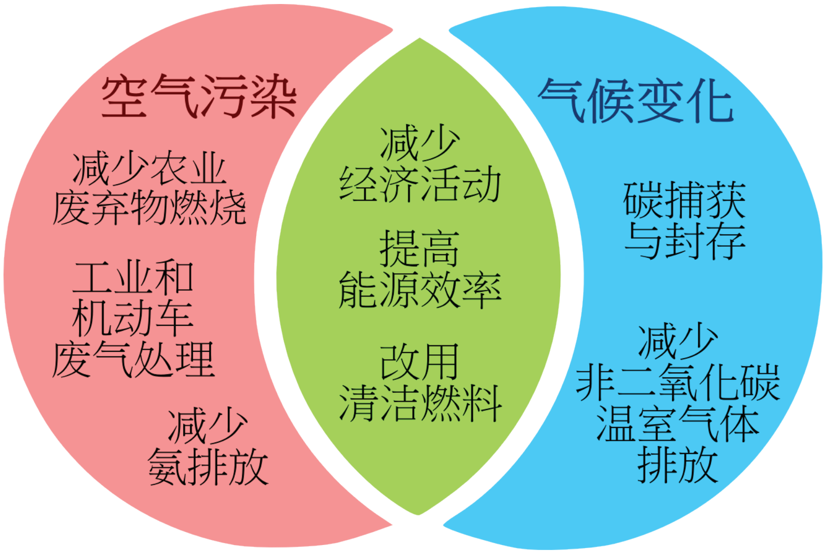
核电一般被认为比天然气发电更便宜），也受能源终端使用燃料可替代性的限制。[5]

因此，如果政策目标仅仅停留在提升空气质量，由于减少煤炭使用的边际成本的逐渐上升，一些末端治理措施，如从燃煤电厂尾气中脱除污染物，将变得更为经济，政府和工业界也将更倾向使用这些末端治理措施。然而需要特别注意的是：末端治理措施不仅基本不会减少二氧化碳排放，还通常会增加能源使用量（如煤电），从而造成二氧化碳排放一定程度上的增加；而由于减少温室气体排放并不像改善空气质量那样紧迫，且其成本相对更高（例如，目前燃煤电厂“去除”碳的唯一可行方式—碳捕获和封存技术的成本十分高昂），应对气候变化将是一个更为艰巨的挑战。

本论文首先分别介绍中国现有的治理大气污染和应对气候变化的政策，讨论政策目标、具体措施及其对于能源使用、温室气体排放、污染物排放和空气质量的影响，并详细解释重视短期空气质量改善的政策设计对长期碳减排的帮助有限，而碳排放权交易机制对实现长期碳减排目标非常重要。

本论文阐明了中国应该尽快建立全国性碳排放定价制度的必要性——末端治理虽然是治理大气污染行动计划的核心手段，并能改善区域空气质量，但并不能完全解决温室气体减排问题。论文最后强调了碳定价能够在早期增加引起空气污染的碳密集型能源的使用成本，降低末端治理手段的使用强度，防止“碳锁定”，从而能够在不牺牲温室气体减排的条件下实现空气质量的改善。

图1：大气污染物和温室气体减排手段的异同



资料来源: 李乔婷博士，清华-麻省理工能源与气候变化研究项目。

中国目前以煤炭为中心的政策

北京目前针对空气质量和应对气候变化的政策，是由国家和地方的政策法规组合而成，其中许多都要求减少能耗强度（或二氧化碳排放强度）和安装污染控制设备。实现能耗强度目标主要是通过提高效率和淘汰落后低效产能的措施来减少能源需求增长；规定安装的污染控制设备包括脱硫和脱硝设备。由于近几十年来空气质量问题日益恶化，政府强化目标实施的动力不断提高。本节将回顾目前中国应对空气污染和气候变化的方法。

清洁空气行动

我们首先介绍改善空气质量的行动。由于在全国范围内燃煤电厂是造成空气质量较差的一个主因，污染物减排的行动主要集中在燃煤电厂的减少、替代、搬迁或烟气净化。2013年9月，中国公布的《大气污染防治行动计划》（“国十条”）要求到2017年中国的可吸入颗粒物（PM10）相对于2012的水平减少10%，三大沿海城市区域的PM2.5浓度也要相应减少：北京-天津-河北（也称为“京津冀”区域）减少25%，长江三角洲减少20%，珠江三角洲减少15%。[6]

> *由于在全国范围内燃煤电厂是造成空气质量较差的一个主因，污染物减排的行动主要集中在燃煤电厂的减少、替代、搬迁或烟气净化。*

该计划以减少煤炭使用为中心来实现空气质量目标，包括在2012年至2017年间能耗强度降低20%，比“十二五”规划（2011-2015年）的国家单位GDP能耗降低16%的目标要更加严格。它同时要求煤炭在一次能源消费中的比例要限制在65%以内，并禁止上述三大城市区域增加煤炭的使用量。

除了这些集中“限煤”的指标，《大气污染防治行动计划》的核心内容还包括通过强制“上大压小”和安装污染控制设备来实现减排等具体措施，如改造区域供热系统，提高电力、更清洁的燃料（如天然气）或洁净煤的使用，要求更多、尤其是靠近城市的工业锅炉和窑炉安装和运行脱硫、脱硝和除尘设备。

最后一类措施正是那些有利于空气质量改善但无助于二氧化碳减排的末端治理措施。这些措施在行动计划中比优化产业结构、加快能源结构调整、增加清洁能源供应处于更优先的地位。实际上，这类措施将在某种程度上增加能源消费量，也同时增加二氧化碳排放。

另外，解决中国雾霾问题不只是识别主要的污染源那样简单，还需要探究复杂的大气化学过程：因为不同空气污染物是以非线性的方式结合起来影响空气质量的。同时，有些污染物并非来自能源系统，其源头（如农业源）更加难以控制。这意味着改善空气质量需要控制各类空气污染物的相对量。

这种复杂的大气化学关系意味着一种或多种污染物排放量的减少不一定能保证空气质量的改善，相反还有可能导致空气质量的恶化。例如，在某些

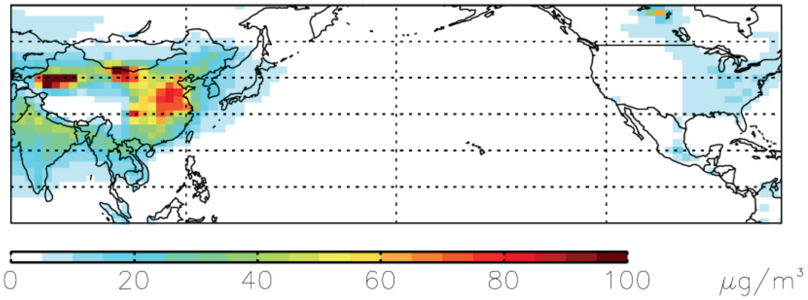
条件下，如果氮氧化物的排放降低，但挥发性有机物的排放没有削减，臭氧（一种引起心肺功能失常的城市大气污染物）的浓度将有可能上升。根据我们麻省理工-清华团队的研究，如果二氧化硫和氮氧化物（主要来自煤炭燃烧）的排放相对减少，但氨气（主要来自难以控制的农业源）的排放没有被控制，PM2.5的下降水平将比同时控制氨气时少得多（参见图2a、2b和2c）。

碳减排行动

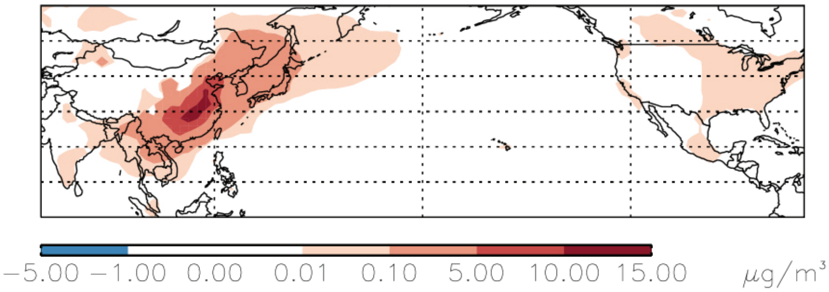
在2009年哥本哈根气候大会上，中国承诺在2020年将单位国内生产总值的碳排放降到比2005年低40%-45%。为了实现这一目标，中国推出了具有约

图2：氨排放量对模拟的未来空气质量的影响

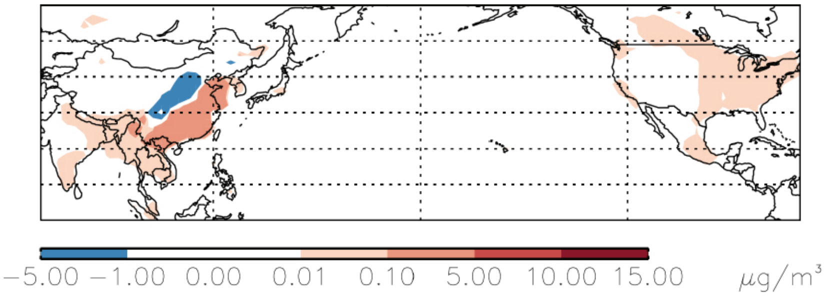
2a. 2010年模拟PM2.5浓度的空间分布



2b. 2030年与2010年相比模拟PM2.5浓度的变化



2c. 如果氨排放保持在2010年的水平，2030年与2010年相比模拟PM2.5浓度的变化



资料来源：Li, M., Selin, N. E., Karplus, V. J., Li, C.-T., Zhang, D., Luo, X., 和Zhang, X. (2014年)。

束力的“十二五”碳强度降低17%的目标。

不久以前，在2014年11月北京亚太经合组织（APEC）峰会期间，中美两国领导人共同宣布了两国2020年后的气候目标。中国气候计划的核心部分是，到2030年达到碳排放峰值，并将非化石能源在一次能源中的比重提高到20%（约是2015年11.4%目标的两倍）。有关碳减排的政策在未来的“十三五”规划（2016-2020年）中可能会占有更重要的地位。中国已经在七个地区（五市两省）进行了碳排放交易试点，为建立全国范围的碳市场奠定了基础。全国性的碳市场将会在“十三五”期间建成。

我们的研究分析了未来气候政策和能源政策（包括由《大气污染防治行动计划》规定的措施）的结合能在何种程度上影响中国到2050年的能源系统演变和碳排放轨迹。我们发现中国需要引入碳价来实现持续降低碳排放强度和2030年“碳峰值”的目标。在加速政策的情况下，中国的碳强度每年下降4%左右，碳排放量可在2030年到达峰值，需要的碳价在2030年上升至38美元/吨。[7]

在给定的经济持续增长的预期下，这种加速政策情景是有关中国未来可行的二氧化碳减排轨迹讨论中比较乐观的情况。相应的预测是，煤炭使用最早在2020年达到峰值，而二氧化碳排放量将在2025年至2035年的之间达到峰值（煤炭和二氧化碳的峰值时间有所差异是由于在煤炭使用稳定之后，其它化石燃料的消费量还将继续增加）。虽然这将与中国的气候承诺相一致，但政府仍将需要额外的措施来改善短期空气质量。

联合控制策略的优点

中国的政府部门应该如何协调监管空气污染和温室气体排放？从经济学视角看，中国需要分别设置大气污染治理和碳减排目标，并通过价格手段来实现最有效率的空气污染和二氧化碳的同时减排。

改善空气质量的气候协同效益

由于空气质量（重点考虑臭氧和PM2.5浓度）受局域复杂的化学反应影响，针对空气质量设置价格政策工具要比针对二氧化碳设置价格政策工具更具挑战性。事实上，这些复杂的化学反应在某些情况下能将污染物排放的增加转化为环境污染物浓度的降低。因此，设计一个针对空气质量的价格工具来反映这些影响虽然不是完全不可能，但将会非常困难。不同行业、不同能源使用的排放对当地空气质量的影响取决于时间、季节、当地环境以及其它需要更多的研究才能全面了解的因素。

> *总的说来，目前中国正在推行的一些空气污染治理措施，未来将会很快阻碍煤炭消费总量的进一步降低。*

鉴于协调空气污染排放定价机制的难度，减少煤炭使用往往被视为一种可行的替代方案。降低中国能源系统中煤炭用量能降低二氧化硫、氮氧化物和一次颗粒物排放。如前所述，如果其它污染物如氨的排放上升，空气质量的提升将会比较有限。一旦削减煤炭用量的低成本机会耗尽，继续替代煤炭将会变得昂贵，特别是当煤炭需求显著下降、煤炭价格相对更加便宜时，长期替代煤炭的成本会更加上升。

因此，如果对空气污染排放定价不够严格，即使考虑各种污染控制措施的成本，使用煤的边际成本仍会低于减少煤使用的成本、煤的燃料替代成本或者碳捕获和储存（CCS）成本。例如，在中国燃煤电厂安装选择性催化还原（SCR）脱硝系统相对便宜，约为150元（25美元）每千瓦[8]，这意味着煤电仍然可能比风电或天然气发电便宜。

这样一来，由于空气污染控制措施将导致碳密集型能源使用的继续锁定，空气污染控制就失去了减缓气候变化的协同效益，而若增加二氧化碳的末端处理（CCS技术）估计至少将中国燃煤发电的平准成本提高50%。[9]

除了减少煤炭使用之外，其它改善空气质量的措施也非常必要，但却往往被忽视。譬如，秸秆田间焚烧能导致总排放量增加和空气质量显著变差，大范围实时监控秸秆田间焚烧已经推行，进一步政策十分必要；控制柴油卡车和其他机动车的颗粒物排放量也是一个成本相对较低的、能够改善城市群和产业带空气质量的有效方法。虽然上述措施能够经济有效的改善空气质量，但它们很少或几乎不能显著减缓气候变化。

总的说来，目前中国正在推行的一些空气污染治理措施，未来将会很快阻碍煤炭消费总量的进一步降低，从而可能导致碳减排进展停滞——仅此一点就可以说明引入碳价有着重要的意义。

减缓气候变化的空气质量协同效益

相比而言，气候变化依赖于温室气体排放量的总累积，不论温室气体是何时何地产生。这一特性使得通过价格机制来控制二氧化碳和其它温室气体的排放量更直接，因为排放的边际成本没有空间和时间区别，也不与其他种类的排放量互相影响。

在协同效益方面，引入碳价将直接导致一部分大气污染物排放量的减少（见图3）。图3A显示了上述加速情景下导入碳价后的二氧化碳排放量，而图3B-3E显示了碳价对PM2.5的各种前体物的影响，而PM2.5是造成空气质量降低以及由此引起的最严重健康影响的关键。然而，二氧化碳减排只能带来燃烧过程产生的二氧化硫和氮氧化物排放量降低，但无助于减少挥发性有机化合物（VOCs）或氨的排放，对空气质量改善也相对有限。

因此，单一的实施碳价或仅仅遵行当前中国改善空气质量的措施都不足以解决二氧化碳减排问题。无论是《大气污染防治行动计划》，或是任何现有的气候政策和能源政策，都不能在2020年前扭转全国总煤炭使用维持高位的轨迹。这意味着在短期内解决空气质量问题将需要大量依赖末端的解决方案。

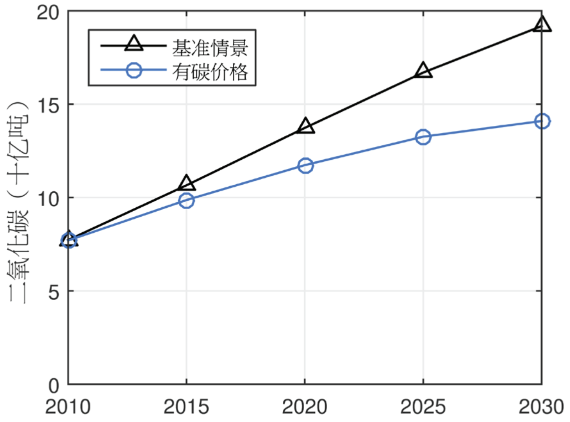
举例来说，假设《大气污染防治行动计划》下的各项积极的政策得到落实，再加上适度的二氧化碳价格，中国的煤炭使用预计能在2020年左右达到顶峰。[10]相比之下，由于《大气污染防治行动计划》在全国层面只限制了煤炭的使用比例而不是绝对水平，如果只限制三大城市地区的煤炭使用而没有其它额外的政策限制，三大区域周边地区的煤炭使用将会增加。[11]

尽管如此，在2020年前维持或降低煤炭需求，对空气污染和碳减排二者仍然都很重要。从长远来看，如果末端的解决方案（如碳捕集和储存）成本仍然居高不下，应对气候变化需要更多的煤炭替代。碳排放价格机制的引入能够进一步激励煤炭替代，如果设计得当，能够对空气污染控制工作起到补充作用。

总的来说，如果中国愿意采取积极行动，引入二氧化碳排放价格机制来应对气候变化，则将同时有助于改善空气质量。这样的联合政策还有助于避免部分落后燃煤电厂烟气控制设施的过度投资，并防止这些投资造成的高碳能源系统锁定。

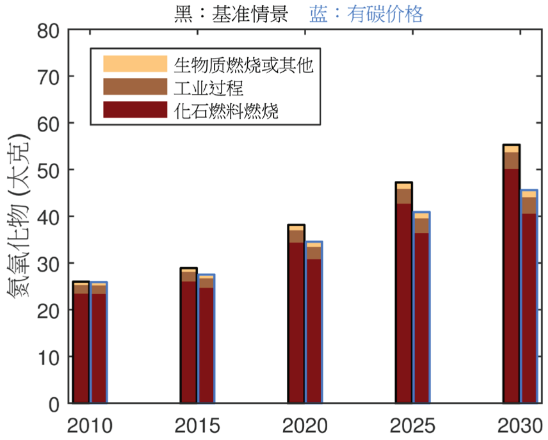
图3：二氧化碳价格对PM2.5形成前体污染物排放量的影响，2010-2030年

3a. 两种情景模拟的二氧化碳排放量*

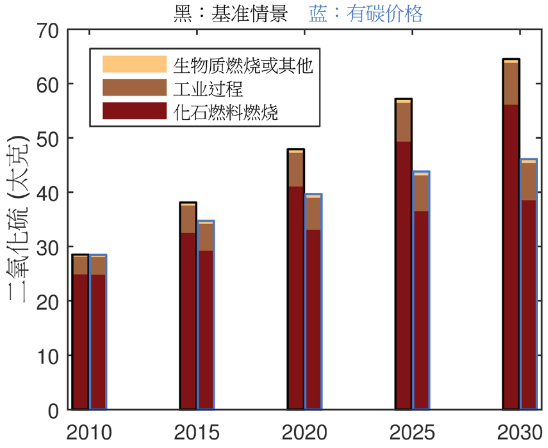


*到2030年，碳价格上涨至38美元/吨，相当于每年减少4%二氧化碳排放量强度。

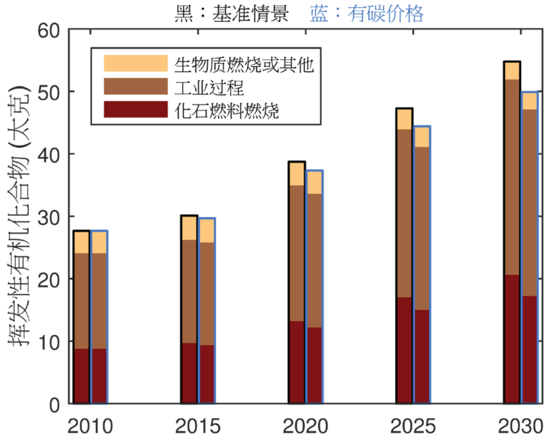
3b. PM2.5的前体物之一，氮氧化物的排放量



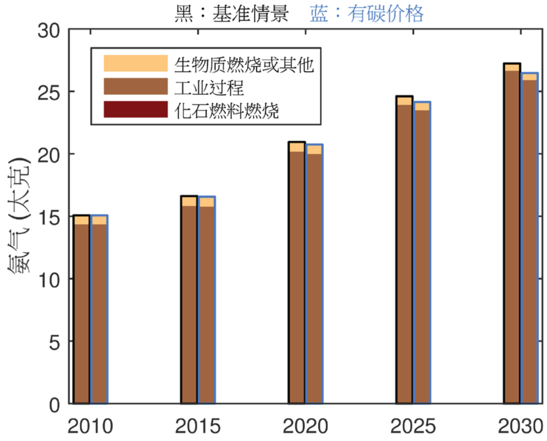
3c. PM2.5的前体物之一，二氧化硫的排放量



3d. PM2.5的前体物之一，挥发性有机化合物的排放量



3e. PM2.5的前体物之一，氨气的排放量



资料来源：Li, C.-T., Karplus, V. J., Selin, N. E., 和Li, M.（2014年）。

结论

实现中国政府碳减排的重大承诺需要引入正确的激励机制来鼓励整个能源系统由化石燃料向低碳或零碳能源转型。能耗强度目标、碳强度目标以及煤炭占一次能源比重65%以下的目标，将有助于遏制能源相关的二氧化碳排放量快速上升。但是，如果中国想要达到在APEC峰会上宣布的碳峰值目标，额外的激励是必要的。

应对气候变化需要专门的策略

无论是通过排放权交易体系还是税收机制来引入碳价，都是把中国的气候承诺转化为清晰的、以价格为基础的激励机制来实现2030年及以后低碳经济目标的最佳途径。这一机制将限制煤炭等化石燃料的扩张，有利于低碳替代和减少化石能源需求。未来几年，在中国能源经济发展的议程中，环境保护（包括空气质量改善）将处于优先地位。引入碳价机制将是确保碳减排目标具有约束力的一个有力举措。

如果中国想要达到在APEC峰会上宣布的碳峰值目标，额外的激励是必要的。

目前来看，构建区域或跨区域碳排放权交易体系市场是最经济有效的碳减排政策工具。建立国家碳排放权交易体系是激励能源系统向低碳转型的关键步骤。中国已开始国家碳排放权交易体系的准备工作，该系统的设计中所作的选择将决定其成本效益。例如，目前由政府管制的电价是否允许调整，以充分体现二氧化碳排放价格信号传递？哪些二氧化碳排放来源需要被计入碳排放权交易体系内？如果中国坚持以二氧化碳排放强度，而不是二氧化碳排放绝对量为目标，在具有不确定性的情况下，体系设计是否可以确保二氧化碳排放量被限制在“可接受区间”内？

政府部门确定了一个与中国近年气候承诺一致的碳排放限额后，应该让排放权交易体系的价格信号作为主要的激励来驱动二氧化碳减排。这种基于市场的排放控制机制符合2013年11月十八届三中全会做出的“深化市场改革，建立排污权市场体系”的决定精神。

碳价将随政策变化（如污染控制措施或能源价格改革）自动调整，并能通过能源系统的演变加强二氧化碳和空气污染物减排。如果按照规定安装的污染控制设备提高了电力和工业活动的成本，碳价的变化将反映由于费用升高、污染密集工业的减少导致的相应的二氧化碳排放减少。

通过这种方式，碳价能够确保未来的能源系统转型与二氧化碳减排目标一致。碳价的实施需要企业不仅监控传统的空气污染物排放量，也要监控能源使用和二氧化碳排放量。为了发挥二氧化碳价格效力，国家碳排放交易体系应该尽可能覆盖众多会产生二氧化碳的活动。否则，由于碳价可能导

致能源需求总量下降，进而使得化石燃料变得更加便宜，减排成效可能会被未覆盖部门使用化石燃料的增加抵消。

除了通过碳排放交易体系建立二氧化碳排放价格，对于大型高耗能项目的评价审批也需要和环境影响评估一致，并应将碳减排包括在更广泛的污染减排措施中。

考虑到未来几十年新建设施的巨大规模，制定积极的环境标准和控制能源密集型投资能够加快低碳转型。项目审批程序还可以成为衡量投资是否响应激励措施（如碳价、排污成本、能源价格改革）的一个手段。

协同控制会更有效地实现目标

实现有效的二氧化碳和空气污染协同控制首先需要分别明确可接受的排放程度，政府部门和相关方面随后需要研究单独解决以上问题的各种选择，衡量各种选择的相对成本。

就目前情况看，末端治理对于改善空气质量是经济的，但同时需要与其他污染物控制手段有效协调。保持一定的碳价水平，同时也需要末端控制措施，让空气污染物排放下降的速度比二氧化碳下降更快，以满足《大气污染防治行动计划》规定的环境空气质量目标。实现这些目标，需要注意较难控制的空气污染物，如对形成PM2.5非常重要的氨。

虽然农村地区的生物质燃烧没有被直接计入到能源消耗和二氧化碳排放中，但控制其排放对于改善空气质量十分必要。最后，也许是最有挑战性的，是确定与燃煤相关的氮氧化物和二氧化硫减排量中，末端控制和燃料替代的比例各应多少，因为后者可能具有直接气候效益。

尽早建立全国碳排放交易体系能保证空气质量的改善不会导致能源系统持续长期采用高碳能源。此外，国家发展和改革委员会（负责国家的碳排放交易体系设计）和环境保护部（负责空气污染治理）的协调行动将是确保中国的能源、气候和环境政策的工作互不掣肘的关键。

最后，加强对空气污染治理有重大效果的初步措施，使其与通过引入碳价实现长期碳减排相协调。与其他方式相比，单独但相互协调的空气污染治理和碳减排政策会带来更持久、长期的煤炭用量削减。这样的政策思路将保证中国以最低成本实现2030年的峰值碳目标，同时为空气质量改善带来显著的协同效益。

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- 支持城镇化发展，包括促进环保政策的优化；
- 培养在国际关注问题上的负责任的行政部门领导力与最佳商业实践。

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