ABaCAS

An Overview of the Air Pollution Control Cost–Benefit and Attainment Assessment System and Its Application in China

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This article describes a policy assessment system that was developed in China in collaboration with the U.S. Environmental Protection Agency (EPA) to address and evaluate control strategies and their benefits.

China has and will continue to encounter episodes of severe air pollution and the burden of disease attributable to air pollution that have resulted from the rapid and continual growth of the economy, energy, and vehicle population.[1] The coherent control of multiple pollutants and joint reduction of regional emission sources can be very beneficial to air quality and has been well demonstrated in a few mandatory short-term control actions and events (e.g., 2008 Summer Olympic Games[2] and 2014 APEC meeting in Beijing). However, the implementation of such temporal actions to improve air quality with no consideration of cost is unrealistic as a long-term control policy. The challenge in China and other developing nations is how to design a cost-efficient strategy that can optimize the control benefits over various types of pollutants from multiple sources and regions.

What Is ABaCAS?

The Air Benefit and Cost and Attainment Assessment System (ABaCAS; www.abacas-dss.com), is a new policy-oriented integrated scientific assessment system, which aims to address the key question whether the proposed control strategy and resulting air quality benefit will be cost-efficient. The prototype of ABaCAS was first developed by the U.S. Environmental Protection Agency in 2012, and designed with a focus for supporting policy analyses. After five years of continual development by an international team of scientists from the United States and China, it can now provide a wide range of applications, including both policy support and scientific research. Members of the general public not only have free access to its usage from the official website (http://www.abacas-dss.com), but can also receive technical support from the training programs given by the core developing members during annual ABaCAS international conferences (www.abacas-dss.com/abacas/Conference.aspx).

In general, cost–benefit assessment requires an estimate of how much benefit one can get back from an investment in air pollution controls, asking questions such as

1. How will the air quality respond to specific emissions control scenarios?
2. How much emissions control is needed to attain the ambient standards or certain air quality goals?
3. How much will specific emissions control scenarios cost?
4. What health and economic benefits will be obtained from changes in air quality resulting from specific emissions control scenarios?

A set of decision-support tools in ABaCAS is designed to address the aforementioned questions, as demonstrated in Figure 1. These include:

1. The International Cost Estimate Tool (ICET), which estimates costs associated with certain control strategies based on cost information of control technologies applied in specific emission sectors.[3]
2. The Response Surface Model (RSM), built on meta-simulation scenarios with advanced statistical interpolation techniques, which provides a real-time estimated response of pollution concentrations to emissions changes.[4-7]

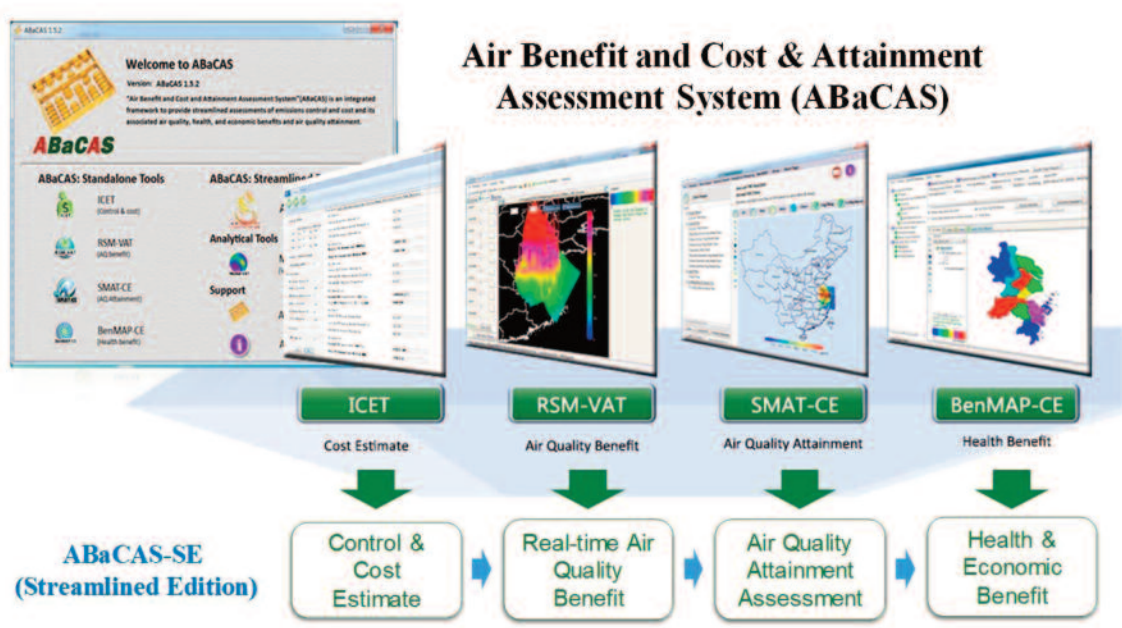


Figure 1. Structure of ABaCAS system.

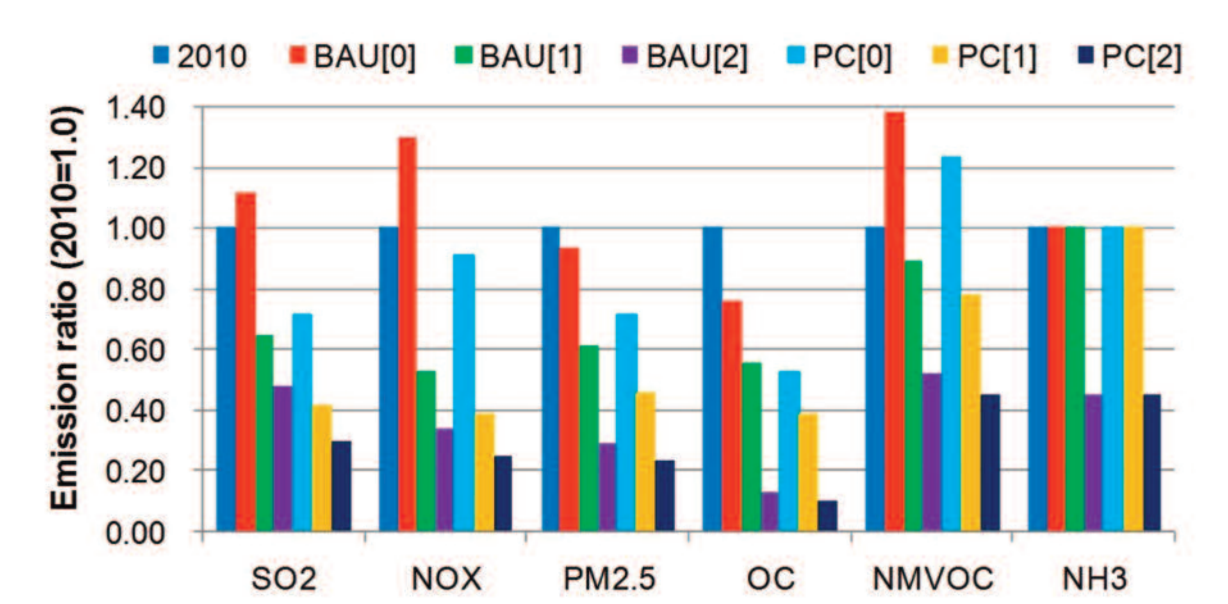


Figure 2. Future emissions of six pollutants in Yangtze-River Delta (relative to 2010).
Note: SO2 = sulfur dioxides, NOx = nitrogen oxides, PM2.5= fine particulate matter, OC = organic carbon, NMVOC = non-methane volatile organic compounds, NH3 = ammonia.

3. The Software of Model Attainment Test (SMAT), merging RSM-predicted and monitor-observed data, which performs attainment tests to examine whether an emission reduction strategy will lower future ambient air pollution concentrations to a certain level.[8]
4. The Environmental Benefits Mapping and Analysis Program (BenMAP), which estimates monetized human health effects resulting from the change in ambient air pollution, based on the health impact function or the concentration-response (C-R) function in epidemiology studies and an estimate of the monetized benefit per avoid endpoint.[9-12]

The cost–benefit ratio can then be calculated from the estimates of BenMAP and ICET. A streamlined edition of the ABaCAS system (ABaCAS-SE) has been developed specifically for policy analyses, which provides a user-friendly interface to run the four ABaCAS tools from ICET to BenMAP sequentially.

ABaCAS Application in China

Since its release in 2011, the ABaCAS system has been used in multiple applications in China. Some studies contribute to policy implication. For example, Xing et al[4] investigated the nonlinear response of ozone to the precursor changes in three megacities, and emphasized the necessary of synchronous control strategy on both local and regional emissions. Wang et al.[5] compared the relative importance of sulfur dioxides, nitrogen oxides, and ammonia emissions for fine particle (PM2.5) formation, and recommended a more effective pathway as a multipollutant control strategy to reduced ammonia emissions in parallel with sulfur dioxides and nitrogen oxides.

Other studies were conducted for a specific policy purpose.

Table 1. Case study in ABaCAS-YRD.

Model	Parameters	Sources
SMAT	By 2030, the PM2.5 should not exceed 35 µg/m^3	Ambient air quality standard
RSM	ERSM for Yangtze-River Delta (YRD)	Zhao et al[6]
ICET	Cost information	Wang et al[16]
BenMAP	C-R function, value of statistical life (VSL)	Wang et al[10]

Table 2. Design of scenarios.

Energy Scenario	End-of-Pipe Control Strategy	Emission Scenario
BAU (current policy)	[0] (current legislation)	BAU[0]
	[1] (new legislation)	BAU[1]
	[2] (maximum reduction)	BAU[2]
PC (alternative policy)	[0] (current legislation)	PC[0]
	[1] (new legislation)	PC[1]
	[2] (maximum reduction)	PC[2]

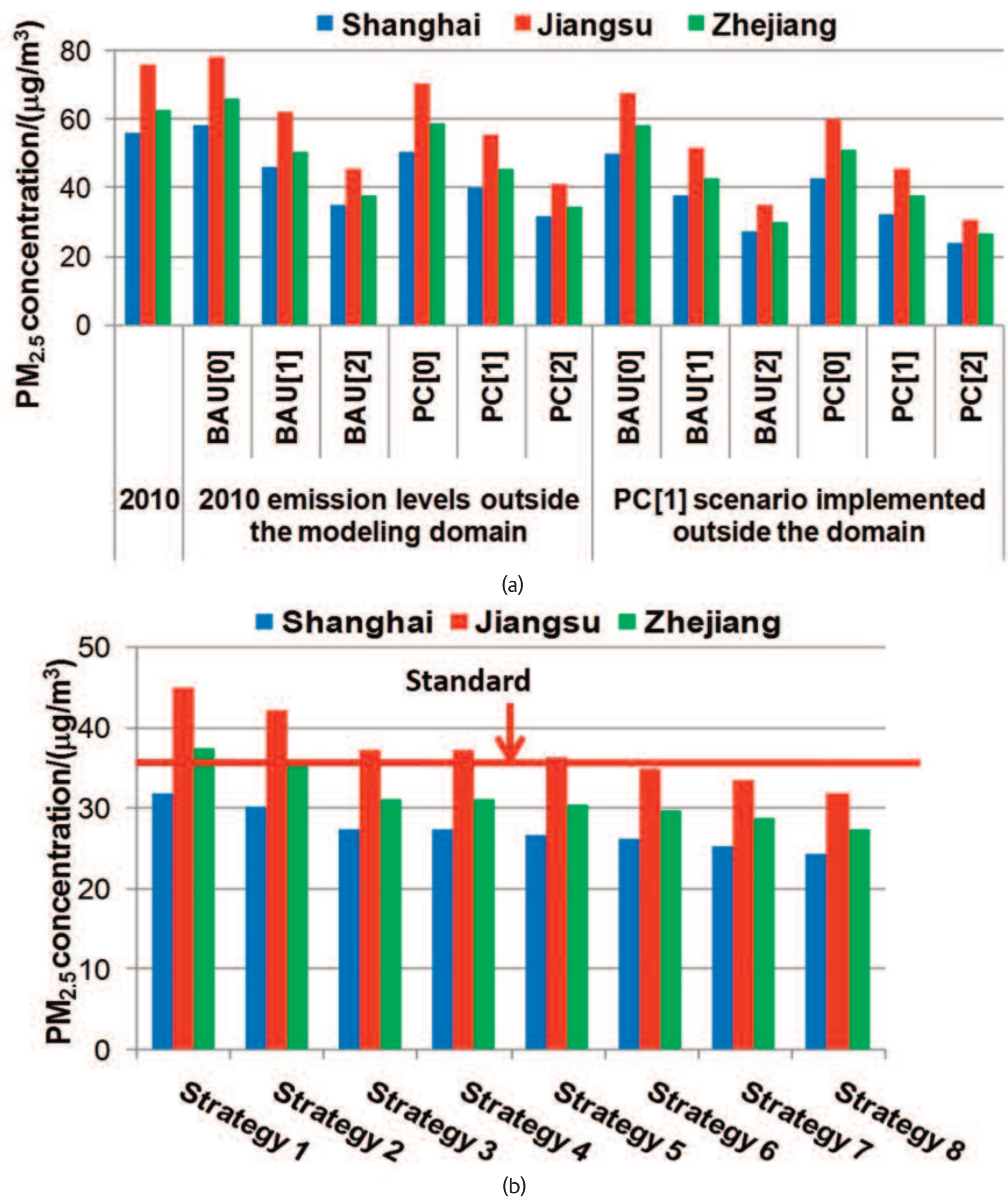


Figure 3. Predicted PM2.5 concentrations at urban averages in Yangtze-River Delta. (a) Future scenarios; (b) Strategy selection.

Ding et al.[12] evaluated the health benefits from emission controls used during the Guangzhou Asian Games. The use of the ABaCAS system has been wide spread across China, including in the North China Plain,[13] Yangtze-River Delta (YRD),[10,14] Perl-River Delta,[12,15] and Sichuan Basin regions, for the purpose of attainment assessments, source apportionment, and health benefit studies.

Case Study in Yangtze-River Delta (YRD)

To demonstrate how the ABaCAS system works, a summary of case study conducted for YRD is included here. The model settings for ABaCAS-YRD are summarized in Table 1. The policy target was set as the annual mean concentrations of PM2.5 less than 35 μg/m,[3] which is the ambient air quality standard in China. The RSM was established by using the extended-RSM method, which improves the model's ability in solving multi-region sources.[6] The cost and health-related parameters were derived from previous studies.[10,16]

First, six future scenarios were designed for two future energy pathways and three control strategies (see Table 2). The relative changes in emissions of sulfur dioxides, nitrogen oxides, ammonia, non-methane volatile organic compounds, primary PM2.5, and organic carbon were estimated for each future scenario (see Figure 2), with the highest emission level in scenario BAU[0] (i.e., based on current energy and control legislation) and the lowest emission level in scenario PC[2] (i.e., more clean energy policy with maximum reduction).

Second, the PM2.5 concentrations under each future scenario were predicted by RSM model (see Figure 3a). Using the SMAT model, the results suggest that none of the six future scenarios could meet the target of 35 $\mu g/m^3$ when the emissions outside the domain were kept as the level in 2010, indicating the importance of joint controls of regional emission sources. When the emissions outside the domain were set to be PC[1], only the PC[2] scenario applied in YRD can meet the target. A candidate control strategy that perfectly matches the target is somewhere between PC[1] and PC[2] scenario. Therefore six extra strategies were designed in the between

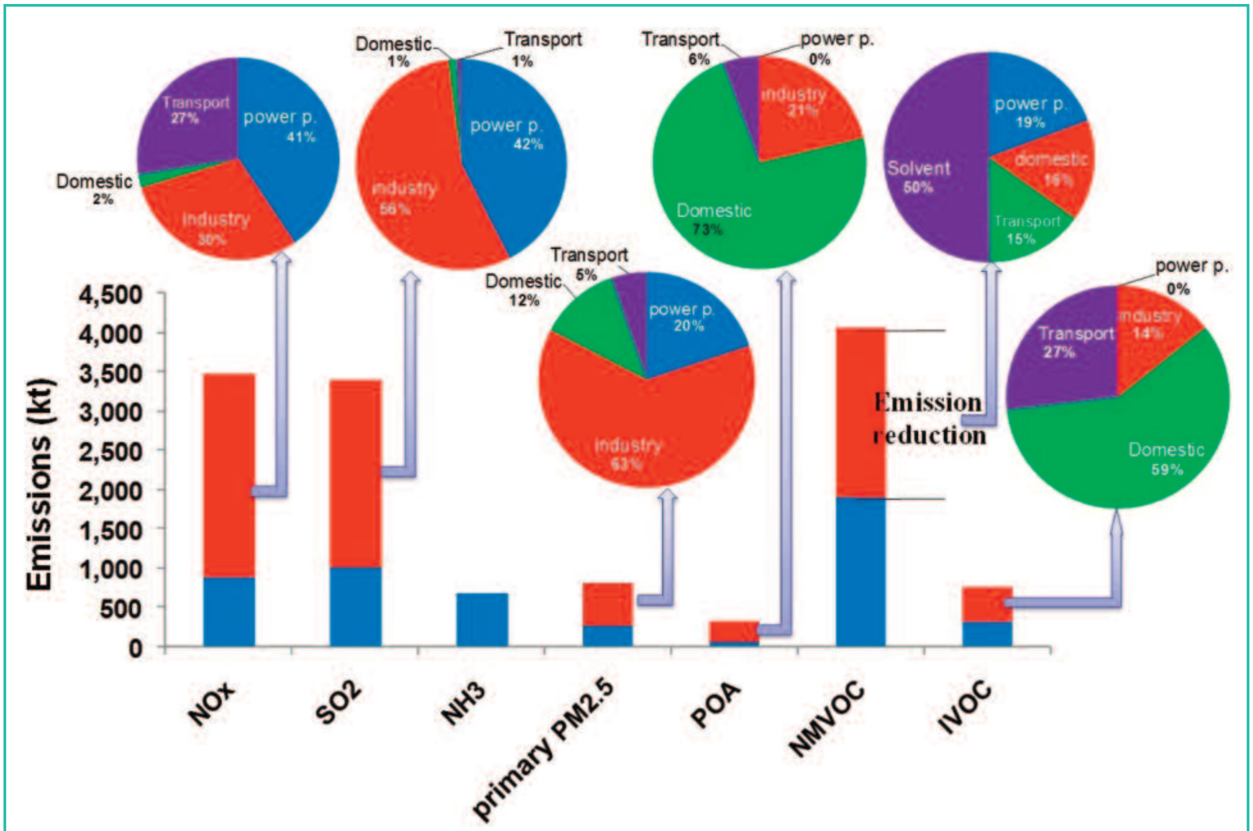
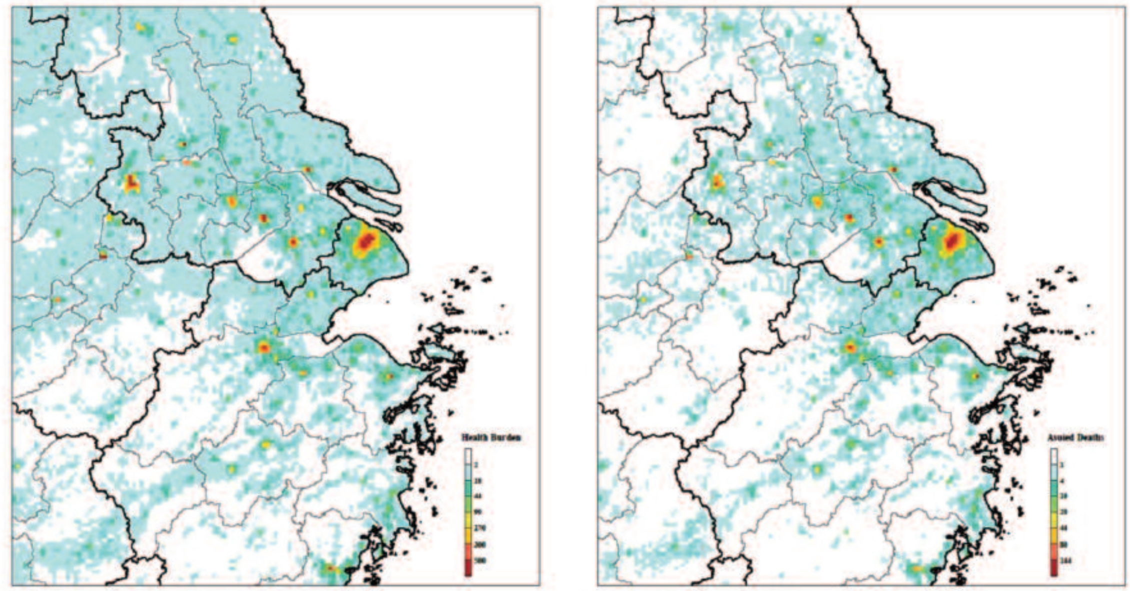


Figure 4. SMAT-selected control strategy to meet the air quality goal in Yangtze-River Delta (pie charts display the relative contribution to total emission reduction from controls on different sectors).
Note: SO2 = sulfur dioxides, NOx = nitrogen oxides, PM2.5= fine particulate matter, POA = primary organic aerosol, NMVOC = non-methane volatile organic compounds, NH3 = ammonia, IVOC = intermediate-volatility organic compounds.



(a) health burden (baseline) (b) avoid deaths (baseline minus controlled)

Figure 5. Reduced PM2.5-related premature mortality in Yangtze-River Delta.

of PC[1] and PC[2] scenario, and the predicted PM2.5 concentrations in each strategy were estimated from RSM (see Figure 3b). Strategy 6 was selected through SMAT.

Third, the detailed emission controls by sector under the Strategy 6 scenario are described in Figure 4. The Strategy 6 scenario suggests substantial reductions in sulfur dioxides, nitrogen oxides, and primary PM2.5 emissions from industry and power plants, and non-methane volatile organic compounds emissions from solvent utilization. The total cost of such controls under PC[2] scenario was estimated to be 98 billion Chinese Yuan by the ICET model.

Fourth, using the BenMAP, long-term premature deaths caused by PM2.5 were calculated from the spatial distribution of population and PM2.5 concentrations in both baseline and

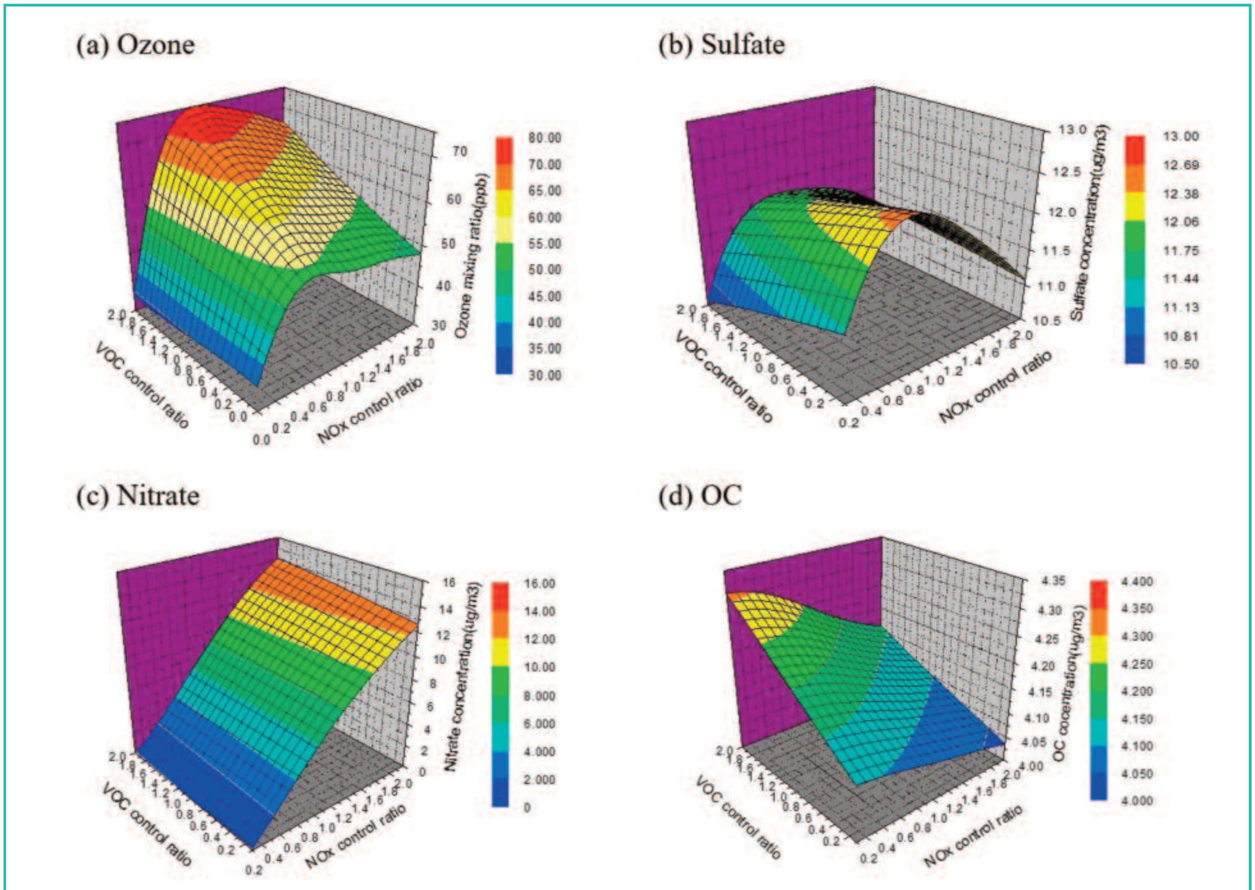


Figure 6. Response of O3 and PM2.5 components to the simultaneous step-by-step reductions in NOx and VOC (created from Xing et al.[4]).
Note: O3 = ozone, NOx = nitrogen oxides, PM2.5= fine particulate matter, OC = organic carbon, VOC = volatile organic compounds.

controlled case under the Strategy 6 scenario (see Figure 5). The results suggest that long-term premature deaths caused by PM2.5 in 2010 are 158 thousand in YRD, and the estimated reductions from the Strategy 6 control scenario would reduce the number of deaths by 32 thousand. The economic gain from the control is estimated to be 189 billion Chinese Yuan on a basis of the estimated value of life as 5.9 million Chinese Yuan.

The cost–benefit ratio of the Strategy 6 scenario is therefore estimated as 189/98 = 1.9, suggesting 190 percent monetary gain from the investment in air quality controls.

Limitations and Future Plans

Most of the previous studies only applied one or several components of the ABaCAS system, such as SMAT combined with RSM or RSM combined with BenMAP. So far, studies using the entire system, including both cost and benefit analysis, are quite limited. In addition, almost all previous studies focused on one pollutant, either ozone or PM2.5. However, the advantage of the ABaCAS system is that it allows scientists to investigate multi-pollution responses to emission changes. As shown in Figure 6, controls on nitrogen dioxides and volatile organic compounds will have substantial impacts on both ozone and PM2.5 components with strong nonlinear behavior. The optimized control policy should consider all the pollution issues together to obtain mutual benefits, considering the possibility that some control strategy reducing one pollution issue might worsen another one due to the nonlinearity.

Difficulties in the application of the ABaCAS system can be summarized into two aspects. One is the model complexity, more specifically for RSM, which requires thousands of air quality simulations resulting in a heavy computing burden. The other is the data localization, particularly for cost and health-related data, which are still very limited in China. Future studies should be focused on the improvement of RSM prediction system and establishment the database for ICET and BenMAP.

China plans to implement stringent control actions aimed at lowering the ambient concentrations of ozone and PM2.5 in the next two decades. Effective action needs guidance from the smart policy and good tools. The ABaCAS system is expected to play an important role in supporting the air quality targeted policy-making in China. **em**

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