

Air Quality Management in Guangdong Province and Implications from the California Air Resources Board Experience

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About Civic Exchange

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Prefaces & acknowledgements

Improving Hong Kong's air quality has become a priority of the HKSAR Government. Its *Clean Air Plan*, released in March 2013, has demonstrated the government's commitment to protecting public health by improving air quality. While targeting local sources of air pollution is important, collaboration with counterparts across the border is also key in addressing air quality, as Hong Kong and Guangdong share the same airshed.

A number of major scientific studies conducted over the past decade in both the Mainland and Hong Kong, individually or collaboratively, served to inform relevant policy deliberation and policy making. Authorities in Hong Kong and Guangdong have also taken measures to improve air quality in the region in recent years. Civic Exchange sees this as a timely opportunity to advance the relevant deliberation. This paper provides an overview of the current air quality management framework and practices in Guangdong. We have also chosen to examine the California Air Resources Board (CARB) in this research to understand the journey California has gone through to improve its air quality. California has, by far, the most stringent air quality management laws in the world. Despite the differences in political systems and levels of economic development, it is believed that the CARB's experience could inform authorities in the Pearl River Delta region how similar initiatives could be taken to improve air quality in the region.

Civic Exchange published a policy report examining the best practices adopted by London and Los Angeles in achieving success in reducing air pollution in 2007. In 2012, we published another report that sets out the key elements that have made the CARB in Los Angeles so successful. This report represents our further attempt to explore what Guangdong Province can learn from the CARB.

We would like to thank Prof. Junyu Zheng, Dr. Huan Liu, Qing Lu and Jiamin Ou, the authors of the report for their efforts in providing an overview of air quality management in the Pearl River Delta and the lessons learnt from CARB. We would like to thank ADM Capital Foundation for supporting this research. We would also like to thank Mike Kilburn and Simon Ng for managing this research project at different stages, and Rae Leung for designing the report cover and laying out the report.

Yan-yan Yip
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Pearl River Delta of Guangdong is a key economic region and a pioneer in environmental protection in China

The Pearl River Delta (PRD) region of Guangdong Province is one of largest economic centres in China, and also a pioneer in environmental protection. The severity and complexity of air pollution in the PRD has been widely studied by both Chinese and overseas academics for many years. This research serves to identify, implement and monitor air quality management practices for improving regional air quality.

California Air Resources Board is effective in cutting air pollution while the State's economy continues to grow. PRD can take a leaf from CARB's success

The California Air Resources Board (CARB) is the administrative agency responsible for air quality management in California, the United States (USA). It has been highly effective in curbing high levels of air pollution in the south California basin. These improvements have been achieved despite the substantial growth of California's economy and, most notably, its vehicle fleet. CARB's success in controlling emissions during a period of economic development offers valuable lessons for PRD authorities seeking to achieve similar improvements in air quality.

Chapter Two of this report reviews the current air quality management framework and practices in Guangdong. Chapter Three explores ways to improve air quality management in Guangdong based on the successful experience of the CARB. A few concluding remarks will be included in Chapter Four.

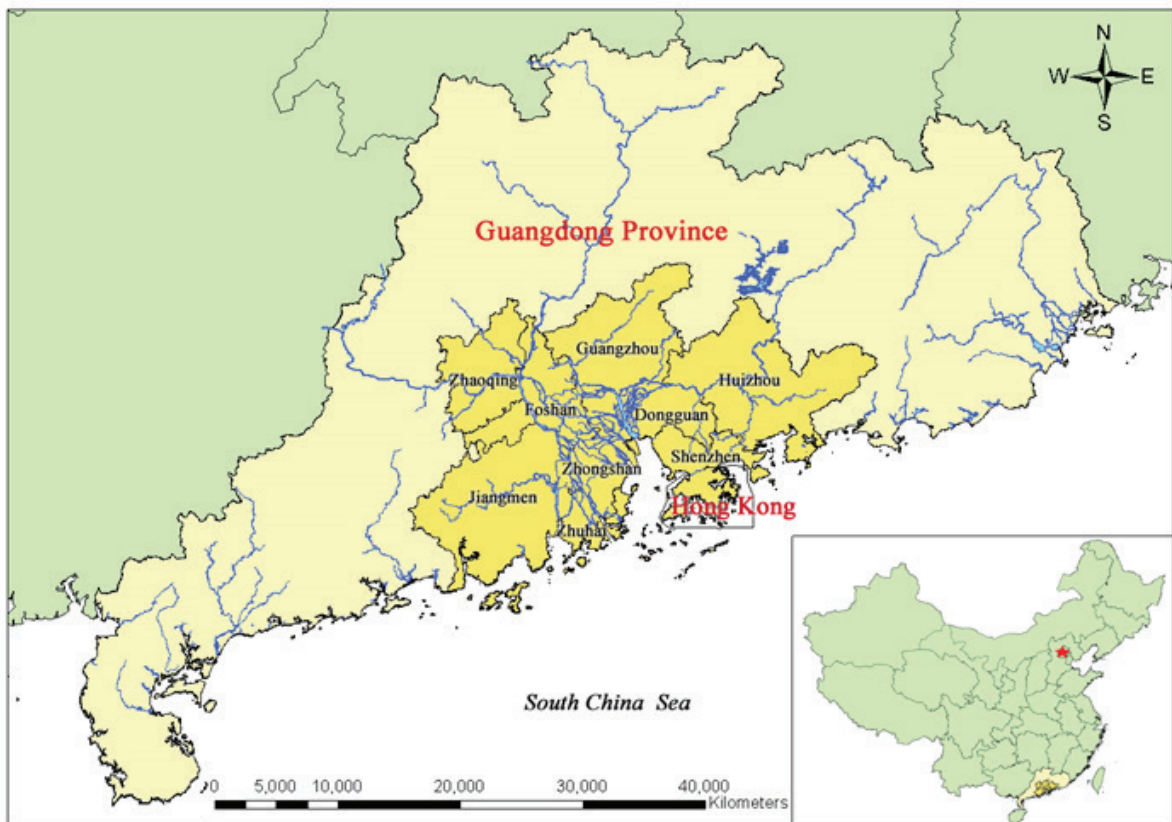
Air Quality Management in Guangdong

2.1 Guangdong and the Pearl River Delta Region

PRD Economic Zone includes nine Guangdong cities, plus Hong Kong and Macau Special Administrative Regions

Guangdong is a coastal province in southeastern China. The three major branches of the Pearl River run through the province and enter the sea at the Pearl River estuary, an area that has developed rapidly to become the Pearl River Delta Economic Zone (PRDEZ). Administratively, the PRDEZ includes the nine cities of Guangzhou, Shenzhen, Zhuhai, Foshan, Dongguan, Zhongshan, Jiangmen, Huizhou and Zhaoqing, as well as the Hong Kong and Macau Special Administrative Regions (Figure 1). The PRD is dominated by a subtropical monsoon climate, characterised by abundant rainfall, high temperatures and long summers.¹

Figure 1: Location of Guangdong Province, PRDEZ and the PRD Region



Guangdong is a major economic hub in China and PRD is the engine. There has been unprecedented economic and social development since the 1980s

Guangdong, and in particular the PRDEZ, is one of the most important economic hubs in China with a population of 104 million and covers an area of 180,000 square kilometres. In 2010, Guangdong's gross domestic product (GDP) of RMB 4,600 billion, contributed 10.9% of the national total, was the highest in China.² The PRDEZ is the economic engine and the political and cultural centre of Guangdong. It has experienced unprecedented economic and social development since the opening of China in the 1980s. In the past decade, GDP grew at a rate of over 10% per annum.³ During the period of China's *Eleventh Five-year Plan (2005-2010)*, Guangdong's vehicle fleet grew at an average annual rate of 13.5% and reached six million vehicles. In the same period, industrial coal consumption grew over 10% per annum to 86 million tonnes.⁴

Economic growth comes with a cost. Air pollution with multiple air pollutants causes region-wide problems like photochemical smog, acid rain, and haze

High emission levels from a wide range of anthropogenic and natural sources have caused severe air pollution in Guangdong.⁵ These are compounded by the high oxidation potential of the atmosphere, creating high concentrations of primary and secondary pollutants including sulphur dioxide (SO₂), nitrogen oxides (NO_x), volatile organic compounds (VOCs), ozone (O₃) and particulate matter (PM). These multiple air pollutants undergo transport, oxidation and complicated interactions among the cities, causing severe region-wide air pollution problems such as regional photochemical smog, acid rain and haze.⁶

General air quality has somewhat improved, as PRD becomes a key area to combat air pollution and to pioneer air quality management strategies

In order to increase the region's economic competitiveness and quality of life, the Guangdong government has identified the PRDEZ as a key area to combat air pollution and to pioneer air quality management strategies. The integrated control measures developed have played an important role in curbing the deterioration of air quality. By 2010, urban ambient air quality in all cities of the PRDEZ had reached China's National Standard II. The annual average concentrations of SO₂ and PM₁₀ in 2010 declined by 23.5% and 13.4% respectively, in comparison with the levels in 2005. No significant change was observed for NO₂ during these five years. The frequency of acid rain decreased by 9% and the general air quality in this region improved to some extent, although ozone concentrations remain high, and have continued to show an upward trend.

Yet, as the economy is expected to grow further, so is the scale and complexity of air pollution in Guangdong

Nevertheless, since the economy is expected to keep growing, the scale and complexity of air pollution in the PRD and throughout Guangdong will continue to grow. This will increase the harm to both the ecosystem and public health, and threaten the sustainable development of the region.

In order to better understand air quality in this region, Guangdong's current air quality management framework and practices will be reviewed in the next section. This part summarises the current framework and practices of air quality management in Guangdong Province.

2.2 Air Quality Management Agencies

In the last few years, China's national and provincial environmental protection agencies underwent a series of reform to reflect their growing importance

Growing public and government concern has led to substantial reform of China's environmental protection agencies. In 2008, the Congress of the People's Republic of China upgraded the State Environmental Protection Administration to become the Ministry of Environmental Protection (MEP),⁷ reflecting the importance of environmental protection in social and economic development. Guangdong's Environmental Protection Agency was correspondingly upgraded to become the Guangdong Environmental Protection Department (GDEPD) in 2009. GDEPD is responsible for implementing both national and provincial policies and regulations for environmental protection. It drafts local laws and regulations, supervises pollution control and coordinates the solutions to various environmental problems.⁸ Figure 2 shows the organisational structure of the GDEPD.

Under Guangdong Environmental Protection Department, the Atmospheric Environment and Waste Management Division is responsible for air quality management, supported by other divisions and units

Under GDEPD, the Atmospheric Environment and Waste Management Division is responsible for air quality management. Its terms of reference include drafting and supervising laws and regulations for air pollution and solid waste control, drawing up environmental protection programmes, implementing environmental management practices such as vehicle labeling systems, and setting vehicle emission standards. Other institutions directly affiliated to the GDEPD include the Guangdong Environmental Monitoring Centre and the Regional Atmospheric Environmental Research Centre (RAERC).

Each city also has its own management institutions whose duty is to implement the air quality targets and control measures set by the provincial agencies.

Given the breadth of air quality management, other departments are also involved

However, since air quality management involves a wide range of economic and social development issues, part of the work is handled by other departments. For example, the Guangdong Development and Reform Commission has responsibility for climate change issues, formulating policy for the environmental protection industry and energy restructuring. The Meteorological Bureau is responsible for monitoring the influence of weather on air pollution.

2.3 Air Quality Management Mechanisms

Guangdong used to take the 'command and control' approach to manage air quality. Co-prevention and co-control strategies are emerging due to complexity of the issue

Guangdong historically employed a 'command and control' approach to air quality management. However, it has become increasingly difficult to create measures that cost-effectively address the severity and complexity of the region's air pollution while maintaining the sustainable growth of economy. Taking advantage of the frequent communications between the PRDEZ and Hong Kong, Guangdong is pioneering new strategies for region-wide co-prevention and co-control of multiple pollutants by multiple cities.

Groundbreaking research also supports policy formulation and implementation

Groundbreaking studies conducted in the PRD continue to provide strong scientific support for the formulation and implementation of air quality management policies. Figure 2 outlines the air quality management mechanism in Guangdong.

GDEPD executes national laws and regulations related to air quality management. It is also responsible for local laws and regulations to address local air pollution issues

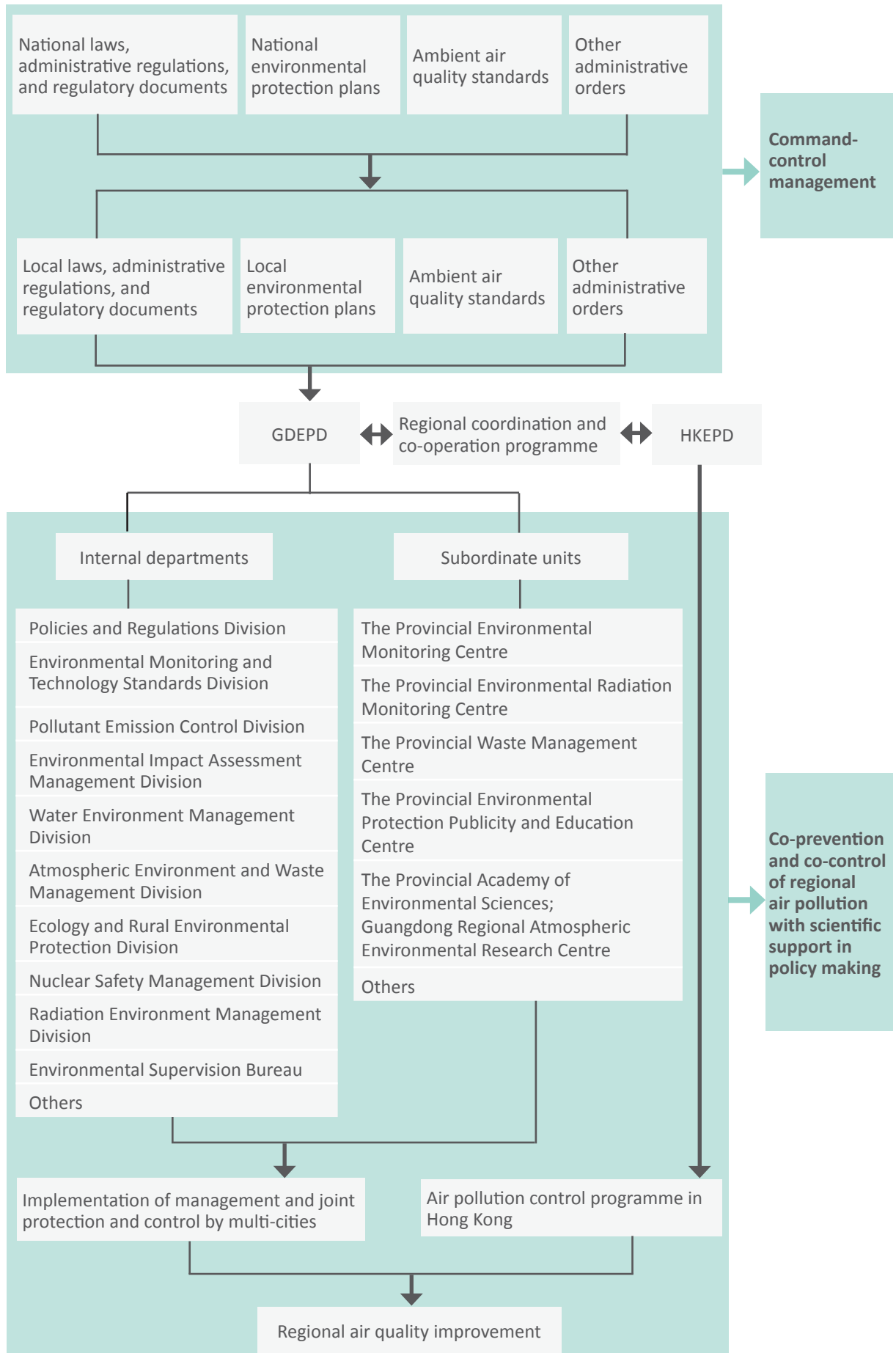
2.3.1 Traditional 'command and control'

GDEPD is responsible for executing the national laws and regulations associated with air quality management. It also drafts local laws, regulations and documents to address local pollution issues. These come into force upon approval by the People's Congress of Guangdong Province (PCGD) or the People's Government of Guangdong Province. For example, the PGCD approved and is responsible for implementing the Guangdong Vehicle Exhaust Pollution Prevention and Control Regulation - the local implementation of the national level Atmospheric Pollution Prevention Act (APPA) and the corresponding laws and regulations.

Guangdong's Environmental Protection Plan, produced every five years, includes emission reduction measures that help Guangdong meet major national targets

Guangdong's Environmental Protection Plan (EPP), an important part of the 'command and control' management system is produced every five years. GDEPD prepares the EPP to meet the major national pollution reduction targets in the MEP's Five-year Plan on Environmental Protection. This includes plans for achieving reductions in SO₂, NO_x, and particulate emissions, and for ensuring that non-attainment days do not exceed the prescribed limits. The local government's ability to meet these targets plays an important role in evaluating their management performance. Guangdong's *Twelfth Five-year Plan for Environmental Protection and Ecological Construction (2010-2015)* requires that by 2015, the air quality for over 95% of days in a year should be better than the National Standard II. SO₂ and NO_x emissions should also meet the national emission reduction limits.⁹

Figure 2: Outline of air quality management framework in Guangdong Province



National Ambient Air Quality Standards were updated in early 2013. With the new standards, urban air quality attainment rate drops in PRD, creating greater motivation to improve air quality

National Ambient Air Quality Standards provide an essential reference for local governments and the public to evaluate air quality. In early 2012, China updated the National Ambient Air Quality Standards by adding the average concentration limits for PM_{2.5} and O₃ (eight-hour average) and tightening the concentration limits for PM₁₀.¹⁰ The new standards have been implemented in the PRD and will be extended to the entire country by 2016. In response, GDEPD began to release hourly pollution concentration data, including PM_{2.5}, making the PRD region the first city-cluster in China to regularly release such data. The introduction of the new standards will see the urban air quality attainment rate in the PRD region drop by 10% to 30%, creating greater motivation to improve air quality.¹¹

Guangdong pioneered co-prevention and co-control of regional air pollution, with Hong Kong as a partner

2.3.2 Co-prevention and co-control of regional air pollution

Guangdong pioneered the co-prevention and co-control of regional air pollution in China. Considerable effort has been made to develop coordination and co-operation mechanisms for multi-pollutant control between Guangdong and Hong Kong, as well as between cities in Guangdong Province (Box 1).

Air pollution emerged as a regional and cross-border problem that accompanied the rapid economic development of the PRD region in the late 1980s and early 1990s. In 1990, the governments of Guangdong and Hong Kong set up the Hong Kong-Guangdong Environmental Protection Liaison Group (the Liaison Group).

Hong Kong/Guangdong Joint Conference was held annually since 1998. Joint study on regional air quality was started

Since 1998, the Hong Kong/Guangdong Joint Conference (the Joint Conference) has been held every year to discuss a series of important issues including environmental protection. The Joint Conference underlines the importance to both governments of improving the environment and marks a new determination to combat cross-boundary air pollution (as both parties share a common airshed).

In the second Joint Conference in 1998, the two governments reached a consensus to investigate regional air quality. The subsequent joint study made clear that the extensive pollution in the region could not be mitigated effectively with existing single pollutant control measures, given the expected economic and population growth rates.

The Hong Kong/Guangdong Joint Working Group was established in 2000, with an expert group that focuses on air quality improvement

In 2000 the Hong Kong/Guangdong Joint Working Group on Sustainable Development and Environmental Protection (JWGSDEP) was also established. It was co-chaired by the Director of GDEPD and the Secretary for the Environment and Food of the Hong Kong Special Administrative Region (HKSAR) Government, and included officials from both governments responsible for environmental protection, land use, transport, construction, trade and economy. The JWGSDEP set up an expert group to draw up annual work plans and coordinate

discussions on specific issues related to air quality improvement and other issues.

Emission reduction targets for Guangdong and Hong Kong by 2010 were agreed. The PRD Regional Air Quality Management Plan was drawn up to meet the targets. Other collaborations continue to follow

In April 2002, Hong Kong and Guangdong agreed to reduce by 2010 the regional emissions of NO_x, SO₂, VOC and PM₁₀ by 20%, 40%, 55%, and 55%, respectively, using 1997 as the base year. In December 2003, the JWGSDEP drew up the *Pearl River Delta Regional Air Quality Management Plan (2002-2010)* (the Management Plan) to implement these targets. The Special Panel on PRD Air Quality Management and Monitoring was set up to review and report on the implementation process to the JWGSDEP Expert Group. In addition to a programme of abatement and control measures, the Management Plan led to the establishment of the PRD Regional Air Quality Monitoring Network in 2005 and an *Air Emission Inventory Handbook* for the PRD Region in 2006. Further co-operation has been achieved through the implementation of the Cleaner Production Partnership Programme and, since 2010, the joint development of the *Regional Co-operation Plan on Building a Quality Living Area*.

Box 1: Multi-city co-operation in Guangdong

In addition to the co-operation between Guangdong and Hong Kong, efforts were also made to enhance coordination of air quality management between different cities in Guangdong. 'The Pearl River Delta Regional Air Pollution Prevention and Control Joint Conference' was established during China's Eleventh Five-year Plan (2005-2010) to coordinate the joint pollution reduction efforts by multiple cities on multiple pollutants. This meeting, chaired by the Vice-Governor responsible for environmental issues in Guangdong, brought together the deputy mayors of the cities and other authorities from associated agencies. This Conference developed the air quality control measures for the Guangzhou 2010 Asian Games and Shenzhen 2011 Universiade.

Additional measures included the following:

- May 2009: Guangdong Pearl River Delta Regional Air Pollution Regulation and Control Measures enacted.
- February 2010: Guangdong Pearl River Delta Region Clean Air Act enacted.
- June 2010: National IV Standards for Vehicles first adopted in the PRD region.

Regional co-prevention and co-control between Guangdong and Hong Kong has been recognised as a national policy

Looking ahead, further regional co-prevention and co-control actions have been proposed to improve air quality as the region continues to develop. Under the *Outline of the Plan for the Reform and Development of the PRD*,¹² which specifies Hong Kong/Guangdong co-operation as a national policy, both governments began a new round of regional co-operation. This

included the signing of the *Framework Agreement on Hong Kong/Guangdong Co-operation on Environmental Protection and Ecology Conservation (2011-2020)*.¹³ The Framework Agreement covers a number of measures to reduce air pollution from a range of sources, including those from ocean-going vessels and river traffic.

In Guangdong, the RAERC included air quality management goals and strategies to strengthen joint prevention and control in the *Twelfth Five-year Plan of Co-prevention and Co-control of Air Pollution in the PRD region (2011-2015)*.

Evidence-based policy formulation is important to the effective management of air quality in PRD

2.3.3 Evidence-based policy formulation

Traditional command and control policies can be effective in reducing emissions of primary pollutants such as SO₂. Given the complexities of managing air quality in the PRD, the need for sound scientific support to formulate effective and affordable air quality management strategies is urgent. In the last decade, investigation of regional air pollution, the establishment of scientific bodies to support decision-making and the establishment of the PRD Regional Monitoring Network have created the foundation for a three-part management mechanism: 'Scientific Study - Policy Making - Policy Implementation'.

Research studies were initiated and scientific bodies were set up

a) Research studies and scientific bodies

With a view to develop effective control strategies, the National, Guangdong and Hong Kong governments have initiated a series of scientific studies, bringing together scientists and scholars from the Mainland, Hong Kong and overseas to formulate new techniques for tackling the PRD's regional air pollution problems. The major scientific activities and supporting policy initiatives are summarised in Table 1.

For example, the PRD Air Quality Special Panel was set up to study the causes of air pollution in the region and to recommend solutions

The Pearl River Delta Region Air Quality Special Panel (Special Panel) under the JWGSDEP and the RAERC are two scientific think tanks working on environmental policy formulation. The JWGSDEP Special Panel was established in 2000. Its first task was the *Study on the Air Quality in the Pearl River Delta Region*. Its responsibilities included identifying the causes of air pollution problems, exploring and recommending effective emission reduction measures, reporting the findings and making recommendations to the Expert Group under the JWGSDEP.

Regional Atmospheric Environmental Research Centre was set up to provide scientific support...

The RAERC was established in 2010 to provide scientific support to the Pearl River Delta Regional Air Pollution Prevention and Control Joint Conference in Guangdong Province. It is responsible for:

- Development and update of dynamic PRD air pollutant emission inventory and database systems;
- Investigation and management of the PRD Regional Monitoring Network;
- Application of reliable regional air quality modeling and decision modeling;
- Air quality forecasting and warning;
- Investigation and recommendation of multi-cities emission reduction plans; and
- Evaluation of the effectiveness of control policies.

... for examples, to the
Guangzhou Asian Games and
Shenzhen Universiade

During the Guangzhou Asian Games and Shenzhen Universiade, the RAERC provided solid scientific support to formulate short- and long-term air pollution mitigation strategies, release air quality forecast and warning information, and organise consultations with the special expert groups for the Asian Games and the Universiade.

The RAERC emphasises the importance of science in policy formulation. It drew up the final assessment of the *PRD Regional Air Quality Management Plan (2002-2010)*, the emission reduction plans for the *Framework Agreement on Hong Kong/Guangdong Co-operation on Environmental Protection and Ecology Conservation (2011-2020)* and the *Twelfth Five-year Plan of Co-prevention and Co-control of Air Pollution in PRD region (2011-2015)*.

Table 1: Major scientific projects on air quality management in the PRD region during the recent decade and the supports for policy making

Time	Projects	Study Tasks	Support for Policy Making
1999-2002	Study on the Air Quality in the PRD Region (Guangdong/Hong Kong Co-operation)	Concentrations and temporal and spatial distributions of SO ₂ , NO _x , PM ₁₀ , PM _{2.5} , O ₃ in the PRD region; the effects of NO _x , VOC on photochemical smog.	Preliminary characterisation of regional air quality issues led to <i>Joint Statement of Emission Reduction and the Pearl River Delta Regional Air Quality Management Plan (2002-2010)</i> .
2003-2005	Feasibility Study on the Regional Air Quality Monitoring Network in the PRD Region (Guangdong/Hong Kong Co-operation)	The plan for the regional monitoring network, including optimization of monitoring locations, selection and integration of monitoring technologies, developing the regional air quality index (RAQI) and establishing the quality assurance/quality control mechanism.	Supporting the establishment of the PRD regional air quality monitoring network which was put into service on 30 November 2005 and issued RAQI to the public in Guangdong and Hong Kong.
2006	Development of Regional Air Pollutant Emission Inventory in the PRD Region (Guangdong/Hong Kong Co-operation)	To unify the development procedures of air pollutant emission inventory and the quality assurance system in Hong Kong and Guangdong.	Compiling the <i>Emission Inventory Handbook for Air Pollutants in the Pearl River Delta Region</i> providing the basis for the quantitative evaluations of effectiveness of emission reduction measures.
2006-2007	Study on the Mid-term Review of the Air Quality Management Plan (Guangdong/Hong Kong Co-operation)	To estimate the SO ₂ , NO _x , PM ₁₀ and VOC emissions and investigate the emission trends based on the <i>Joint Statement of Emission Reduction</i> and to evaluate the effectiveness of the established measures.	Providing recommendation and control measures for meeting emission reduction targets by 2010.
2003-2008	Tridimensional observations and contamination process of the regional integrated air pollution (National Basic Research and Development 973 Programmes of China)	The structure of the boundary layers along with the atmospheric diffusion conditions and their relationships with atmospheric pollution, the formation mechanism and influence factors of photochemical smog, the physical-chemical-photochemical properties of fine particles and the major sources of ozone, fine particles and their precursors (NO _x and VOC).	Supporting the issue and implementation of the <i>Pearl River Delta Environmental Plan on Air Pollution Control Programme</i> (Approved by the People's Congress of Guangdong Province in 2004); Proposing control strategies for the air pollution complex in the PRD region (especially photochemical smog).

Time		Projects	Study Tasks	Support for Policy Making
2007-2010	Study on the Key Industrial Air Pollution Sources in the Pearl River Delta Region (Guangdong/Hong Kong Co-operation)	The first large-scale field investigation and monitoring of industrial air pollution sources in the PRD region. Study of the best available control technologies for industrial air pollution sources and for controlling typical industrial VOC sources.	Providing technical support for governments to formulate control measures for key industrial air pollution sources under the background of industrial restructuring.	
2007-2010	Study on VOC and Photochemical Ozone Pollution in the Pearl River Delta Region (Guangdong/Hong Kong Co-operation)	Collecting the VOC and OVOC samples in 80 grid squares in the PRD region to characterise the emission sources and spatial distributions of VOC and OVOC, and to investigate photochemical smog formation mechanisms.	Proposing measures and strategies to combat regional smog pollution based upon investigation of photochemical smog precursors and formation mechanisms.	
2006-2011	Synthesised Prevention Techniques for Air Pollution Complex and Integrated Demonstration in Key City-Cluster Region (National 863 Key High-Tech Scientific Programmes of China)	Developing on-line monitoring technologies for multiple major air pollutants, developing control technologies for NO _x from middle or small size-boilers and of VOC control technologies, developing regional dynamic air pollutant inventory technologies, establishing 3D-regional air quality monitoring networks, developing the multi-models assemble regional air quality forecasting system.	Providing direct support for the air quality assurance measures and air quality forecasting during the Guangzhou Asia Games; Promoting the implementation of the clean air action plan in the PRD region and the operation of the Guangdong Regional Atmospheric Environmental Research Centre.	

PRD Regional Air Quality Monitoring Network was established and upgraded to provide long-term data for effective control

b) PRD Regional Air Quality Monitoring Network

A regional monitoring network with large spatial coverage and consistently accurate air quality data provide the foundation for scientific research. Between 2003 and 2005, Guangdong and Hong Kong jointly established the first regional air quality monitoring network in China. The PRD Regional Air Quality Monitoring Network consists of thirteen stations in Guangdong and three stations in Hong Kong. There are two background stations in Guangzhou and Hong Kong, and fourteen urban or sub-urban monitoring stations. The network was further upgraded between 2006 and 2011 by adding real-time monitoring of multiple pollutants such as SO₂, NO₂, O₃, CO, PM₁₀ and PM_{2.5}, along with three-dimensional observation by 'Ground monitoring - Radar detection - Satellite remote sensing'. The network provides long-term data, which is used to monitor air quality, identify potential air pollution events, and evaluate the effectiveness of control measures. Data from this network has supported a number of important scientific studies, such as the National '863' and '973' programmes.

2.4 Air Pollution Control Measures

A series of control policies and measures have been rolled out to combat regional air pollution, covering sources such as power plants, the industrial sector, vehicles, and other VOC-related activities

Guangdong has formulated and issued a series of control policies and measures to combat regional air pollution. The major sources requiring control measures include power plants, the industrial sector, motor vehicles, and VOC-related emission sources. The main control measures implemented during 2000-2011 are summarised as follows:

- (a) Power plants
 - Prioritising the development of power generation by hydroelectric, nuclear and natural gas;
 - Active sourcing of hydroelectric power from the southwest of China;
 - Phasing out small thermal power generation units and developing large-scale units;
 - Banning development of new coal-fired or fossil fuel-fired power plants;
 - Reducing the sulphur content in fuels; and
 - Constructing desulfuration and denitrification facilities.
- (b) Industrial sector
 - Phasing out small-scale cement, metallurgy and casting plants;
 - Phasing out industrial coal boiler of less than four tonne/hour, or ten tonne/hour in use for more than eight years;

- Forbidding new cement plants, ceramics factories and glassworks;
- Installing particulate matter control devices for cement plants and industrial boilers; and
- Upgrading air pollutant emission standards for boilers.

(c) Motor vehicle sources

- Upgrading motor vehicle emission standards: National I, II, III, IV standards were introduced for all new vehicles in the PRD region in 2000, 2005, 2008, and 2010, respectively;
- Introducing an inspection and maintenance (I/M) programme for in-use vehicles and encouraging the phasing-out of high emitting vehicles;
- Establishing and implementing vehicle labeling systems for in-use vehicles;
- Enforcing strictly the vehicle scrapping system;
- Restricting the driving of motorcycles within urban areas;
- Improving the quality of vehicle fuel and promoting the use of unleaded petrol;
- Encouraging green public transportation such as electric and gas-powered cars, and constructing inter-city light-rail transportation; and
- Constructing urban intelligent transportation systems.

(d) VOC-related emission sources

- Promoting the use of hermetically-sealed gas recovery facilities for filling stations, main oil storage tanks and new fuel trucks;
- Phasing-out high-VOC products and promotion of low-VOC products;
- Controlling VOC emissions from the chemical and petrochemical industry, the automobile industry and garages, furniture and shoe manufacturers, the printing industry, electronic goods manufacturers and the textile dyeing industry;
- Controlling VOC emissions from commercial and domestic solvents such as dry cleaning agents;
- Establishing VOC emission control standards for typical VOC-related industries; and
- Enhancing the attainment and management of emission standards and control targets.

(e) Other important emission sources

- Adjusting the domestic fuel structure and promoting the use of cleaner energy (e.g. natural gas, coal gas, LPG and electricity);

- Enhancing the pollution management of cooking emissions from the catering trade (by using cleaner energy, e.g. electricity, natural gas and LPG; installing cooking emissions scrubbers and flues);
- Strengthening controls on dust from road and buildings construction;
- Controlling emissions from the combustion of waste and biomass and prohibiting the reclamation of metals by open burning;
- Reinforcing the control of emissions from vessels, ports, construction sites, and garden and agricultural machinery, and promoting the use of low-sulphur diesel;
- Establishing the regional air quality monitoring network system, the haze monitoring, forecasting and warning system and the air pollution alarm (e.g. ozone concentration) system, and on-line monitoring network for major emission sources; and
- Monitoring and controlling emissions of ammonia from the use of chemical fertilizers, mercury emissions from coal combustion and controlling other toxic or harmful substances.

2.5 Air Quality Improvement

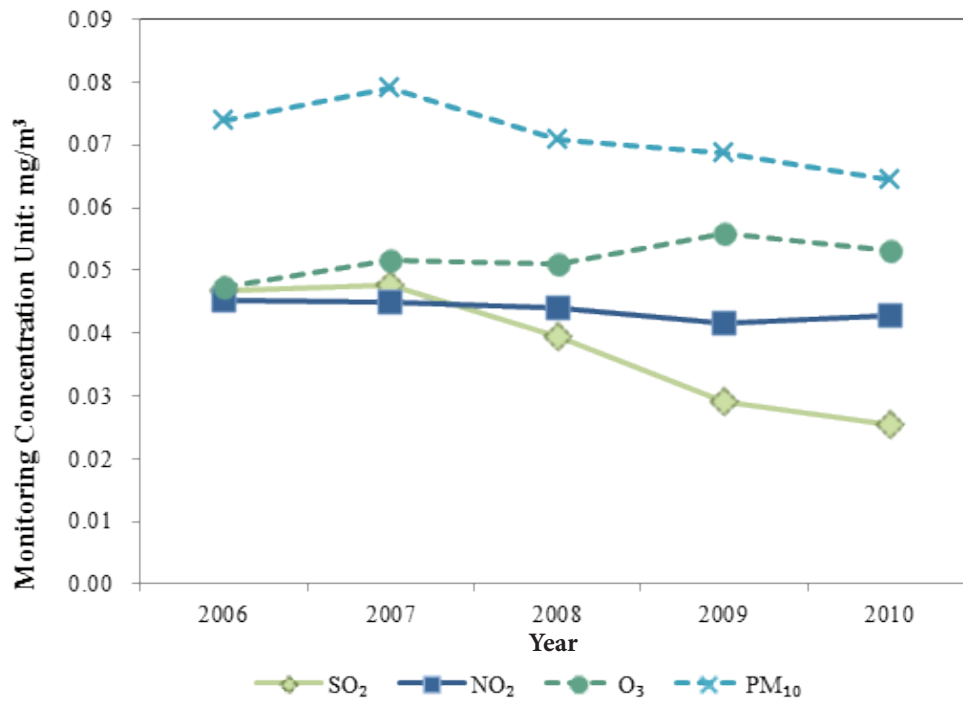
Deterioration of air quality has been slowed down, despite rapid economic development in the region

In the first PRD regional study on air quality (1999-2002), results indicated that large increases in SO₂, NO_x, VOC and PM₁₀ emissions would be expected owing to predicted economic and population growth, leading to deteriorating air quality in the whole region. Efforts have been made to establish an air quality management mechanism, and to explore and implement sufficient control measures to reduce pollution. These efforts slowed the predicted deterioration of air quality and regional air quality improved to some extent, despite the rapid rate of economic development.

Annual concentrations of SO₂ and PM₁₀ decreased most significantly. NO₂ remains constant. O₃ shows an upward trend

Figure 3 shows the concentrations of major pollutants in the PRD from 2006 to 2010, according to monitoring data collected from the PRD Regional Air Monitoring Network.¹⁴ Annual concentrations of SO₂ and PM₁₀ decreased most significantly, especially after 2007. Concentrations of SO₂ and PM₁₀ in 2010 decreased by 46% and 13% in comparison to 2006 levels. The significant decrease can be attributed principally to the implementation of desulphurisation and dust removal in power plants and the industrial sector during the *Eleventh Five-year Plan (2006-2010)*. Concentrations of NO₂ kept relatively steady, while O₃ showed an upward trend. The air quality control measures taken during the Guangzhou Asian Games and the Shenzhen Universiade delivered impressive blue skies and much improved air quality, and serve as two important examples of successful air quality management and improvement in Guangdong.

Figure 3: Trends in concentrations of major air pollutants in the PRD region from 2006 to 2010



Secondary pollutants will remain a major challenge in the coming decades

In summary, the concentrations of some primary pollutants in Guangdong (such as SO₂) show a declining trend, but the concentrations of some other primary and secondary pollutants still remain at relatively high levels. Although the control of primary air pollutants has proven effective to some degree, Guangdong still faces the more serious challenge of controlling secondary pollutants in the coming decade.

Lessons for Air Quality Management in Guangdong from the Experience of California Air Resources Board

CARB is an autonomous science-driven agency that manages air quality in California

CARB has a full-time chairperson and other board members drawing from disciplines related to air quality management

CARB has eleven divisions overseeing areas such as law and regulation, enforcement, emission sources, research, and technical supports

3.1 Air Quality Management in California

CARB is an autonomous science-driven agency that manages air quality in the State of California. It aims to promote and protect public health, welfare and ecological resources through the effective and efficient control of air pollution, while taking into account the effects on the economy of the State. The CARB has the authority to enact legally enforceable air quality management regulations.

The CARB's eleven board members, appointed by the governor with the consent of the State Senate, are drawn from various fields related to air quality management. These include medicine, chemistry, engineering, physics, business, and law. The chairperson is the only full-time member. The board members meet monthly at various locations in the State. These meetings are open to the general public, and may receive comments and observations from interested parties.

CARB has eleven divisions:

- **The Office of Legal Affairs** oversees enforcement of air pollution laws, CARB administration, board administration and regulatory coordination;
- **The Research Division** gathers scientific information regarding the causes and effects of air pollution, and develops technologies and solutions that protect public health from the effects of air pollution;
- **The Enforcement Division** handles enforcement of air pollution laws, and provides training and compliance assistance;
- **The Stationary Source Division** regulates and monitors motor vehicle fuels, toxic pollutants in consumer products, and pollution from stationary sources such as refineries and power plants;

- **The Mobile Source Operations and Control Divisions** develop statewide programmes and strategies to reduce smog-forming pollutants and toxics by mobile sources, including passenger cars, motorcycles, trucks, buses, heavy-duty construction equipment, recreational vehicles, marine vessels, lawn and garden equipment, and small utility engines;
- **The Planning and Technical Support Division** coordinates statewide development of clean air plans and pollution control strategies to improve air quality;
- **The Office of Information Services** provides information and internet systems management;
- **The Office of Climate Change** provides climate change programme planning, development, and management;
- **The Monitoring and Laboratory Division** provides accurate air quality measurements and tracks air quality trends in California; and
- **The Administrative Service Division** manages a variety of services, including finances, human resources, accounting, labour relations, contractors and others.

CARB has developed strict laws and standards, a proactive compliance monitoring programme, and a clear penalty system

CARB has led efforts to improve air quality in California for several decades. It has developed, implemented and enforced strict air quality laws and standards, and has developed regulations for vehicles, factories, ships, consumer products and others under the California Air Pollution Controls Law. It has a highly proactive compliance monitoring programme, and penalties for failure to comply with these regulations are clearly defined. One unusual provision is that enterprises may report their competitors to CARB for non-compliance.

CARB's achievements can be attributed to its clearly defined functions, strict enforcement of regulations, and scientific support for policies

CARB has achieved considerable success in improving air quality. This can be attributed to the following:

- Clearly defined authority in enacting and implementing air quality management law and regulations;
- The strict enforcement of relevant air pollution control laws or regulations; and
- Scientific support for air pollution control policies.

Further details about the CARB can be found on its website at: <http://www.arb.ca.gov/homepage.htm>.

3.2 Why Guangdong Can and Should Learn from CARB

In 2010, California contributed over 13% of the United States' national GDP. Sprawling has led to population growth and motorisation, which in turn causes severe air pollution problem

Yet, CARB managed to improve California's air quality through carefully developed and rigorously implemented programmes

Guangdong's challenge is more acute. Despite the difference in political system and social development, Guangdong can learn from CARB

In 2010 California had a GDP of 1936.4 billion dollars, accounting for 13.34% of the nation's total GDP.¹⁵ After World War II, urban sprawl began in California. More people moved to the State, built homes and factories, bought cars and trucks, and began to construct freeways at an unprecedented rate. The population grew rapidly from 11 million in 1950 to about 37 million in 2010, while the number of registered vehicles grew almost eight times from 4.5 million to 35 million vehicles during the same period.¹⁶

This economic growth brought severe air pollution, including high concentrations of primary pollutants from stationary sources and motor vehicles, as well as high levels of secondary pollutants including ozone, PM_{2.5} and other contaminants.

However, CARB's carefully developed and rigorously implemented programme has brought about considerable improvement in California's air quality. This makes CARB's example a useful model to study for Guangdong, which is also trying to reduce emissions while the economy and the number of vehicles on the road continue to grow rapidly.

Guangdong's challenge is even more serious because of its much later start in air quality management, the higher growth rate and the much greater number of factories in a relatively small area. In spite of the differences in the political systems and the forms of social development, California's air quality management experience can be applicable to Guangdong. The key is for Guangdong to follow CARB's lead in proposing evidence-based policies and measures supported by scientific studies that are adapted to Guangdong's particular pollution characteristics.

3.3 Early and Pilot Implementation to Establish and Improve the Air Quality Management Law and Regulation System

Legislation is the foundation of all environmental protection measures

Independent legislative power allows California to set more stringent regulations than federal laws

Legislation is the foundation of all environmental protection measures. Air quality management requires the establishment of relevant policies and regulations with clear and executable objectives.

CARB is an independent state agency that reports directly to the US Environmental Protection Agency (USEPA) under the terms of the Clean Air Act (CAA). The CAA acknowledges California's severe pollution problems and has granted the State a waiver exempting it from federal laws, and allowing it to enact its own more stringent regulations instead. Independent

The legal frameworks for air quality management in China and Guangdong have to be optimised

legislative power ensures the autonomy of California in the development of air quality management. As a result, California generally sets the lead in air pollution control in the US.

There is a need to optimise legal frameworks for air quality management in China and Guangdong. The most important national law is the Atmospheric Pollution Prevention Act (APPA). However, since the APPA came into force on 1 September 2000, China's air pollution characteristics have tremendously changed. It is recommended that the following regulations and policies should be revised as a matter of urgency:

- The current penalties are so low that the cost of compliance with the law is much higher than the punishment for non-compliance;
- The regulations and control measures in different areas are sometimes independent of one another, which does not follow the spirit of regional co-prevention and co-control of regional air pollution; and
- Emission caps for motor vehicle pollution prevention and automotive fuel management lack strong legal support.

In Guangdong, GDEPD is authorised to draft regulations under the aegis of national legislation, which must be approved by the People's Congress of Guangdong Province (PCGD) before taking force across the Province.

Guangdong should become the national pioneer in air pollution control legislation. Improvements are required in areas such as law enforcement, compliance, standards, and information disclosure

Like California, Guangdong should become the national pioneer in establishing regulations in air pollution control legislation. Fundamental improvements required to underpin a robust air quality management framework include:

- Improving the basic principles of justice in environmental law enforcement (e.g. ensuring that compliance is not more costly than the penalties for non-compliance);
- Disclosing environmental information and increasing opportunities for public scrutiny;
- Increasing air quality compliance requirements, including setting up daily punishment thresholds;
- Implementing an emission permit system, and others;
- Establishing special regulations and policies in sectors whose emissions cause serious impacts on human health, for instance:
 - > The implementation of mandatory low sulphur fuel standards in marine vessels should be promoted as a matter of urgency;

- > Evidence-based VOC emission standards and technical specifications for key industries should also be released as early as possible;
- Environmental standards should be regularly updated to maximise their value as drivers of improved air quality management; and
- The newest information on health data, improvement in measurement techniques, and progress in atmospheric research, also need to be constantly adjusted and updated.

Regular review of environmental standards is also important

California's environmental standards are reviewed and adjusted every five years, but may be adjusted more often if required. These verified and adjusted standards often become the reference for regulators in other states. Guangdong was the first province to put the new Ambient Air Quality Standards into practice. It can secure its position as a leader in China through early attainment and regular updates of air quality standards.

3.4 Strengthening Enforcement of Environmental Law and Refining the Penalty Mechanism

Strong law enforcement is vital to air pollution control

Strong law enforcement also plays a vital role in air pollution control. China continues to experience a range of difficulties in environmental law enforcement. The expertise of environmental law enforcement staff is relatively weak, and greater collaboration with the public and the judiciary is essential. During the Asian Games, the 'iron-hand pollution control' and 'zero tolerance for environment pollution violation' measures proved to be very effective. However, a more general and sustained enforcement regime is still required to ensure the long-term effectiveness of environmental law enforcement.

There are two aspects to public participation. First, the public has the right to the best available information about the levels, sources and impacts of air pollution. Second, the public should be encouraged to challenge polluters in the courts.

CARB's enforcement mechanism is well-defined. China's approach, in contrast, is oversimplified

CARB's enforcement mechanism outlines a series of penalties and fines for offenders, ranging from first-time violations to repeated and intentional transgressions. By setting up different penalties for different circumstances, implementation is both more practical and more effective. In contrast, current China's approach to enforcement is oversimplified. Further study of CARB's mechanism would be useful for refining Guangdong's penalty system to take into account different classes of polluters (e.g. first and repeated violations).

3.5 Strengthening Regional Co-prevention and Co-control

Co-prevention and co-control are necessary within a common airshed

Since air pollution is not controlled by political boundaries, trying to control air within a single city cannot be effective. Rather, joint control and unified regional planning are necessary to improve air quality where multiple jurisdictions share a common airshed.

In US, interstate rules are in place to facilitate regional co-operation. In PRD, joint effort is in the early stage, and capacity building is important to support science-based policy formulation

In 2005, the USEPA released the Clean Air Interstate Rules in order to better control the transport of air pollutant emissions between states. Regional offices were set up to address the problem, mainly through setting emission caps and emission trading. In the PRD, joint prevention and control has had some early success, but it is important to build capacity to support science-based regional co-control policy formulation, implementation and evaluation. This should be done through national-level approval of the *Instructions for promoting the co-prevention and co-control of air pollution to improve regional air quality*. Additional administrative and economic measures are also required to reinforce and promote joint prevention and control efforts in the PRD region. These should be explicit enough to specify and monitor the responsibilities of individual cities. In the meantime, unified models for air quality planning and monitoring and unified assessment and evaluation mechanisms for co-prevention and co-control of regional air pollution should be established as soon as possible.

3.6 Improving Support for Science-based Policy Making

CARB attaches great importance to scientific research and collaboration with experts

CARB attaches great importance to scientific research and collaboration with experts. Scientific evidence underpins the formulation of air quality management and policies, and determines the optimal timing for putting new regulations into effect. In Guangdong, the RAERC and the expert panel attached to the JWGSDEP provide key scientific support to decision makers. Their expertise is supported by the evidence from successful past projects.

Guangdong should encourage scientific collaboration and academic exchanges to support decision makers

Learning from the experience of the CARB, Guangdong should encourage close collaboration between domestic scientists and provide support for international academic exchanges and co-operation.

On-going study of regional photochemical smog, acid rain and haze formation and the associated atmospheric transport mechanisms, and how these are influenced by changing energy and economic structures and improved pollution controls is essential. This will provide a solid scientific foundation for the sustained and steady improvement of regional air quality.

The size and capacity of the RAERC need to be strengthened through further scientific training. It would also be highly beneficial to establish an international expert panel consisting of scientists and academic scholars from a range of disciplines. In the meantime, the expert panel should play a more prominent role in pollution control policy formation and decision-making.

3.7 Enhancing Co-control of Multiple Pollutants

Atmospheric chemistry is complex. Control of one pollutant may lead to the rise in concentration of another pollutant

The complex atmospheric chemistry and interactions among the atmospheric pollutants may cause policies that control one pollutant to reduce or elevate the concentration of another pollutant. For instance, the formation of photochemical smog is related to NO_x and VOCs, but often appears to be non-linear. Therefore, there is a need to develop integrated multi-pollutant control measures.

For example, control of VOC or NO_x may lead to elevated O_3 concentrations

Disproportional control of VOC or NO_x emissions may lead to elevated ozone concentrations, which typically occurs when VOC or NO_x are limited. This phenomenon has already been observed in the PRD region. In recent years a slight upward trend in ozone concentration has been attributed to a lack of strict VOC emission control measures.

CARB's experience shows that co-control of multiple pollutants has to be implemented

In the early 1970s, CARB initiated emissions control strategies for the concurrent and continuing reductions of NO_x and VOC from mobile sources and consumer solvents, as well as other stationary and area sources. From 1975 to 2000, the peak O_3 levels in Los Angeles fell by more than 60%, and the number of smog alerts decreased. Most significantly, these improvements occurred as the population increased by 50% and vehicle miles increased by 93%.¹⁷

Same idea was introduced in Guangdong, but more research is needed to determine better multi-pollutant co-control measures

The idea of co-control of multi-pollutants was introduced into Guangdong in 2002, when Guangdong and Hong Kong jointly proposed to reduce NO_x and VOC emissions at the ratio of four to eleven. This has helped to improve regional air quality, but further studies are still needed to determine proper multi-pollutant co-control measures, including greenhouse gases, in the next five or ten years.

CARB's success in improving California's air quality while maintaining a sustained level of economic growth is not a coincidence. It has been a decades-long process that requires a vision, dedication, commitment and self-reflection. Specifically, it is achieved through setting high standards over many decades to drive improvement, rolling out well-thought plans to cut emissions, devising proactive programmes for implementation and enforcement, encouraging scientific research and collaboration to support policy making, and maintaining a regional, multi-pollutant approach in air quality management.

CARB's achievement makes it an attractive model for Guangdong, who is already a pioneer in air quality management in China, but the pressure to deliver national and provincial emissions reduction targets is ever-growing. In this paper, it is explained that Guangdong can learn valuable lessons from the CARB in areas such as legal framework, enforcement mechanism, co-control policy, science and research development, as well as multi-pollutant strategies. It may take years, or even decades, to develop a regional air quality management framework in Guangdong similar to CARB's, but it is anticipated that such framework will bring enormous benefits to Guangdong in terms of air quality improvement, and also to other regions in China with respect to regional air quality management experience. In the same airshed, Hong Kong will be a key partner and a main beneficiary in this important journey.

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