Environmental Protection Department

Agreement No. CE57/2006 (EP) Review of the Air Quality Objectives and Development of a Long Term Air Quality Strategy for Hong Kong - Feasibility Study

Final Report

Executive Summary

ARUP

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Executive Summary

July 2009

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Executive Summary

Background

The Environmental Protection Department (EPD) has commissioned Arup in June 2007 to carry out this study (hereafter referred to as "the Study") to review the Hong Kong Air Quality Objectives (AQO) and develop a long term air quality strategy for Hong Kong, in response to the release of a new set of Air Quality Guidelines (AQG) and interim targets (IT) by the World Health Organization (WHO) on 5 October 2006 for global application.

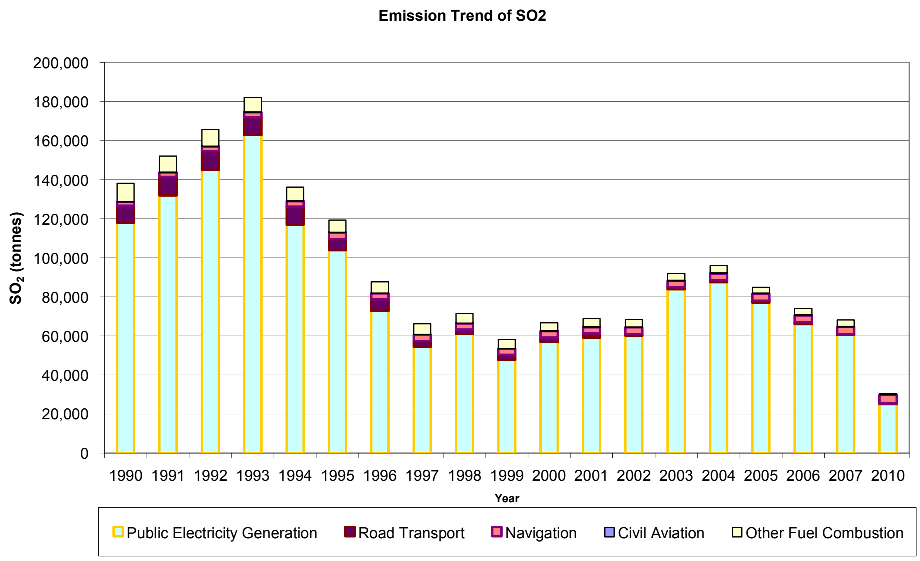
Current Legislative Framework in Hong Kong

The Air Pollution Control Ordinance (APCO, Cap 311) is the principal law for managing air quality. Under the APCO, a set of AQO was established in 1987 for 7 air pollutants, i.e. sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), lead (Pb), total suspended particulates (TSP) and respirable suspended particulates (PM_{10} or RSP) for promoting the conservation and best use of air in the public interest. Protection of public health is therefore a key consideration in updating the AQO because to do otherwise will not be in "public interest". The APCO also requires the Government to aim at achieving the AQO as soon as practicable and thereafter to maintain the quality so achieved. To do so, compliance with the AQO is pre-requisite for the issuance of specified process permits under APCO to specified processes such as power generation for their operation or environmental permits under the Environmental Impact Assessment Ordinance (EIAO, Cap 499) to allow designated projects (i.e. projects that have adverse impacts on the environment) to proceed.

Current State of Air Quality in Hong Kong

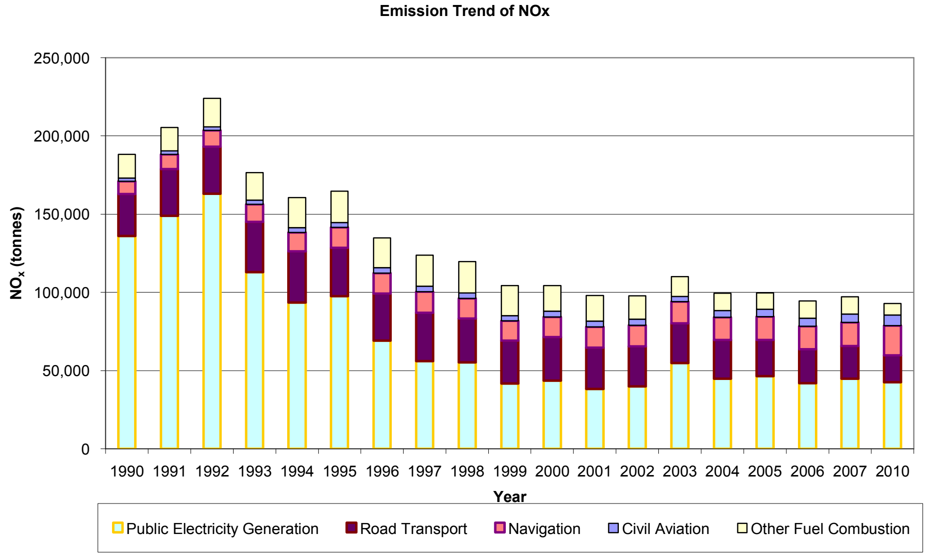
The Government has been stepping up its efforts since the early 90s to improve air quality. Up to 2007, emissions of key pollutants such as SO_2, NO_X, PM_{10}, non-methane volatile organic compounds (VOC) and CO have fallen by 43% to 63% from their peaks (within 1990 to 2007). **Figures E.1** to **E.5** show the emission trends of SO_2, NO_X, PM, VOC and CO from 1990 to 2007 and the projected emissions in 2010.

Figure E.1: Emission trend of SO_2 in HKSAR



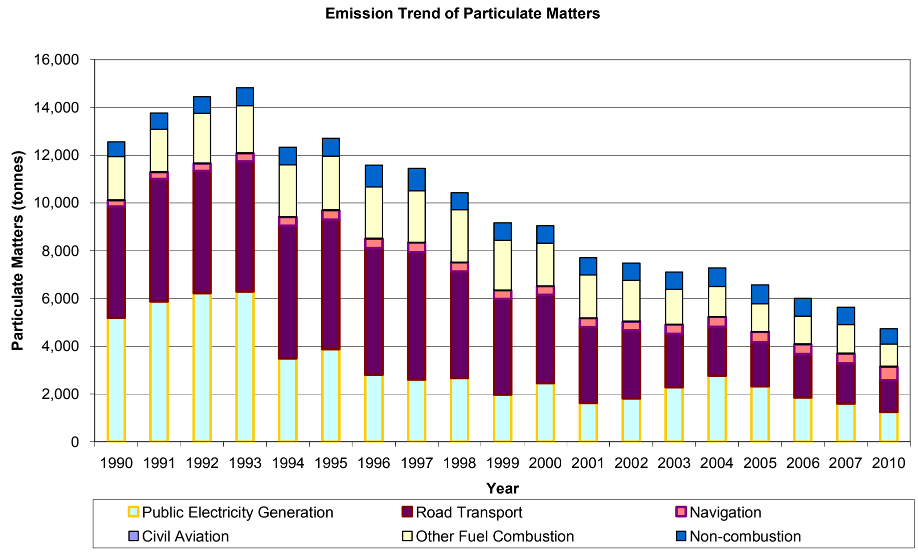
[Note: Emissions in 2010 are projected figures]

Figure E.2: Emission trend of NO_X in HKSAR



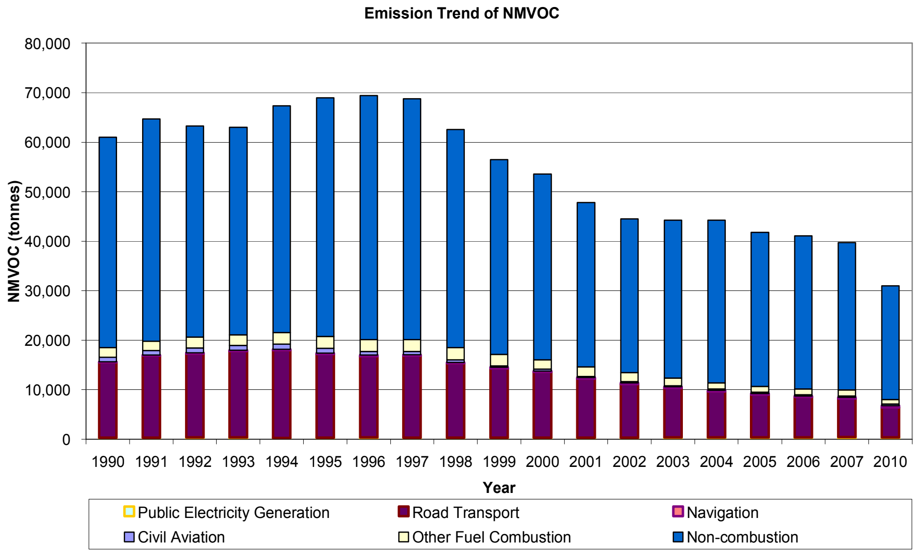
[Note: Emissions in 2010 are projected figures]

Figure E.3: Emission trend of PM in HKSAR



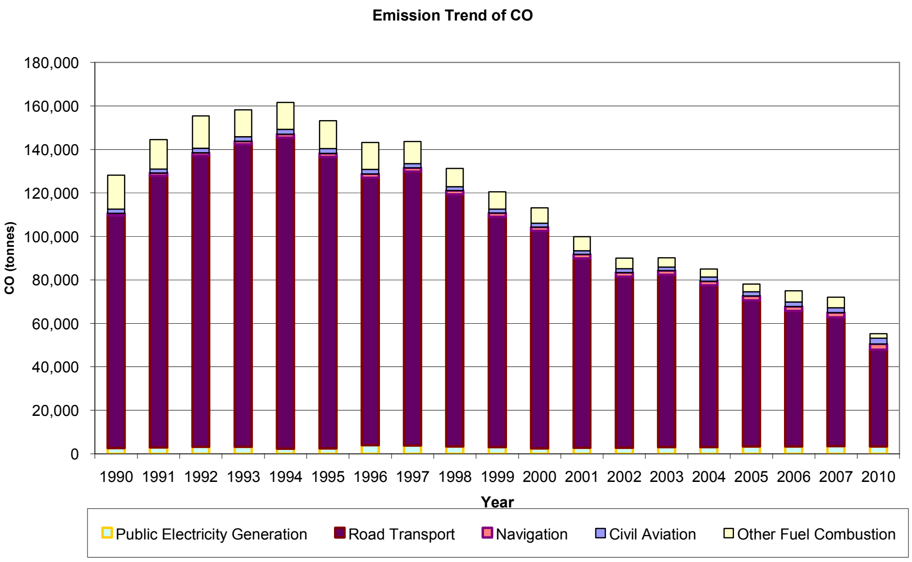
[Note: Emissions in 2010 are projected figures]

Figure E.4: Emission trend of NMVOC in HKSAR



[Note: Emissions in 2010 are projected figures]

Figure E.5: Emission trend of CO in HKSAR



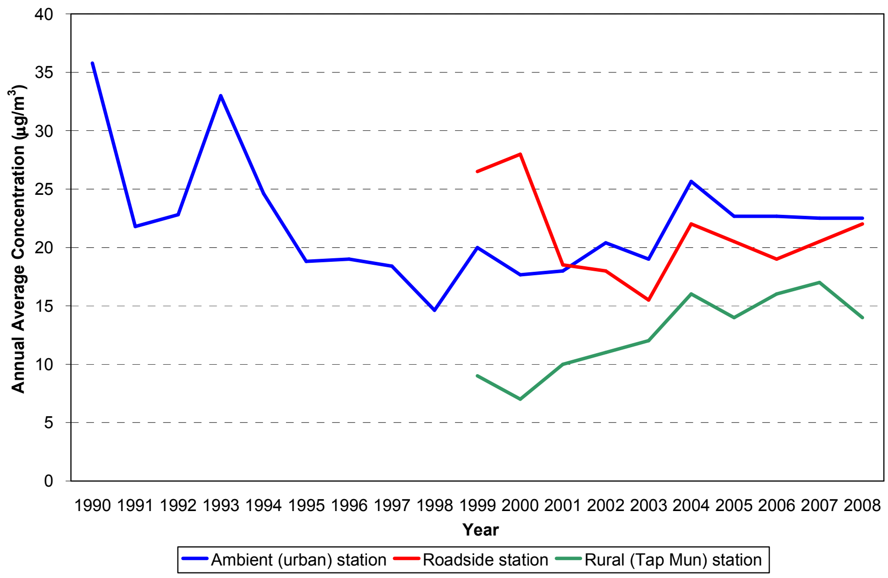
[Note: Emissions in 2010 are projected figures]

However, the air quality monitoring data obtained by the EPD at its monitoring network during the period of 1990 to 2008 did not show a commensurate air quality improvement trend. The urban ambient concentration levels of these pollutants dropped by 36% (SO_2) to 5% (PM_{10}) between 1990 and 2008. At the roadside, the concentration levels fell by 19% (SO_2) to 22% (PM_{10}) between 1999 to 2008. Yet Hong Kong's visibility, a general indicator of the state of our air quality, has deteriorated owing to the growing impact of regional air pollution. The deterioration has been managed as a result of the joint efforts of the Mainland and Hong Kong Governments to improve regional air quality. Detailed analysis of the trend for the key pollutants is in the ensuing paragraphs.

<u>Sulphur Dioxide</u>

Figure E.6 shows the long term trends of SO_2. The SO_2 concentrations in Hong Kong have reduced and remained at levels well below the annual AQO because of a number of control measures including the implementation of the Air Pollution Control (Fuel Restriction) Regulations in Year 1990 for limiting sulphur content of industrial fuels, the Air Pollution Control (Motor Vehicle Fuel) Regulations in Year 1995 for controlling motor vehicle fuel quality and the measures to reduce emissions in power plants such as the introduction of natural gas for power generation. There was a slight increase in SO_2 emission in Year 2003 and 2004 due to increased emission from coal-fired power generation in Hong Kong and the PRD but the trend levelled off in the last 5 years as a result of control measures implemented in the region in recent years. Furthermore, as a result of the introduction of ultra low sulphur diesel for vehicle fleet in late 2000, the average SO_2 concentration at roadside in Year 2008 (22 µg/m^3) dropped by 19% as compared with the Year 1999 value (27 µg/m^3). The SO_2 monitoring data of the Tap Mun Ambient Monitoring Station, which is located at a remote site at the north-east of Hong Kong away from the local emission sources, shows an increasing trend from 1998. This reflects the regional influence on local air quality.

Figure E.6: Long-term annual SO_2 trends



<u>Nitrogen Dioxide</u>

Figures E.7 and **E.8** show the long term trends of NO_X and NO_2. The NO_2 concentration levels have exhibited slow rising trends during the period from Year 1990 to Year 2008 despite the general decrease of emissions and ambient concentrations of NO_X. Apart from the concentration of NO_X, the concentrations of NO_2 are also dependent on the concentrations of ozone and VOCs in the ambient air which promote the conversion of nitric oxide to NO_2. Given that the long term NO_X trend is slowly decreasing, the slowly increasing trend of NO_2 levels in urban and new town areas suggests the aggravation of the regional photochemical and ozone pollution. The average NO_2 concentration level at roadside is almost constant at about 97 µg/m^3. The NO_2 data of the Tap Mun Ambient Monitoring Station are much lower than the ambient and roadside readings, suggesting that NO_2 in urban area of Hong Kong is contributed mainly by local sources in particular the emissions from motor vehicles.

Figure E.7: Long term annual NO_X trends

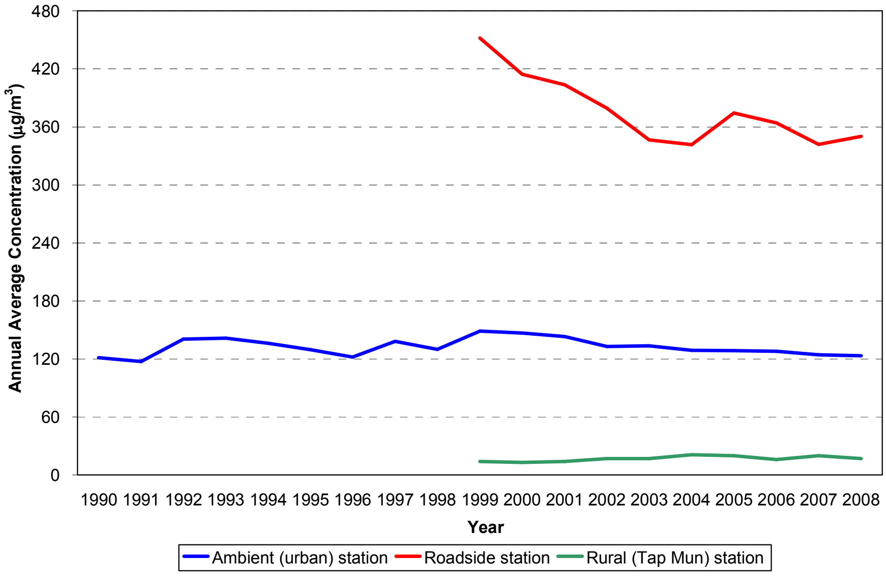
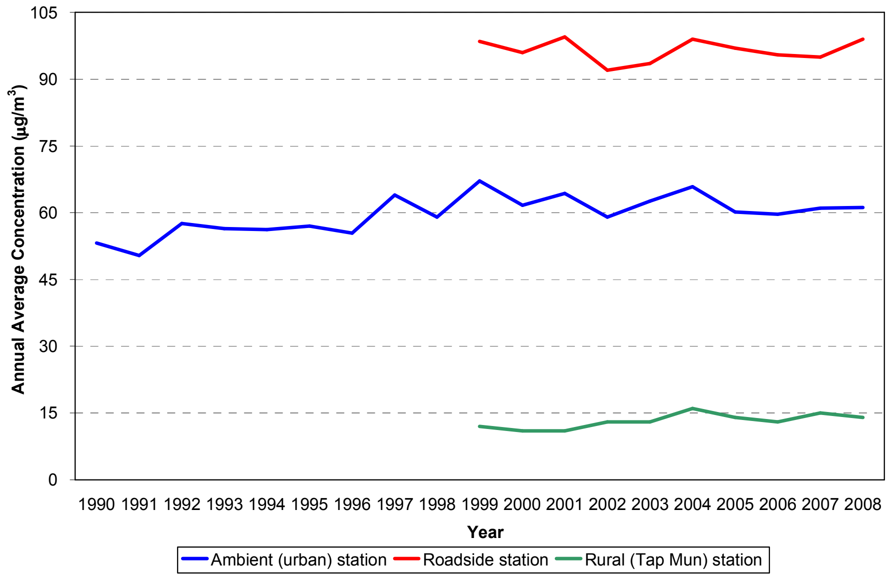


Figure E.8: Long-term annual NO_2 trends

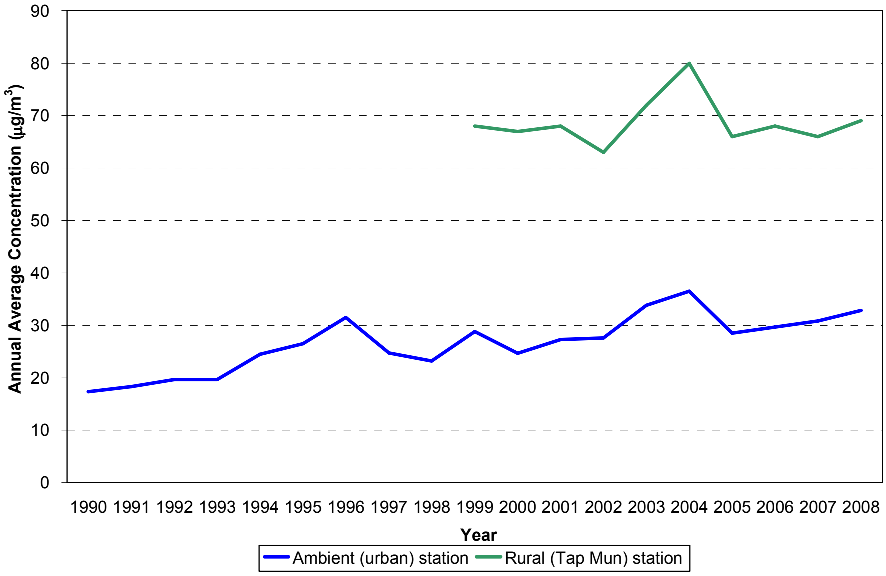


Ozone

Figure E.9 shows the long term trends of O_3. The ozone concentrations in the ambient have shown a moderate upward trend since Year 1990. Ozone is generated from the photochemical reaction between VOC and NO_X under sunlight. Due to the abundance of its precursors (VOC and NO_X) from a great variety of sources such as motor vehicles, industries, power plants and consumer products, etc., ozone can be widely formed in the region and can be transported over long distance. The general rising trend of ozone levels in Hong Kong over the past years reflects a worsening in the photochemical smog problem on a regional scale.

As nitric oxide emissions from motor vehicles can react with and remove ozone in the air, areas with heavy traffic normally have lower ozone levels than areas with light traffic. This explains why the ozone level in Tap Mun rural station is much higher than that measured in the urban ambient stations. Its rising trend of ozone generally reflects deterioration in air quality on a regional scale over the past decade.

Figure E.9: Long-term annual ozone trends

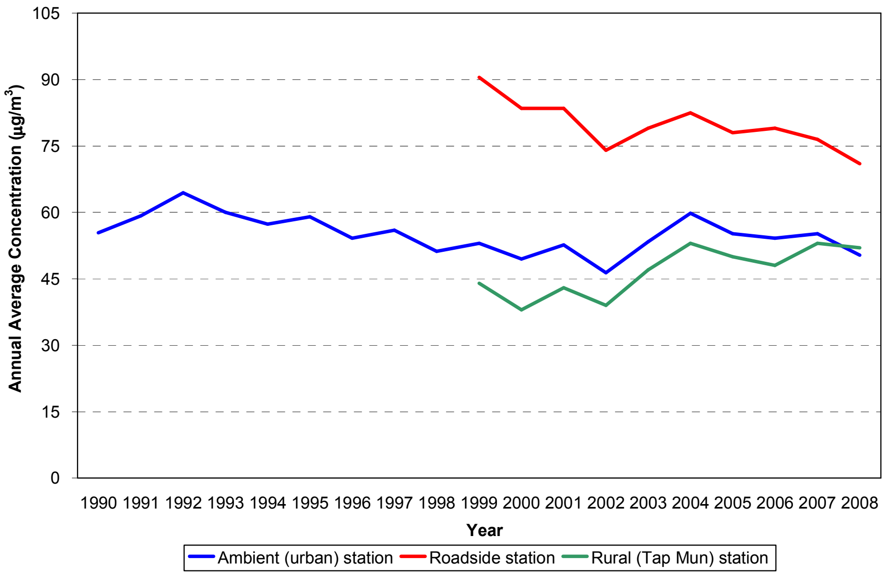


Respirable Suspended Particulates

Figure E.10 shows the long term trends of PM_{10}. The PM_{10} concentrations recorded in the territory showed a primarily downward trend between Year 1995 and Year 2002 but rebounded afterwards in Year 2003 and 2004 due to the increase in regional background PM_{10} levels. The gentle rising trend of PM_{10} in the territory since 2002 was mainly caused by the increase in its regional background levels. In Hong Kong, high level of roadside PM_{10}, caused mainly by the exhaust emissions of diesel vehicles, has long been a major air pollution concern. In the last 5 years, the ambient PM_{10} level exhibited a mild decreasing trend, as a result of the joint efforts by the HKSAR and Guangdong governments in cutting emissions in the region. At the roadside, the PM_{10} concentration has exhibited a discernible decreasing trend with annual average reduced by 22% between Year 1999 and Year 2008, reflecting that the vehicle emission control measures implemented over the last decade have taken effect.

It is noted that the PM_{10} concentrations at Tap Mun, which is far away from local emission sources, are comparable with those measured at the urban ambient stations. This suggests that our PM_{10} would be contributed significantly by sources outside Hong Kong. The increasing trend from Year 1998 also reflects the growing influence of these sources on local PM_{10} concentration.

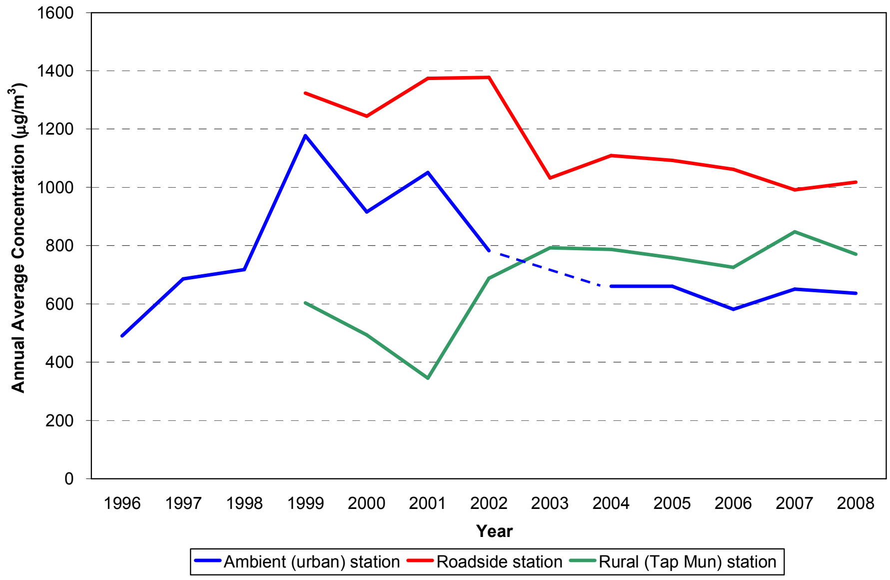
Figure E.10: Long-term annual PM_{10} (RSP) trends



Carbon Monoxide

Figure E.11 shows the long term trends of CO. The CO concentrations in Hong Kong remained very low (< 1600 µg/m^3) in the past few years and were well within the current AQO, even at the roadside close to the vehicular emission sources.

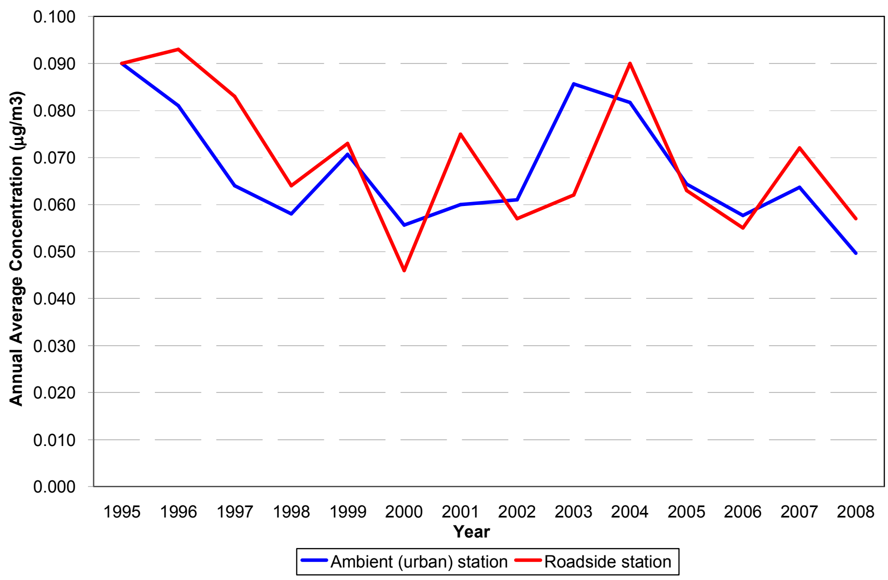
Figure E.11: Long-term annual carbon monoxide trends



Lead

Figure E.12 shows the long term trends of Pb. In Hong Kong, the sale and supply of leaded petrol, which is a known major source of lead, was banned from 1 April 1999. As in previous years, the ambient lead concentrations continued to linger at very low levels during Year 2008. The annual ambient and roadside averages were 0.05 µg/m^3 and 0.057 µg/m^3 respectively, which were well within the current AQO.

Figure E.12: Long term annual lead trends



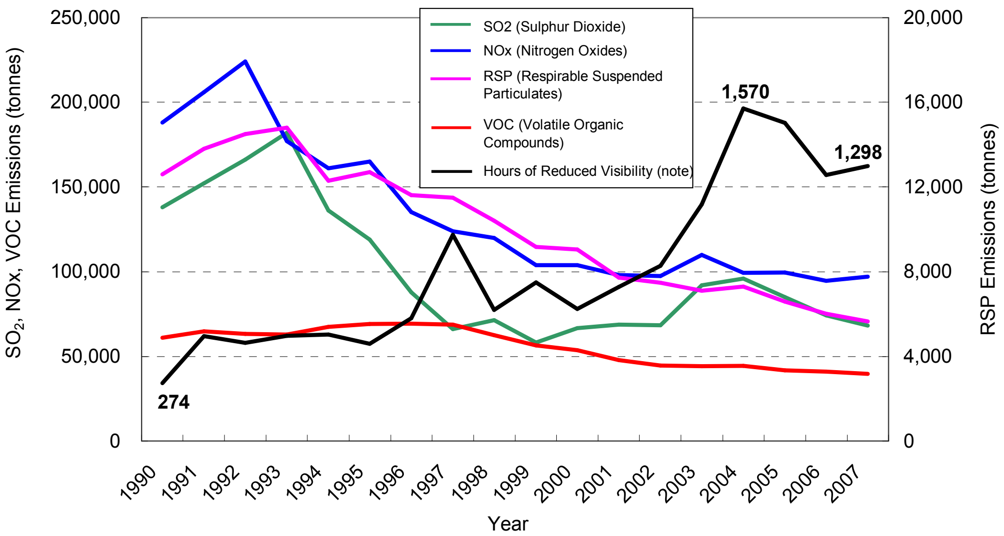
Toxic Air Pollutant

The EPD has been monitoring the ambient levels of toxic air pollutants. The risk to public health has also been reviewed by a study – "Assessment of Toxic Air Pollutant Measurements in Hong Kong". The study has concluded that the ambient levels of the chemical carcinogens other than $PM_{2.5}$ were low and should be of no major concern from the public health angle. These pollutants are reported in various other studies conducted by EPD. Besides, review of air quality standards and objectives in relation to chemical carcinogens is not part of the scope of this study.

Visibility

Figure E.13 shows the long term trends of visibility. The frequency of visibility impairment in Hong Kong showed an increasing trend from 1990 (about 274 hrs) to 2007 (about 1,298hrs), although some improvement has been observed recently. Notwithstanding the very substantial reduction in local emissions, the visibility has been deteriorating due to worsening of the regional background air quality. Smog has now become a common phenomenon for the entire Pearl River Delta (PRD) area.

Figure E.13: Emission and Reduced Visibility Trends of Hong Kong



Emission Sources Trends in Hong Kong and PRD

Hong Kong and Guangdong need to work together to improve the air quality in the PRD region. To this end, the Hong Kong Special Administrative Region (HKSAR) Government and the Guangdong Provincial Government reached a consensus to reduce, on a best endeavour basis in April 2002, the anthropogenic emissions of SO_2, NO_X, PM_{10} and VOC by 40%, 20%, 55% and 55% respectively in the PRD Region (i.e. covering the PRD Economic Zone in Guangdong and the HKSAR) by 2010, using 1997 as the base year.

According to the findings of the Mid-term Review prepared by the Guangdong Provincial and HK SAR governments, Hong Kong's emissions account for 1% (PM_{10}) to 15% (NO_X) of the air pollutants in the entire PRD region in 2003. It is forecast that the economy, population, electricity consumption and vehicle mileage of the HKSAR will increase by 72%, 11%, 43% and 8% respectively in 2010, using 1997 as the base year. It is anticipated that implementation of the existing preventive and control measures mentioned in the Mid Term Review Report will significantly reduce the emissions of SO_2, NO_X, PM_{10} and VOC in 2010 to around 30,000 tonnes, 90,000 tonnes, 5,000 tonnes and 30,000 tonnes respectively.

As for the PRD Economic Zone, findings of the Mid-term Review indicate that the economy, population, electricity consumption and vehicle mileage in the area will increase by 509%, 56%, 158% and 319% respectively in 2010 compared to the 1997 levels. Notwithstanding the various abatement and control measures implemented by the Guangdong Provincial Government in recent years, which have resulted in emission reductions in various pollutants, it is anticipated that the rapid economic developments in the area will result in an increase in the emissions. To further strengthen control on air pollutant emissions so as to achieve the reduction targets, the Mid Term Review Report has proposed that, apart from the existing measures, additional control measures should be introduced to target at various emission sources in the Region. These include retrofitting selective catalytic reduction in coal-fired power plants, strengthening the emission control of industrial boilers and mobile sources. With the implementation of the additional control measures, it is estimated that the emissions of SO_2, NO_X, PM_{10} and VOC in the PRD

Economic Zone will decrease to around 430,000 tonnes, 500,000 tonnes, 210,000 tonnes and 180,000 tonnes respectively in 2010. The predicted relative contributions of pollutants from Hong Kong and PRDEZ in 2010 are summarized in **Table E.1**.

Table E.1: Emission inventories of HKSAR and PRDEZ in 2010 under strengthened control strategies

Region	Emissions (tonnes)			
	SO_2	NO_X	PM_{10}	VOC
Hong Kong	30,237 (6.6%)	92,847 (15.6%)	4,737 (2.2%)	31,017 (14.8%)
PRDEZ	431,300 (93.4%)	503,600 (84.4%)	207,500 (97.8%)	178,200 (85.2%)
Total	461,537	596,447	212,237	209,217

Latest Development of Air Quality Standards

The WHO announced a new set of AQG on 5 October 2006 "for worldwide use, and are intended to support actions aiming for the optimal achievable level of air quality in order to protect public health" [1]. The WHO has also recommended interim targets for countries to progressively improve the air quality:

"Given that air pollution levels in some countries often far exceed the recommended guideline levels, interim target levels are proposed, in excess of the guideline levels themselves, to promote steady progress towards meeting the WHO guidelines" [1]

Table E.2 summarizes these new WHO AQG and IT.

Table E.2: The new WHO AQG and IT with the current AQO of Hong Kong

	Averaging Time	Current AQO	Concentration in micrograms per cubic metre			
			Interim Target - 1	Interim Target - 2	Interim Target - 3	AQG
Sulphur Dioxide (SO_2)	10-minute	--				500
	24-hour	350	125	50		20
Respirable Suspended Particulates (PM_{10})	24-hour	180	150	100	75	50
	1-year	55	70	50	30	20
Fine Suspended Particulates ($PM_{2.5}$)	24-hour	--	75	50	37.5	25
	1-year	--	35	25	15	10
Nitrogen Dioxide (NO_2)	1-hour	300				200
	1-year	80				40
Ozone (O_3)	8-hour	240 [1]	160			100
Carbon Monoxide (CO)	15-minute	--				100,000
	30-minute	--				60,000
	1-hour	30,000				30,000
	8-hour	10,000				10,000
Lead (Pb)	1-year	1.5 [2]				0.5

Note:
[1] 1-hour average
[2] 3 month average

The WHO AQG are the most authoritative set of guidelines that provides a good source of reference for all countries to build their air quality standards to minimize the risk of air pollution to public health. They are, however, far tougher than the national standards being applied in many parts of the world. Achievement of such levels will be a challenge for many cities. WHO accepts the need for governments to set national standards according to their own particular circumstance:

"The standards set in each country will vary according to specific approaches to balancing risks to health, technological feasibility, economic considerations and other political and social factors"

"In formulating policy targets, governments should consider their own local circumstances carefully before using the guidelines directly as legal standards"

It has also noted that other countries/economies such as USA, EU, UK, Australia, have also established and/or updated their respective AQO. However, none has fully adopted or committed to the adoption of the WHO's ultimate AQG. EU and UK adopted standards comparable to a combination of WHO IT and AQG, with allowances for exceedences, based on their local circumstances. The EU, which has one of the most stringent AQO among others, has just updated their air quality objectives on 21 May 2008. Its AQO for SO_2, ozone, PM_{10} and $PM_{2.5}$, however, are still less stringent than those respective AQG recommended by the WHO. For example, the EU has promulgated an annual $PM_{2.5}$ limit of 25 μg/m^3, which is equivalent to WHO's IT-2 value for $PM_{2.5}$. For 24-hour SO_2 limit, it has adopted IT-1 value of 125 μg/m^3

New AQO for Hong Kong

Hong Kong is a world city and should strive for the best possible air quality for protection of the public. Taking account of the international practices and our local situations, it is considered that the following key principles should be adopted in proposing the new AQO:

- Protection of public health as the primary objective;
- Adopting a progressive, forward looking approach to setting the AQO with reference to the WHO guidelines and interim targets with a view to achieving continued progressive long term air quality improvement;
- Regular review system to update the AQO for the protection of public health;

The WHO AQG should be pursued as the long term goal.

<u>Sulphur Dioxide</u>

Table E.3 summarizes the SO_2 data at ambient monitoring stations in Hong Kong in Year 2008. The SO_2 data at Tap Mun ambient station, which is representative of the local Hong Kong background from regional influence, is also presented for comparison.

Table E.3a: Comparison of 2008 SO_2 concentrations with WHO guidelines

Air Pollutant	Avg time	WHO AQG / IT (ug/m^3)	Highest Concentration in 2008 (Ambient)	Highest Concentration in 2008 (Tap Mun)
SO_2	10-min	AQG: 500	1173	409
	24-hour	IT-1:125	149	71
		IT-2: 50		
		AQG: 20		

Table E.3b: Number of exceedences of the WHO's SO_2 guidelines in 2008

Air Pollutant	Avg time	WHO AQG / IT	No. of Exceedences in 2008 (Ambient)	No. of Exceedences in 2008 (Tap Mun)
SO_2	10-min	AQG: 500	20	0
	24-hour	IT-1:125	2	0
		IT-2: 50	86	1
		AQG: 20	284	63

The 2008 monitoring data show that the 24-hr SO_2 levels in ambient monitoring station exceeded the WHO IT1, WHO IT2 and WHO AQG by 2, 86 and 284 times respectively. The highest recorded concentrations at ambient and Tap Mun monitoring stations were 149 μg/m^3 and 71 μg/m^3 respectively. According to 2008 monitoring data, the 10-min SO_2 at ambient and Tap Mun monitoring stations exceeded the WHO AQG by 20 times and 0 time respectively. The highest recorded concentrations at ambient and Tap Mun monitoring stations were 1173 μg/m^3 and 409 μg/m^3 respectively. As Tap Mun monitoring station is representative of the local Hong Kong background, this suggests that SO_2 in urban area is contributed mainly by the local sources.

Hong Kong has been taking strong actions to reduce sulphur dioxide emissions. In particular, diesel vehicles have been using since December 2007 Euro V diesel, which has virtually no sulphur and is the cleanest form of diesel; and industrial diesel has been upgraded since October 2008 to the level of ultra-low sulphur diesel, which is the cleanest industrial diesel that very few places have introduced. Moreover, power plants are being retrofitted with flue gas de-sulphurisation devices as part of the efforts to meet with the regional emission reduction target for 2010. The scope of further reducing drastically the local emissions of sulphur dioxide so as to meet with the WHO IT2 is thus rather limited. To further reduce local sulphur dioxide concentrations, efforts have to be targeted at the regional front and vessels, both local and ocean-going. These efforts, particularly the last one, which requires international consensus, will take time.

Taking into account of these local circumstances and making reference to the EU air quality standards (i.e., 125 μg/m^3 with 3 exceedences), the WHO IT1 of 125 μg/m^3 with 3 exceedences for 24-hour SO_2 is proposed as a first step towards the long term of goal of adopting the WHO AQG.

EU has not set any limit for 10-min SO_2. However, UK has adopted a limit value for 15-min SO_2 of 266μg/m^3 but allowed 35 exceedences a year (average over 3 years). It is proposed to adopt the WHO AQG of 500 μg/m^3 and allowing 3 exceedences a year for 10-min SO_2.

<u>Nitrogen Dioxide</u>

Table E.4 summarizes the NO_2 data at ambient monitoring stations in Hong Kong in Year 2008. The NO_2 data at Tap Mun ambient station, which is representative of the local Hong Kong background from regional influence, is also presented for comparison.

Table E.4a: Comparison of 2008 NO_2 concentrations with WHO guidelines

Air Pollutant	Avg time	WHO AQG / IT	Highest Concentration in 2008 (Ambient)	Highest Concentration in 2008 (Tap Mun)
NO_2	1-hour	AQG: 200	282	119
	Annual	AQG:40	69	14

Table E.4b: Number of exceedences of the WHO's NO_2 guidelines in 2008

Air Pollutant	Avg time	WHO AQG / IT	No. of Exceedences in 2008 (Ambient)	No. of Exceedences in 2008 (Tap Mun)
NO_2	1-hour	AQG: 200	84	0
	Annual	AQG: 40	×	✓

The 2008 monitoring data show that the annual NO_2 at Hong Kong ambient (excluding Tap Mun) monitoring stations exceeded the WHO AQG. There was no exceedence observed in Tap Mun monitoring station. The highest recorded concentrations at ambient and Tap Mun monitoring stations were 69 µg/m^3 and 14 µg/m^3 respectively. As for 1-hr NO_2, the data from the ambient monitoring stations in 2008 exceeded the AQG by 84 times. The highest recorded concentrations at ambient monitoring stations was 282 µg/m^3 . No exceedence was recorded at Tap Mun. As Tap Mun monitoring station is representative of the local Hong Kong background, this suggests that NO_2 is contributed mainly by local sources. Implementation of suitable emission control measures locally should be able to bring down the concentration level of NO_2 in Hong Kong.

The WHO has not proposed any interim targets for the concentration levels of NO_2. Having considered the standards being adopted by other advanced countries, particularly the EU, and our local circumstances, the WHO AQG of 40 µg/m^3 and 200 µg/m^3 are proposed for annual and 1-hr NO_2 respectively. On the number of exceedences allowed for 1-hr NO_2, it is recommended that 18 exceedences per year be allowed taking account of the allowable exceedences being adopted by EU and our modelling results.

Ozone

Table E.5 summarizes the ozone data at ambient monitoring stations in Hong Kong in Year 2008. The ozone data at Tap Mun ambient station, which is representative of the local Hong Kong background, is also presented for comparison.

Table E.5a: Comparison of 2008 O_3 concentrations with WHO guidelines

Air Pollutant	Avg time	WHO AQG / IT	Highest Concentration in 2008 (Ambient)	Highest Concentration in 2008 (Tap Mun)
Ozone	8-hr	IT-1: 160	320	320
		AQG: 100		

Table E.5b: Number of days with exceedences of the WHO's O_3 guidelines in 2008

Air Pollutant	Avg time	WHO AQG / IT	No. of Exceedences in 2008 (Ambient)	No. of Exceedences in 2008 (Tap Mun)
Ozone	8-hr	IT-1: 160	29	19
		AQG: 100	185	184

The 8-hr O_3 in Hong Kong ambient monitoring stations exceeded the WHO IT1, and WHO AQG by 29 and 185 times respectively. The highest recorded concentration at ambient monitoring stations was 320 µg/ m^3, which occurred at Tap Mun background station. The 8-hr O_3 in Tap Mun Stations exceeded the WHO IT-1 and WHO AQG by 19 and 184 times respectively. It suggests that the 8-hr O_3 is largely affected by regional sources. Based on the data, it is difficult to achieve the WHO IT-1 interim target without further NO_X and VOC reduction in the region.

Taking into account the local circumstances, the WHO IT1 of 160 µg/m^3 is proposed for 8-hr O_3. It is noted that the EU sets the O_3 at 120 µg/m^3 with allowance of 25 exceedences according to its local circumstances. However, given the difference between the proposed objectives for Hong Kong and EU's limit values, and taking account of the results of the mathematical air quality modelling following implementation of Phase I control measures, it is proposed that an exceedence of 9 times per year be allowed. The proposed new AQO with exceedences for ozone is statistically similar to the EU air quality standard for ozone.

Fine Suspended Particulates

According to WHO document, health risk attributable to exposure to particulate matter is better represented by $PM_{2.5}$. In view of the latest findings on the health effects of $PM_{2.5}$ in WHO, US, UK, and other leading countries on the subject, it is recommended to include $PM_{2.5}$ in the new AQO to reflect its importance as a pollutant of significant risk on health.

Table E.6 summarizes the $PM_{2.5}$ data at ambient monitoring stations in Hong Kong in Year 2008. The $PM_{2.5}$ data at Tap Mun ambient station, which is representative of the local Hong Kong background, is also presented for comparison.

Table E.6a: Comparison of 2008 $PM_{2.5}$ concentrations with WHO guidelines

Air Pollutant	Avg time	WHO AQG / IT	Highest Concentration in 2008 (Ambient)	Highest Concentration in 2008 (Tap Mun)
$PM_{2.5}$	24-hour	IT-1: 75	113	99
		IT-2: 50		
		IT-3: 37.5		
		AQG: 25		
	Annual	IT-1: 35	41	35
		IT-2: 25		
		IT-3: 15		
		AQG: 10		

Table E.6b: Number of exceedences of the WHO's $PM_{2.5}$ guidelines in 2008

Air Pollutant	Avg time	WHO AQG / IT	No. of Exceedences in 2008 (Ambient)	No. of Exceedences in 2008 (Tap Mun)
$PM_{2.5}$	24-hour	IT-1: 75	39	13
		IT-2: 50	128	87
		IT-3: 37.5	191	160
		AQG: 25	259	219
	Annual	IT-1: 35	×	✓
		IT-2: 25	×	×
		IT-3: 15	×	×
		AQG: 10	×	×

The 2008 monitoring data shows that the annual $PM_{2.5}$ at Hong Kong ambient (including Tap Mun) monitoring stations exceeded the WHO IT1. The annual concentrations at ambient and Tap Mun monitoring stations were 41 µg/m^3 and 35 µg/m^3 respectively. The 24-hr $PM_{2.5}$ at Hong Kong ambient monitoring stations exceeded the WHO IT1 by 39 times. The highest recorded concentrations at ambient monitoring stations was 113 µg/m^3. As Tap Mun monitoring station is representative of the local Hong Kong background, this suggests that $PM_{2.5}$ is contributed mainly by the regional sources. Based on the data and the fact that Hong Kong's PM emissions account for only about one to two percent of the entire emissions in the PRD region, it would be difficult to significantly bring down the concentration level of $PM_{2.5}$ in Hong Kong solely through local efforts.

Taking into account the strong regional influence, the WHO IT-1 of 35 µg/m^3 and 75 µg/m^3 are proposed for annual and 24-hr $PM_{2.5}$ respectively. The EU directive does not have 24-hr $PM_{2.5}$ limit. Given that $PM_{2.5}$ concentration is contributed significantly by regional sources, it is proposed to allow 9 exceedences in a year, which has been determined with reference to the results of the mathematical air quality modelling under Phase I control measures.

Respirable Suspended Particulates

Table E.7 summarizes the PM_{10} data at ambient monitoring stations in Hong Kong in Year 2008. The PM_{10} data at Tap Mun ambient station, which is representative of the local Hong Kong background, is also presented for comparison.

Table E.7a: Comparison of 2008 PM_{10} concentrations with WHO guidelines

Air Pollutant	Avg time	WHO AQG / IT	Highest Concentration in 2008 (Ambient)	Highest Concentration in 2008 (Tap Mun)
PM_{10}	24-hour	IT-1: 150	164	147
		IT-2: 100		
		IT-3: 75		
		AQG: 50		
	Annual	IT-1: 70	60	52
		IT-2: 50		
		IT-3: 30		
		AQG: 20		

Table E.7b: Number of exceedences of the WHO's PM_{10} guidelines in 2008

Air Pollutant	Avg time	WHO AQG / IT	No. of Exceedences in 2008 (Ambient)	No. of Exceedences in 2008 (Tap Mun)
PM_{10}	24-hour	IT-1: 150	4	0
		IT-2: 100	51	19
		IT-3: 75	134	78
		AQG: 50	211	167
	Annual	IT-1: 70	✓	✓
		IT-2: 50	✗	✗
		IT-3: 30	✗	✗
		AQG: 20	✗	✗

Based on 2008 monitoring data, the annual PM_{10} at Hong Kong ambient (including Tap Mun) monitoring stations exceeded the WHO IT2. The highest recorded concentrations at ambient and Tap Mun monitoring stations were 60 µg/m^3 and 52 µg/m^3 respectively.

The local $PM_{2.5}$ / PM_{10} ratio is estimated to be in the region of 0.7. Taking account of this $PM_{2.5}$ / PM_{10} ratio and the targets for $PM_{2.5}$ proposed above, the WHO IT-2 of 50 µg/m^3 and 100 µg/m^3 are proposed for annual and 24-hr PM_{10} respectively. In line with the number of exceedences for $PM_{2.5}$, 9 exceedences per year are proposed for PM_{10}.

Carbon monoxide

There is no interim target for CO in WHO document. The WHO AQG for 15-min CO, 30-min CO, 1-hr CO and 8-hr CO are 100,000 μg/m^3, 60,000 μg/m^3, 30,000 μg/m^3 and 10,000 μg/m^3 respectively. The EU Directive 2008/50 / EC adopted the WHO AQG of 10,000 μg/m^3 for 8-hr CO limit.

Table E.8 summarizes the CO data at ambient stations in Hong Kong in Year 2008. The CO data at Tap Mun ambient station, which is representative of the local Hong Kong background from regional influence, is also presented for comparison.

Table E.8a: Comparison of 2008 CO concentrations with WHO guidelines

Air Pollutant	Avg time	Concentration (ug/m^3)	Concentration in 2008 (Ambient)	Concentration in 2008 (Tap Mun)
CO	15-min	AQG: 100,000	3,439	2,312
	30-min	AQG:60,000	3,324	2,116
	1-hour	AQG: 30,000	3,220	2,060
	8-hr	AQG:10,000	3,034	1,536

Table E.8b: Number of exceedences of the WHO's CO guidelines in 2008

Air Pollutant	Avg time	Concentration (ug/m^3)	No. of Exceedences in 2008 (Ambient)	No. of Exceedences in 2008 (Tap Mun)
CO	15-min	AQG: 100,000	0	0
	30-min	AQG:60,000	0	0
	1-hour	AQG: 30,000	0	0
	8-hr	AQG:10,000	0	0

Based on 2008 monitoring data, the 15-min CO, 30-min CO, 1-hr CO and 8-hr CO at Hong Kong ambient monitoring stations (including Tap Mun) complied with the WHO AQG. The highest recorded 15-min CO concentrations at ambient and Tap Mun monitoring stations were 3,439 μg/m^3 and 2,312 μg/m^3 respectively. As Tap Mun monitoring station is representative of the local Hong Kong background, this suggests that CO is contributed by both local and regional sources.

The EU directive only adopts WHO AQG for 8-hr CO limit with no exceedence allowed. US adopt both 1-hr CO limit and 8-hr CO limit with allowance of 1 exceedence for each limit. On making reference to international practices and taking into account our local circumstances, short term CO measurement (i.e 15-min and 30 min averaging time) is not proposed for Hong Kong. Instead, the 1-hr CO WHO AQG of 10,000 μg/m^3 and 8-hr CO WHO AQG of 30,000 μg/m^3 are proposed. As the CO levels are already below the respective WHO AQG, no allowance of exceedence is proposed.

Lead (Pb)

There is no interim target for Pb in WHO document. The WHO AQG for annual Pb is 0.5 μg/m^3. The EU Directive 2008/50 / EC adopted the WHO AQG of 0.5 μg/m^3 for annual Pb limit.

Table E.9 summarizes the Pb data at ambient stations in Hong Kong in Year 2008. There is no Pb data at Tap Mun ambient station, which is representative of the local Hong Kong background from regional influence.

Table E.9a: Comparison of 2008 Pb concentrations with WHO guideline

Air Pollutant	Avg time	Concentration (ug/m^3)	Concentration in 2008 (Ambient)
Pb	Annual	AQG: 0.5	0.064

Table E.9b: Number of exceedences of the WHO's Pb guideline in 2008

Air Pollutant	Avg time	Concentration (ug/m^3)	No. of Exceedences in 2008 (Ambient)
Pb	Annual	AQG:0.5	0

Based on 2008 monitoring data, the annual Pb at Hong Kong ambient monitoring stations complied with the WHO AQG. The highest recorded annual Pb concentration at ambient monitoring stations was 0.064 $\mu g/m^3$. On making reference to the EU directive, the WHO AQG of 0.5 $\mu g/m^3$ is thus proposed for annual Pb.

Other Pollutants

As the effect of total suspended particulates (TSP) is rather a dust nuisance than health threat, it is proposed that the existing AQO of TSP should be revoked.

In summary, the proposed new AQO are presented in the **Table E.10**. It is proposed that the existing practice of having the same AQO applicable to both ambient and roadside exposure should be continued. Following the UK practices, it is recommended that the proposed new AQO with long averaging time (i.e. annual limits) will not be applicable for roadside locations.

Table E.10: Proposed new AQO for Hong Kong

Pollutants	Avg. Time	Concentration ($\mu g/m^3$)	No. of exceedences
SO_2	10-min	500	3
	24-hr	125	3
PM_{10}	24-hour	100	9
	1-year	50	0
$PM_{2.5}$	24-hour	75	9
	1-year	35	0
NO_2	1-hr	200	18
	1-yr	40	0
O_3	8-hr	160	9
CO	1-hr	30,000	0
	8-hr	10,000	0
Pb	1-yr	0.5	0

Air Quality Management Strategies

A host of comprehensive emission reduction measures which Government may consider implementing for improving Hong Kong's air quality has been identified for achieving the proposed new AQOs. Selection criteria have been established for shortlisting these measures. They include:

- Emission reduction potential
- Practicability (i.e. the maturity of technology and readiness for implementation)
- Cost benefit
- Concentration reduction potential

Based on the above established selection criteria, a set of conceptual measures has been identified and can be grouped into 4 main categories: emission capping and control, transport management, infrastructure development and planning and energy efficiency measures. The shortlisted measures are further refined and grouped into three packages according to the potential implementation time frames: Phase I, Phase II and Phase III according to their practicability, maturity of technologies and readiness of the affected sectors in accepting the proposed measures. The control measures for different time frames implementation are summarized below:

Phase I Control Measures:

Emission Capping and Control

- Increasing the ratio of natural gas in local electricity generation to 50% together with additional emission abatement measures
- Early retirement of aged / heavily polluting vehicles (pre-Euro, Euro I and Euro II commercial diesel vehicles and franchised buses)
- Earlier replacement of Euro III commercial diesel vehicles with models meeting latest Euro standards
- Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance (20% private cars and 10% franchised buses)
- Ultra low sulphur diesel (ULSD) for local vessels
- Selective catalytic reduction (SCR) for local vessels
- Electrification of aviation ground support equipment
- Emission Control for off-road vehicles / equipment
- Strengthening volatile organic compounds control

Transport Management

- Low Emission Zones
- Car-free zone / pedestrianisation scheme
- Bus route rationalization

Infrastructure Development and Planning

- Expand rail network
- Cycling network to major public transport hubs

Energy Efficiency Measures

- Mandatory implementation of Building Energy Codes
- Energy efficient electrical appliance standard for domestic use
- Light-emitting diode (LED) or equivalent alternatives for traffic signal / street lighting
- Tree planting/ roof-top greening
- District cooling system for Kai Tak Development

Phase II Control Measures:

Emission Capping and Control

- Increasing the ratio of natural gas in local electricity generation to 75% with additional emission abatement measures
- Increasing the ratio of renewable energy
- Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance [30% private cars, 15% buses (including franchised buses), 15% light goods vehicles (LGVs) plus 15% heavy goods vehicles (HGVs)]
- Ultra low sulphur diesel for ocean-going vessels and local vessels
  Selective catalytic reduction for ocean-going vessels and local vessels
- Electrification of on-shore power supply
- Tightening aviation emission standards

- Further strengthening volatile organic compounds Control

Transport Management

- Electronic road pricing (ERP) / congestion charging scheme for Hong Kong Island North
- Reduce parking provision (25%) to restrain car usage for Central

Energy Efficiency Measures

- District cooling system (35% in existing areas and 90% in other new development areas)

Phase III Control Measures:

Emission Capping and Control

- Increasing the ratio of natural gas in local electricity generation to 100%
- 50% nuclear power and 50% natural gas
- Wider use of hybrid vehicles / electric vehicles or other environmental-friendly vehicles with similar performance (50% private cars, 50% buses (including franchised buses), 50% HGVs plus 50% LGVs)
- Vehicle permit quota system (to reduce around 50% private cars and 50% motorcycles)
- Use of hydrogen fuel cell vehicles or equivalent alternatives (40% penetration)

Transport Management

- Rail for transport of cross-boundary goods

In estimating the projected emissions after implementation of the proposed air quality improvement measures, reference has been made to existing information on the effectiveness of the various measures, the application experience of other places, the relevant local factors, etc. However, many of these proposed measures are no more than conceptual outlines. Implementation details such as space constraint in upgrading more polluting equipment, detailed design of emission reduction devices, the timing for the availability of cleaner vehicles or equipment on the local market, etc. are not yet known. Given the importance of the emission reduction in evaluating the effectiveness of these measures to attain the proposed new AQO, best endeavour has been made to project the emission reduction based on a host of assumptions which may be subject to changes. After their implementation, their actual effectiveness in improving air quality will have to be assessed as part of the regular review of the AQO. The projected emissions upon implementation of these proposed control measures are presented in **Tables E.11** below. The 2006 emissions are also present in **Table E.12** for comparison.

Table E.11: Projected emissions (tonnes) – With Phase I Measures

Sector	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Power	11,718	17,375	737	420
Transport	4,910	38,048	1,933	6,040
Vehicles	*263*	*9,354*	*1,262*	*5,257*
Marine (Figure in brackets for local vessels)	*4,263* *(7)*	*21,380* *(3690)*	*658* *(161)*	*436* *(91)*
Aviation	*384*	*7,314*	*13*	*348*
Industry and Others	12	3,658	385	23,104

Table E.12: Emissions (tonnes) – Year 2006

Sector	**SO_2**	**NO_X**	**PM_{10}**	**VOC**
Power	66,000	41,800	1,860	416
Transport	5,170	43,520	2,330	8,645
Vehicles	*956*	*21,800*	*1,810*	*8,080*

Sector	SO_2	NO_X	PM_{10}	VOC
Marine (Figure in brackets for local vessels)	*3,920* *(682)*	*16,700* *(3994)*	*499* *(179)*	*304* *(91)*
Aviation	*294*	*5,020*	*21*	*261*
Industry and Others	2,660	9,530	1,675	32,198

Cost Benefit Analysis

Cost benefit analyses (CBAs) have been conducted for most of the above proposed control measures in order to provide a systematic framework for assessing and presenting the territory-wide impacts of the proposed policy interventions in monetary terms. The objective of undertaking the CBAs is to assess whether the society as a whole would secure greater cost savings from air quality improvements than the additional costs that would be imposed by the policy. It should be noted that the CBA estimates the net economic costs to be borne by the entire community and makes no distinction as to whether they would eventually be borne by taxpayers, the operators or consumers at this stage. The analyses provide a broad indication of the relative cost-effectiveness since the dollar estimates are subject to uncertainty depending, amongst other things, on the detailed design and delivery arrangements as and when specific proposals are being taken forward.

The benefits of the control strategy are primarily cost savings of a direct nature (principally short and long term health related cost savings, including the reduced costs of illness and reduced premature mortality, and savings in electricity cost) and indirect nature (principally impacts on the productivity of the workforce and costs of maintenance and repair to buildings and structures arising from material damage caused by the air pollutants, and some lesser items). These have been assessed for future years and compared with the higher costs imposed over the same time period arising from implementation of the measures. Due allowance has been made for the uncertainties which are inherent in the analysis. Strategies vary in size, cost-effectiveness and uncertainty as to outcomes, but overall the net cost and benefit of the Phase I control strategies (expressed as a net present value or capital sum at 2008) are estimated to be HK$ 596 million and HK$ 1,228 million respectively. The attainment of the proposed new AQO could reduce about 4,200 unnecessary hospital admissions and 7,400 statistical life years would be saved (roughly 1 month improvement in life expectancy) for each year.

In consideration of the pursuit of certain measures, factors other than the sizes of the respective costs and benefits should be considered, and in particular, the emission reduction potential. Moreover, some of the measures would have significant cost/tariff implications for consumers if the policy of “polluter pays” is adhered to. For instance, raising the current share of natural gas of our domestic electricity generation to 50% or even higher could increase tariff by phases to at least 20% from the current level because of the need to install additional gas-fired generators and other emission reduction measures and that natural gas is significantly more expensive than coal. However, the actual level of tariff increase will depend on a number of factors, such as the price of the natural gas and the capital investments required by the power companies. Subject to further formulation of implementation details, the control measures affecting the transport sector may likewise carry fare or price implications due to an increase in the capital expenditure. For example, depending on the scale of the exercise, advancing the replacement of older (and more polluting) franchised buses could drive the fare increase pressure to about 15% in a single year. This will be on top of fare increases due to factors such as higher operating costs. However, bus fare impacts are only one facet of the implications. The questions of how to fund the early replacement of nearly three thousand buses, as well as how this would impact on bus companies' financial accounts and operations will also need to be addressed. The technical feasibility and the cost implications of some of the proposed measures such as the proposed use of ULSD on domestic ferries is subject to a trial scheme to be launched later. The benefit-cost ratios of some of the proposed measures could be relatively low. Furthermore, some measures may require legislation and impose significant resources implications on the Government. All these issues would need to be carefully assessed when the full consultation is being rolled out.

Details of the cost benefit analysis of the proposed Phase I measures with the respective emission reduction potentials are presented in the **Annex 1**.

Air Quality Prediction

On the basis that the Guangdong side will continue to align itself with the best practices in the world to curb emissions from its power, transport and industrial sectors in tandem with its economic growth, the mathematical air quality modelling shows that with the full implementation of the Phase I control measures, the proposed new AQO could be achieved subject to suitable allowance for exceedence is provided. To go beyond the proposed new AQO, more radical measures are required in both Hong Kong and Guangdong. Implementation of the Phases II and III measures will further reduce the local emissions and help take us towards achieving the next higher targets, where applicable, under the WHO AQG. These additional measures will require more drastic changes or technologies that are still not yet fully developed.

Air Quality Management Framework

For ensuring better protection of public health, in addition to the adoption of a new set of AQO and formulation of the air quality management plan, it is recommended that a mechanism be established to regularly review and update the air quality standards and the air quality management plan in the light of the latest findings on health effects and technological advancement.

An effective and robust air quality management framework is required to implement the strategy satisfactorily and effectively. This framework should comprise the following elements:

- Establishment of new AQO
- Development and implementation of control measures
- Monitoring of air quality
- Identification and assessment of air pollution problem areas
- Research and educational promotion
- Periodic review of the progress and the AQO

<u>Establishment of new AQO</u>

The new AQO need to be established through the issue of a Technical Memorandum of the APCO. Consideration could be given to spelling out the principle of “the protection of public health” explicitly in the TM when the new AQO are promulgated.

<u>Development and implementation of control measures</u>

Given the different natures of pollution sources, the control strategies can be grouped into six types, namely: Emission capping and control, Transport management, Infrastructure development and planning, Energy efficiency measures, Regional collaboration and Indirect measures. To enable the attainment of the new AQO within a reasonable time frame, new measures have been developed over three phases; Phase I near term, Phase II medium term and Phase III long term according to technological advancement and practicability. Implementation of some of the Phase I control measures could commence early and will contribute to a reduction in pollutant emissions in the near term.

<u>Monitoring of Air Quality</u>

Air quality monitoring data is a key component of the overall Management Framework as it forms the backbone of the review and assessment in determining whether the AQO are being met. The existing air quality monitoring network should be reviewed to ensure that it is serving its purpose and to identify whether there are any data gaps to address. The EPD will continue to issue an annual report that details the monitoring data over the past year and identify new problem areas to address

Identification and assessment of air pollution problem areas

Based on the monitoring data, the compliance status of air quality against the AQO as well as the effectiveness of the control measures can be analysed. Use of this data will identify where there are particular problem areas or episodes that require further attention, investigation and control actions.

Research and Education Promotion

The most critical air pollution problem areas identified will form part of the focus for future studies and research. This in turn will facilitate further development of new control measures and air policy. Upon completion of the API review, a plan should be developed to educate the public on the air pollution risk communication system.

Periodic Review of AQO

A regular review should be introduced to regularly ascertain the extent to which the new AQO have been achieved, the progress of the air management strategy, as well as the need and practicality of further tightening the AQO. Based on overseas experience, an interval of about five years is recommended.

Annex 1

Proposed Phase I Emission Control Measures and Their Respective Emission Reduction Potential and Cost-Benefit Analysis

Emission Capping and Control		Emission Reduction Potential (t)				Cost – Benefit Analysis[1]		
		SO_2	NO_X	RSP / PM_{10}	VOCs	Cost ($M)	Bene-fit ($M)	B / C Ratio[2]
1.	Increasing the ratio of natural gas in local electricity generation to 50% together with additional emission abatement measures[3]	13,402	25,225	523	0	2,032[4]	1,803	0.9[4]
2.	Early retirement of aged / heavily polluting vehicles (pre-Euro, Euro I and Euro II commercial diesel vehicles and franchised buses)	0	3,102	300	184	3,882[5]	24,344	6.3
3.	Earlier replacement of Euro III commercial diesel vehicles with models meeting latest Euro standards	0	743	75	24	2,668[5]	6,134	2.3
4.	Wider use of hybrid / electric vehicles or other environment-friendly vehicles with similar performance (20% private cars and 10% franchised buses)	15	216	7	173	4,326[5]	2,417	0.56
5.	Ultra low sulphur diesel (ULSD) for local vessels	675	0	18	0	378	6,331	16.7
6.	Selective catalytic reduction (SCR) for local vessels	0	304	0	0	249	74	0.30
7.	Electrification of aviation ground support equipment	85	759	21	67	1,449	3.8	0.003
8.	Emission control for off-road vehicles / equipment	4	950	239	326	845	2,123	2.5
9.	Strengthening volatile organic compounds control	0	0	0	700	18	124	6.9
Transport Management								
10.	Low emission zones	Note [6]	Note [6]	Note [6]	Note [6]	3,696	2,586	0.7
11.	Car-free zone / pedestrianisation scheme	Note [6]	Note [6]	Note [6]	Note [6]	42	400	10
12.	Bus route rationalization	4	156	7	9	14	548	39
Infrastructure Development and Planning								
13.	Expand rail network	17	501	46	207	Note [7]	3,850	Note [7]
14.	Cycling network to major public transport hubs	0.1	2.3	0.1	0.1	836	8	0.01
Energy Efficiency Measures [8]								
15.	Mandatory implementation of Building Energy Codes	151	256	8	3	95	2,634	28

Emission Capping and Control		Emission Reduction Potential (t)				Cost – Benefit Analysis[1]		
		SO_2	NO_X	RSP / PM_{10}	VOCs	Cost ($M)	Bene-fit ($M)	B / C Ratio[2]
16.	Energy efficiency standards for domestic electrical appliances	84	142	4	1	84	2,277	27
17.	Light-emitting diode or equivalent alternatives for traffic signal / street lighting	3	5	0.1	0	47	105	2.2
18.	Tree planting / roof-top greening [9]	Note [9]	Note [9]	Note [9]	Note [9]	6,357	1,603	0.3
19.	District cooling system for Kai Tak Development	6	16	0.5	0.2	2,788[10]	4,047	1.5

Notes:

[1] In its simplest form, the costs and benefits of each policy are quantified and valued in monetary terms. The cost-benefit analysis is subject to a wide range of assumptions used by the consultant for compiling the assessment of different proposed emission control measures. As these assumptions are subject to change, the findings of the cost-benefit analysis should be read with caution. Nonetheless, it provides a systematic framework to compare the potential cost-effectiveness of different measures.

[2] A benefit-cost ratio above one indicates that the overall monetized benefits of the proposed measure are expected to be higher than the costs to be borne by the society. A ratio below one indicates the otherwise.

[3] Possible additional emission abatement measures include enhancing the SCR systems of the existing coal-fired units. However, the technical feasibility and financial viability of retrofitting the existing coal-fired units with enhanced SCR systems are not yet established and subject to more detailed examination with the concerned power company.

[4] The figure includes estimated costs due to increasing the ratio of natural gas in local electricity generation to 50%. It does not cover the costs of the additional emission abatement measures, such as enhancing the SCR systems of the existing coal-fired units, the technical feasibility and financial viability of which would be subject to further examination.

[5] The cost of early retirement of the concerned vehicles is calculated based on the residual value foregone of these vehicles over the remaining period of their normal serviceable life. The upfront capital costs required for procuring the replacement vehicles would be higher than the figures set out in the table.

[6] Emission reduction potential would not be substantial as it involves mainly transferring emission from one place to another.

[7] The railway strategy includes the Express Rail Line, the Sha Tin to Central Link (the Tai Wai to Hung Hom section), the West Island Line, the South Island Line (East), the Kowloon Southern Link and the Kwun Tong Line Extension. The railway strategy will have additional ride-on effect on improvement of air quality. Only benefits are presented.

[8] Benefits include material damage, energy saving as well as acute and chronic health benefits. For strategies 15, 16, 17 and 19, the majority of benefits are due to energy savings, not health benefits. Emission reduction of energy efficiency measures is generated from less electricity demand. To be conservative, they have not been included in the net total emission reduction.

[9] The proposed measures help reduce urban heat island effect and improve air pollution dispersion. No local emission and cost data are available. Estimates are based on overseas data for roof top greening of 10% of the urban area.

[10] The figure includes both the capital and operational costs of the plant for the coming 50 years.