AS&H Paper 1/2018

For discussion
On 13 December 2018

Air Quality Objectives Review Working Group
Air Science and Health Sub-group

Assessments on Air Quality for *2025* and the Associated Health and Economic Benefits

PURPOSE

This paper presents the air quality assessment results for *2025* as a result of the implementation of on-going and new air quality improvement measures, the potential scope for further tightening the Air Quality Objectives (AQOs), and the associated health and economic benefits arising from the improvement in air quality.

BACKGROUND

Air Quality Improvements Measures deliberated by the three Sub-groups on Road Transportation, Marine Transportation, and Energy and Power Generation

2. The current AQOs are set out at **Annex A**. The three Sub-groups on Road Transportation, Marine Transportation, and Energy and Power Generation have identified 70 possible new air quality improvement measures and deliberated on the practicability of their implementation, taking into account technical and operational feasibility, trade demand and reactions, cost-effectiveness, implementation time frame and likely public reactions, etc.. Year 2025 has been used as the assessment year, taking into consideration the target of broadly attaining the current AQOs by 2020 and the need to review the AQOs at least once every five years.

3. Among the 70 possible air quality improvement measures identified, 27 of them are considered by the relevant Sub-groups as either on-going or already under consideration by the Government which are likely to produce results by 2025 (**short-term)**. Four measures are considered ready for further deliberation in the next AQOs review period, i.e. before end 2023 (**medium-term measures)**; 13

measures require detailed planning or further study to ascertain the practicability for implementation beyond the next review period (**long-term measures**) and 26 measures are considered by the relevant Sub-groups as not practicable, short of air quality benefits or not suitable to be considered under the current scope of the review (**others**).

4. Another eight possible new measures for other air pollution sources which are not covered in the three Sub-groups, namely products containing volatile organic compounds (VOCs), non-road mobile machinery (NRMM), civil aviation and cooking fumes, were examined separately through the engagement of the Environmental Protection Department (EPD) with relevant stakeholders. Of the eight measures, three are short-term. A summary of the possible new control measures categorized by their practicability of implementation is set out in **Annex B**. Separately, two new Government initiatives[1] for reducing emissions from motor vehicles were announced in the 2018 Policy Address.

Current State of Air Quality

5. As the implementation of various on-going and committed control measures set out in *A Clean Air Plan for Hong Kong*[2] started to bear fruits, there have been substantial improvements in the air quality. Over the past five years, between 2013 and 2017, the ambient concentrations of respirable suspended particulates (RSP/PM_{10}), fine suspended particulates ($FSP/PM_{2.5}$), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) decreased by 26% to 38%, whereas their roadside concentrations reduced by 28% to 36%. Nevertheless, the ambient and roadside concentrations of ozone (O_3), which is a secondary air pollutant potentially attributed to the regional photochemical smog as well as the reduction in nitric oxide (NO) emission from vehicles, resulting in less NO in the atmosphere to react and titrate O_3, exhibited a rising trend and increased by 19% in the ambient and 64% in the roadside during the same period. The air quality in Hong Kong between 2013 and 2017 and compliance status of the current AQOs in 2017 are shown in **Annex C**.

6. Hong Kong's air quality is greatly affected by the surrounding areas and also from afar, apart from local emission sources. To identify the relative

[1] The two new measures included

- Tighten the emission standards for newly registered motor cycles to Euro IV in 2020
- Launch an incentive-cum-regulatory scheme to progressively phase out Euro IV diesel commercial vehicles by end of 2023

[2] The Clean Air Plan for Hong Kong was released in March 2013 to set out the strategy for improving the air quality and a list of air quality improvement measures. The Plan was subsequently updated in June 2017.

contributions of local and regional emission sources to the ambient $PM_{2.5}$ level in Hong Kong, source apportionment (using Positive Matrix Factorisation, PMF[3]) was conducted by analyzing filter-based samples collected in 2015 at eight Environmental Protection Department (EPD)'s air quality monitoring stations[4]. Nine factors were identified by the PMF, including vehicle exhaust, residual oil, fresh sea salt, aged sea salt, crustal soil, secondary sulphate (ammonium sulphate $(NH_4)_2SO_4$ or ammonium bisulphate (NH_4HSO_4), secondary nitrate (NH_4NO_3), trace metals and biomass burning. The factors could be roughly classified into local and non-local origin[5] based on their patterns of seasonal and spatial variation. The PMF results are then broadly delineated into clean days (FSP < 35μg/m^3) (the cut-off point of 35 μg/m^3 is the World Health Organisation (WHO) Interim Target-1 (IT-1) level), light pollution days (FSP was ranged from 35 to 50 μg/m^3) and high pollution days (FSP > 50 μg/m^3). PMF results show that total contribution of local sources accounted for 38% of total $PM_{2.5}$ level during clean days, but decreased to 22% during light pollution days and 13% during high pollution days (see **Annex D**). This reveals the significant contribution by non-local sources to the ambient $PM_{2.5}$ level, particularly during light and heavy pollution days. Nevertheless, one should note that the results are indicative only given pollutants will undergo different chemical reactions under varied meteorological conditions.

ASSESSMENT RESULTS

7. This Sub-group has at the past meetings endorsed the approaches and methodologies for air quality assessment and the health and economic impact assessment proposed by its Task Forces (namely "Emission Reduction Estimation & Air Quality Modelling (E&AQ) Task Force" and "Health & Economic Impact Assessment (HEIA) Task Force"). Accordingly, the assessment results are provided in the ensuing paragraphs.

Assessments on Air Quality

8. The air quality of Hong Kong in 2020 and 2025 have been assessed based on the projected emissions in 2020 and 2025, respectively. The emissions were

[3] PMF is a factor analysis method for estimating profiles and contributions of emission sources.

[4] The eight air quality monitoring stations include Mong Kok, Central/Western, Clear Water Bay, Tung Chung, Tsuen Wan, Yuen Long, Kwai Chung and Hok Tsui.

[5] Among the nine sources identified by PMF, *vehicle exhaust, sea spray such as fresh sea salt and aged sea salt, as well as residual oil used in vessels* are considered as "local sources". *Secondarily formed nitrate and sulphate, biomass burning and trace metals metals (e.g. zinc (Zn), manganese (Mn), arsenic (As), manganese (Mn) and Pb)* are considered non-local as these could be laden by regional transport especially during the wintertime when north or north westerlies wind is prevailing.

estimated according to the Hong Kong & Pearl River Delta (PRD) regional emission targets, emission reductions arising from the implementation of on-going and committed measures, short-term measures identified by the three Sub-groups that are with quantifiable results, as well as the new Government initiatives in the 2018 Policy Address as mentioned in paragraphs 3 & 4.

9. The air quality assessment results indicate that there would be continuous improvement in PM_{10}, $PM_{2.5}$, NO_2 and SO_2, while O_3 levels would have slight increase. The relevant figures are summarised in Table 1 and the pollutant concentration distributions over the Hong Kong territory are illustrated in **Annex E**.

Table 1: Comparison of 2020 & 2025 air quality assessment and the air quality recorded in 2015

Pollutants	Averaging Time	Prevailing HK AQOs		2015 Air Quality [a]		2020 Air Quality Assessment [b]		2025 Air Quality Assessment [b]	
		Conc. ($\mu g/m^3$)	No. of Exceedance Allowed Amongst Stations	Conc. ($\mu g/m^3$)	Highest No. of Exceedance Amongst Stations	Conc. ($\mu g/m^3$)	Highest No. of Exceedance	Conc. ($\mu g/m^3$)	Highest No. of Exceedance
PM_{10}	Annual	50 (IT-2)	NA	45	NA	38	NA	37	NA
	24-hr	100 (IT-2)	9	110 (10th highest)	18	91 (10th highest)	6	90 (10th highest)	6
$PM_{2.5}$	Annual	35 (IT-1)	NA	30	NA	25	NA	24	NA
	24-hr	75 (IT-1)	9	78 (10th highest)	11	72 (10th highest)	8	72 (10th highest)	8
NO_2	Annual	40 (AQO)	NA	64	NA	69	NA	67	NA
	1-hr	200 (AQO)	18	271 (19th highest)	67	206 (19th highest)	20	199 (19th highest)	18
SO_2	24-hr	125 (IT-1)	3	58 (4th highest)	0	51 (4th highest)	0	26 (4th highest)	0
O_3	8-hr	160 (IT)	9	182 (10th highest)	24	207 (10th highest)	29	216 (10th highest)	30

Notes:
NA – Not Applicable
a. 2015 air quality is based on the measurement data of 12 general air quality monitoring stations. Highest concentration among the 12 general air quality monitoring stations is presented.
b. 2020 & 2025 air quality assessment result is based on the territorial wide air quality modelling outcome. Spatial maximum concentration and maximum number of exceedances are presented.

10. The AQOs for NO_2, SO_2 (10-min), carbon monoxide (CO) and lead (Pb) are already set at the most stringent WHO Air Quality Guidelines (AQGs) levels. Hence our focus are on PM_{10}, $PM_{2.5}$, SO_2 (24-hr) and O_3, with a view to identifying possible scope for further tightening the current AQOs based on the air quality assessment results for Hong Kong in 2025.

11. The 2025 air quality assessment results show that if the AQOs for **PM_{10}** and **O_3** are to be tightened to the next Interim Target (IT) level, i.e. IT-3 and AQG respectively, the concentrations of **PM_{10} and O_3** in 2025 will not be able to meet the AQOs, as set out in Table 2 below. In fact, the concentrations in most areas in

Hong Kong will far exceed the AQOs.

Table 2: Comparison of 2025 air quality assessment with the next higher level of the AQOs for PM_{10} and O_3

Pollutants	Averaging Time	Prevailing HK AQOs		Next Higher Standard (µg/m³)	2025 Air Quality Assessment Results[a]	
		Conc. (µg/m³)	No. of Exceedance Allowed Amongst Stations		Conc. (µg/m³)	Highest No. of Exceedance against the Next Higher Standard
PM_{10}	Annual	50 (IT-2)	NA	30 (IT-3)	37	NA
	24-hr	100 (IT-2)	9	75 (IT-3)	90 (10th highest)	22
O_3	8-hr	160 (IT)	9	100 (AQG)	216 (10th highest)	113

Notes:
NA – Not Applicable
a. 2025 air quality assessment result is based on the territorial wide air quality modelling outcome. Spatial maximum concentration and maximum number of exceedances are presented.

12. The assessment results indicate that AQO for **SO_2 (24-hr)** can meet the next IT level (IT-2) at 50µg/m³ (Table 3), with the current number of exceedance allowable (three) remains unchanged.

Table 3: Comparison of 2025 air quality assessment with the next higher level of AQOs for SO_2

Pollutants	Averaging Time	Prevailing HK AQOs		Next Higher Standard (µg/m³)	2025 Air Quality Assessment Results [a]	
		Conc. (µg/m³)	No. of Exceedance Allowed Amongst Stations		Conc. (µg/m³)	Highest No. of Exceedance against the Next Higher Standard
SO_2	24-hr	125 (IT-1)	3	50 (IT-2)	26 (4th highest)	0

Notes:
a. 2025 air quality assessment result is based on the territorial wide air quality modelling outcome. The maximum number of exceedances is presented.

13. For **$PM_{2.5}$**, the annual averaged concentration in 2025 can possibly meet the next IT level (IT-2) at 25µg/m³. There is potential for $PM_{2.5}$ 24-hour concentration to meet IT-2 level (50µg/m³), if the number of allowable exceedances is to be relaxed from the current nine to 35[6] (Table 4).

[6]According to the air quality modelling results, the number of exceedances against IT-2 is 33. A certain extent of buffer is needed, and hence it would be more realistic if the maximum number of allowable exceedances is set at 35. The European Union also allows 35 exceedances for the 24-hour air quality standard for PM_{10} though its PM_{10} standard (50µg/m³) is more stringent than Hong Kong's prevailing AQO (100µg/m³).

Table 4: Comparison of 2025 air quality assessment with the next higher level of AQOs for $PM_{2.5}$

Pollutants	Averaging Time	Prevailing HK AQOs		Next Higher Standard ($\mu g/m^3$)	2025 Air Quality Assessment Results [a]		
		Conc. ($\mu g/m^3$)	No. of Exceedance Allowed Amongst Stations		Conc. ($\mu g/m^3$)		Max. No. of Exceedance against the Next Higher Standard
$PM_{2.5}$	Annual	35 (IT-1)	NA	25 (IT-2)	24		NA
	24-hr	75 (IT-1)	9	50 (IT-2)	72 (10th highest)	49 (36th highest)	33

Notes:
NA – Not Applicable
a. 2025 air quality assessment result is based on the territorial wide air quality modelling outcome. Spatial maximum concentration and maximum number of exceedances are presented.

Health and Economic Impact Assessment (HEIA)

14. Exposure to air pollution has been associated with a variety of adverse health effects such as respiratory and cardiovascular effects attributed to short- and long-term impact. During the review, the health impact, including both short-term and long-term of selected health outcomes, for the exposure to the predicted air pollutant concentration between 2015 and 2025 are quantified and monetised. The HEIA is based on a tool developed by the Chinese University of Hong Kong[7]. Locally available concentration-response (CR) functions (or the relative risks) that relate to the percentage change in the health outcome to a unit change in air pollutant concentration, have been adopted as far as practical, otherwise, references from the WHO are adopted (see **Annex F**). The health statistics such as mortality and morbidities (e.g. respiratory and cardiovascular diseases) were obtained from the Census and Statistics Department and the Hospital Authority. The economic value of the health impact attributable to the changes in air quality level between 2015 (base year) and 2025 (target year) have been monetized as a reference. All costs are adjusted to 2017 values.

[7] The study "Developing an Instrument for Assessing the Health and Economic Impacts of Air Pollution in Hong Kong" (Tool Study) commissioned by EPD was completed in 2016. In the study, a tool was developed based on the internationally accepted methodologies incorporating the local health statistics and air quality data. The association between long term and short term exposures of air pollution and the health outcomes are usually established by cohort studies, time-series studies and statistical models. For mortalities, concentration-response (CR) functions recommended by WHO were adopted in the study owing to a lack of local CR functions. For morbidities, local CR functions were adopted. To assess the health impact of air pollution, the pollutant concentration values of WHO AQGs were taken to be the reference level, assuming the health impact of the pollutant concentration level below the WHO AQGs was zero. Though pollutant concentrations below this level still have health effects, statistical uncertainties in the exposure-response function below the WHO AQG levels are much higher.

15. Improvement in air quality can bring direct health benefits, such as reducing premature death, hospital admission, clinic visits, and medical cost in particular to respiratory and cardiovascular diseases, and indirectly raising labour productivity. Based on the air quality assessment results of 2025, improvement in the long-term exposure (in terms of annual concentration level of $PM_{2.5}$ and NO_2) could reduce about 1,850 premature deaths, as compared with 2015. The predicted reduction in NO_2 concentration to below the AQO level could reap the most health benefits[8]. Based on the "value of a statistical life" (VOSL) approach[9] and with an estimated VOSL value of about HK$18 million[10], the monetary gain in preventing the premature death was estimated at a total of about HK$ 33 billion (equivalent to about 1,850 premature deaths saved). About 1,530 cases of hospital admission and 262,580 cases of clinic visits (both public and private practitioners) could be saved owing to improvement in short-term exposure (in terms of 1-hr or 24-hr concentration levels) of air pollutants, in particular the improvement of 1-hr concentration level of NO_2, as compared with 2015. The corresponding direct savings from hospital admissions and clinic visits[11] were estimated at about HK$ 96 million while the saving in productivity loss[12] which was broadly estimated at about HK$ 150 million. Nevertheless, the slight increase in O_3 concentration level in 2025, as above-mentioned in paragraph 9, could offset some of the health benefits[13] owing to short-term exposure of air pollutants. The related cost saved is provided in **Annex G**.

---

8 In spite of the existing associations between long-term exposure to $PM_{2.5}$ and mortality/morbidity are the strongest described in the journal references, the present review identified the predicted NO_2 reduction would yield the most benefit.

9 The "VOSL" approach refers to the amount of money a person (or society) is willing to spend to save a life. It is derived from the trade-offs people are willing to make between fatality risk and wealth. Hence, it varies among different areas/countries and could be diverse. The measurement of monetary gain in preventing premature mortality based on the VOSL approach is only for indicative purpose.

10 The VOSL used in the assessment is derived from the Tool Study (see paragraph 14), which was based on the average of VOSL in 2012 from European WHO Regional Office Report (US$2,872,817, as the upper limit) and VOSL in China from a World Bank reference (US$1,171,048 as the lower limit). These values were adjusted to the price in 2017 based on composite consumer price index, at about HK$18,103,200. These two references entailed the upper and lower bounds of the VOSL.

11 The savings due to the potential reduction in hospital admissions of patients with cardiovascular and respiratory diseases through the Accidents and Emergency Departments operated by the Hospital Authority are referenced to the unit attendance cost at HK$1,230 (as of 2017 value). The unit costs of clinic visits to general practitioner (GP) and general outpatient clinic (GOPC) are based on the Tool Study at respectively at $250 (the value adopted from the Tool Study) and $445 (as of 2017 value).

12 The associated productivity loss due to hospital admission and clinic visit is estimated based on the median length of hospital stay (four days for cardiovascular and 3 days for respiratory illnesses) and a sick leave of one day granted by the attending doctor. Nevertheless, the productivity loss is only a broad-brush estimate for reference only given that different estimation methods (e.g. different lengths of hospital stay, different lengths of sick leave) may yield quite different results.

13 The hospital admission and clinic visits (for public and private practitioners) owing to the predicted increase in ozone concentration in 2025 were estimated at about 30 cases and 8,210 cases respectively. The corresponding costs on these short-term impact such as hospital admission, clinic visits and productivity loss were estimated at about HK$ 7 million.

POTENTIAL SCOPE TO FURTHER TIGHTENING THE AQOs

16. As set out in the onset of the Review, we shall adopt a progressive approach to update the AQOs by benchmarking against the AQGs and interim targets of the WHO. Having regard to the 2025 air quality assessment results as set out in paragraphs 11 to 13, there is scope for tightening AQOs of SO_2 and $PM_{2.5}$ (i.e., if the AQOs are tightened, the concentrations of the pollutants could possibly meet the tightened AQOs by 2025) as below:

(i) the 24-hour AQO for SO_2 can be tightened from the WHO AQGs IT-1 level at 125μg/m^3 to IT-2 level at 50μg/m^3 with the current number of exceedance allowed (three) remains unchanged; and

(ii) the annual AQO for $PM_{2.5}$ can be tightened from IT-1 (35μg/m^3) to IT-2 (25μg/m^3), and its 24-hr AQO from IT-1 (75μg/m^3) to IT-2 (50μg/m^3), with the number of exceedances allowed increased from current nine to 35.

ADVICE SOUGHT

17. Members are invited to offer views on the assessments and the potential scope to further tighten the AQOs as set out in paragraph 16.

Environment Bureau / Environmental Protection Department
December 2018

Annex A

Hong Kong Air Quality Objectives (AQOs) vs. World Health Organisation Air Quality Guidelines (AQGs)

Pollutants	Averaging Time	Prevailing HK AQOs		World Health Organization Air Quality Guidelines			
		Conc. (μg/m^3)	No of Exceedances Allowed	WHO IT-1[1] (μg/m^3)	WHO IT-2[1] (μg/m^3)	WHO IT-3[1] (μg/m^3)	WHO AQGs (μg/m^3)
Respirable Suspended Particulates (PM_{10})	24-hr	100 (IT-2)	9	150	**100**	75	50
	Annual	50 (IT-2)	NA	70	**50**	30	20
Fine Suspended Particulates ($PM_{2.5}$)	24-hr	75 (IT-1)	9	**75**	**50**	37.5	25
	Annual	35 (IT-1)	NA	**35**	**25**	15	10
Nitrogen Dioxide (NO_2)	1-hr	200 (AQGs)	18	-	-	-	**200**
	Annual	40 (AQGs)	NA	-	-	-	**40**
Sulphur Dioxide (SO_2)	10-min	500 (AQGs)	3	-	-	-	**500**
	24-hr	125 (IT-1)	3	**125**	**50**	-	20
Carbon Monoxide (CO)	1-hr	30,000 (AQGs)	0	-	-	-	**30,000**
	8-hr	10,000 (AQGs)	0	-	-	-	**10,000**
Ozone (O_3)	8-hr	160 (IT)	9	**160**	-	-	100
Lead (Pb)	Annual	0.5	NA	-	-	-	**0.5**

Note:

[1] IT – WHO's interim targets

xx	**Current AQOs adopted**

Annex B

Possible New Air Quality Improvement Measures

A. PRACTICABILITY OF IMPLEMENTATION

The practicability to implement the possible new measures are identified as follows,

(a) "Short-term" measures refer to those that are either on-going or ready under consideration by the government which are likely to produce results by 2025 or earlier;

(b) "Medium-term" measures refer to those that may be ready for consideration in the next AQOs review period of 2019 – 2023;

(c) "Long-term" measures refer to those that require detailed planning or further study to ascertain the practicability for implementation beyond the next review period;

(d) “Others” refer to those that are not practicable, short of air quality improvement benefits or not suitable to be considered under the current scope of the AQOs review.

B. KEY EMISSION SOURCES

Possible short-term new air quality improvement measures

Road Transportation

1. Review the tunnel toll policy and level to alleviate traffic congestion, thereby reducing the emission caused by congestion at the tunnels
2. Establish a maintenance information database of vehicle tailpipe emission system
3. Raise awareness on the importance of vehicle maintenance and repair
4. Foster "pedestrian-friendly" environment (such as widening of footpaths, construction of covered walkways and enhancing the pedestrian connections) to encourage people to walk in *existing new towns and urban areas* (Possible short-term and medium-term)
5. Foster “bicycle-friendly” environment and study into the provision of ancillary facilities for cycling (such as provision of cycling track network and bicycle parking spaces, park-and-ride facilities at public transport interchanges and bike-friendly policies to facilitate carriage of bicycles on public transport) in existing new towns and urban areas. (Possible short and medium-term) [Note: Cycling for commuting purposes in urban areas is not encouraged on road safety grounds.]

6. Use urban planning and design solutions together with transport management to improve air ventilation in high density development
7. Enhance district-based publicity on bus route rationalisation*
8. Manage the growth of vehicles in particular private cars#
9. Enhance enforcement against illegal parking
10. Review on-street metered parking fees
11. Launch one-stop mobile app for the public to choose the most time-saving, economical and low-emission transportation mode^
12. Launch one-stop mobile app for the public to access real-time information on car parking vacancies which helps them choose the best parking location and shortening the driving distance^
13. Introduce intelligent transport systems (e.g. manage traffic flow by traffic signal control, install smart sensors and surveillance cameras for illegal parking enforcement) <u>(This measure is considered as possible short, medium, and long-term practicality for implementation.)</u>
14. Raise public awareness on environmental protection, promote green living and encourage the public to use public transport systems as well as low emission transportation options

Marine Transportation

15. Ocean-going vessels (OGVs) at berth to use marine diesel with lower fuel sulphur content, e.g. not exceeding 0.1%*
16. Local vessels to use electricity from the power grid while at berth*

Energy and Power Generation

17. Encourage stakeholders in the commercial sector and the non-government sector, e.g. universities and hospital to adopt demand-side management measures*
18. Explore building energy efficiency measures for old existing buildings which are not covered by the Buildings Energy Efficiency Ordinance*
19. Encourage or provide incentives for the private sector to develop distributed renewable energy (RE)*
20. Facilitate distributed RE systems to connect to the power grid*
21. Encourage the development of more waste-to-energy facilities, such as waste incinerators, organic resources recovery centres, etc. for waste disposal as well as recovering energy for local use*
22. Increase the use of wind and solar energy in electricity generation*
23. Replacement of coal-fired generating units by gas-fired units*
24. Upgrade burners of gas-fired generating units to improve fuel efficiency and emission performance*

25. Review operations of gas-fired power generating units with a view to identifying further emission reduction potential
26. Explore the use of waste materials such as corncobs, waste wooden pallets (i.e. biomass) as fuel*
27. Encourage major electricity users to reduce peak load demand so as to reduce the operation and emissions from coal-fired generating units for coping with peak load demand

    [Updates: In the light of the approval of the power companies' 2018-2033 Development Plans by the Government in July 2018, the power companies will replace their electromechanical meters by smart meters in seven years to support the energy efficiency & conservation initiatives (including reducing peak load demand) under the post-2018 Scheme of Control Agreements. Hence, this long-term measure as deliberated in the Energy and Power Generation Sub-group is proposed to bring forward as a short-term measure subject to Members' agreement.]

Possible medium-term new air quality improvement measures

Road Transportation

1. Conduct comprehensive review on the development of road transportation infrastructure and networks (such as construction of new tunnels and roads) to cope with population growth and to tackle road traffic congestion
2. Address the personal and operational needs of heavy vehicle drivers, such as provision of parking space and arrangement of meal and rest breaks at the Kwai Chung Container Terminals area, so as to reduce air pollution arising from idling engines

Marine Transportation

3. Impose emission standards on outboard engines of local vessels
4. Explore financial incentive and disincentive schemes to encourage liners to use less polluting OGVs calling Hong Kong ports

Possible long-term new air quality improvement measures

Road Transportation

1. Foster "pedestrian-friendly" environment (such as widening of footpaths, construction of covered walkways and enhancing the pedestrian connections) to encourage people to walk in *new towns and new development areas (NDAs)*
2. Foster "bicycle-friendly" environment and study into the provision of ancillary facilities for cycling (such as provision of cycling track network and bicycle parking spaces, park-and-ride facilities at public transport interchanges and bike-friendly policies to facilitate carriage of bicycles on public transport) in

new towns and NDAs (Possible long-term) [Note: Cycling for commuting purposes in urban areas is not encouraged on road safety grounds.]

3. Set up cycling and walking shared space at harbourfront areas.
4. Electric vehicles pilot schemes - switching the existing vehicle fleet of selected routes to electric vehicles
5. Implement electronic road pricing scheme to tackle road traffic congestion at busy roads
6. Through proper land use planning to redress the current imbalance in home-job distribution and bring jobs closer to home so as to reduce commuting time and private car usage
7. Provide low-emission transport mode to the residents of NDAs

Marine Transportation

8. Explore the use of Liquefied Natural Gas for marine vessels
9. Explore the use of biofuel (e.g. B5), fuel cell, Liquefied Petroleum Gas , compressed natural gas, methanol, nuclear and renewable energy, e.g. wind and solar energy, etc. for marine vessels
10. Explore the use of hybrid, diesel electric and electric vessels
11. OGVs to use onshore power supply (OPS) while at berth at Cruise Terminal
12. Encourage academia to carry out studies on fuel and energy efficient measures in terms of operation and maintenance for local vessels; and collaboration between academia and local marine trade for the development of best practice guidelines and award system to facilitate adoption of the measures

Energy and Power Generation

13. Explore the use of old EV batteries as an electrical energy storage system for the power grid

<u>Other measures considered as not practicable, short of air quality benefits or not suitable to be considered under the current scope of the Review</u>

Road Transportation

1. Consider replacing the existing toll collection system with completely automatic systems
2. Propose to use chassis dynamometer for testing vehicle tailpipe emissions
3. Tighten the annual vehicle examination for private cars from over six years old to over three years old (or consider adopting vehicle kilometres travelled as the vehicle examination criterion)
4. Provide vehicle tailpipe emission testing equipment for rent by small and medium-sized vehicle repair workshops
5. Establish lower vehicle speed limits zones (e.g. 30km/h) in community roads,

school zone and areas with elderly centres, to foster pedestrian environment (Note: This measure has been assessed together with "Foster pedestrian-friendly environment" above as it carries the same spirit.)

6. Tram or electric bus interchange schemes at busy road sections (e.g. Nathan Road) to replace the franchised bus services so as to reduce the number of buses and boarding/alighting passengers on the road section
7. Promotion of hybrid private cars
8. Exploring the use of new-energy vehicles
9. Provide information on the energy efficiency, emission performance and noise level of vehicles, etc. to facilitate the public to make a more environmentally-friendly choice
10. Set out objectives/policies to support the use of cleaner vehicle fuels
11. Extend the coverage areas of the existing low emission zones and its restriction to other vehicle types
12. Set up a continuous and effective priority road network for public vehicles
13. Review the policy on replacement of franchised buses
14. Provide funding to support District Councils for implementing air quality improvement projects
15. Raise the first registration tax and annual licence fees of more polluting vehicles[#]

Marine Transportation

16. River trade vessels to use OPS while at berth at terminals
17. Ocean-going vessels to use OPS while at berth at container terminals
18. Install emission reduction device (e.g. particulate filters) to reduce particulate matters emitted from local vessels
19. Impose control on nitrogen oxides emissions from engines of local vessels
20. Optimise port efficiency to shorten waiting and turnaround time of OGVs, river trade vessels at container terminals, river trade terminals and public cargo working areas
21. Slow-steaming of OGVs in Hong Kong waters
22. Remove floating rubbish for smooth operation of small local vessels (Note: This measure is not related to air quality improvement not further discussed in the respective Marine Transportation Sub-Group.)
23. Government to expedite the approval process of new local vessels (Note: This measure is not related to air quality improvement not further discussed in the respective Marine Transportation Sub-Group.)

Energy and Power Generation

24. Consider importing more nuclear electricity from the Mainland
25. Explore the idea of "SolarRoad" for promoting the use of solar energy
26. Explore the feasibility of using electric vehicles (EV) as electrical energy storage for power grid

Remarks:

*These are short-term measures that have quantifiable emission reduction results.

#The original title of this measure entails two ideas with different practicalities for implementation, one considered as short-term and the other is not practicable for implementation. For clarity, it is suggested to split into two.

^The Transport Department has launched an all-in-one mobile application "HKeMobility" since July 2018 which integrated the mobile applications namely "Hong Kong eTransport", "Hong Kong eRouting" and "eTraffic News". The public can acquire real-time traffic and transport information anytime and anywhere to plan their journeys in a single mobile app.

C. OTHER EMISSION SOURCES

Possible short-term new air quality improvement measures

VOC-containing Products *Note 1*

1. Review the feasibility to impose VOC limits on consumer products that are not regulated under the Air Pollution Control (Volatile Organic Compounds) Regulation*
2. Review the feasibility to further tighten the VOC limits on regulated architectural paints*

Non-Road Mobile Machinery

3. Explore the feasibility to further tighten the emission standards on non-road vehicles newly supplied to Hong Kong*

Possible medium-term new air quality improvement measures

Non-Road Mobile Machinery

1. Explore the feasibility to further tighten the emission standards on regulated machines newly supplied to Hong Kong

Cooking Fume Emissions

2. Explore the feasibility of using new types of air pollution control equipment
3. Promote "low-emission" cooking (e.g. use of clean and efficient cooking stoves and healthy cooking style, etc.)

Possible new air quality improvement measures - Others

Non-Road Mobile Machinery

1. Explore the feasibility of retrofitting exempted regulated machines and non-road vehicles to improve their emission performance (Note: we have further explored the feasibility and practicality of certain regulated machines such as generators and air compressors for retrofitting diesel particulate removal devices.)

Civil Aviation

1. Review on aviation emission control in the local context (Note: This emission control has followed the international practice.)

Note 1: The Air Pollution Control (Volatile Organic Compounds) Regulation (VOC Regulation) sets limits on the VOC contents of 51 types of architectural paints/coatings, 7 types of printing inks and 6 broad categories of consumer products (air fresheners, hairsprays, multi-purpose lubricants, floor wax strippers, insecticides and insect repellents) in phases starting from 1 April 2007, and was amended in October 2009 to extend the control in phases starting from 1 January 2010 to other high VOC-containing products, namely 14 types of vehicle refinishing paints/coatings, 36 types of vessel and pleasure craft paints/coatings, and 47 types of adhesives and sealants.

Remarks: *These are short-term measures that have quantifiable emission reduction results.

Annex C

Concentrations of key air pollutants from 2013 to 2017

Ambient Air Quality

Pollutants	Concentration (µg/m^3)					% Difference 2017 vs 2013
	2013	2014	2015	2016	2017	
Respirable Suspended Particulates (RSP/PM_{10})	47	43	39	34	35	-26%
Fine Suspended Particulates (FSP/$PM_{2.5}$)	31	29	25	22	22	-29%
Nitrogen Dioxide (NO_2)	54	49	49	47	40	-26%
Sulphur Dioxide (SO_2)	13	11	10	9	8	-38%
Ozone (O_3)	43	46	42	39	51	19%

Roadside Air Quality

Pollutants	Concentration (µg/m^3)					% Difference 2017 vs 2013
	2013	2014	2015	2016	2017	
Respirable Suspended Particulates (RSP/PM_{10})	57	50	45	38	39	-32%
Fine Suspended Particulates (FSP/$PM_{2.5}$)	37	32	30	26	26	-30%
Nitrogen Dioxide (NO_2)	120	102	99	82	86	-28%
Sulphur Dioxide (SO_2)	11	9	8	7	7	-36%
Ozone (O_3)	14	21	19	19	23	64%

AQOs Compliance Status in 2017

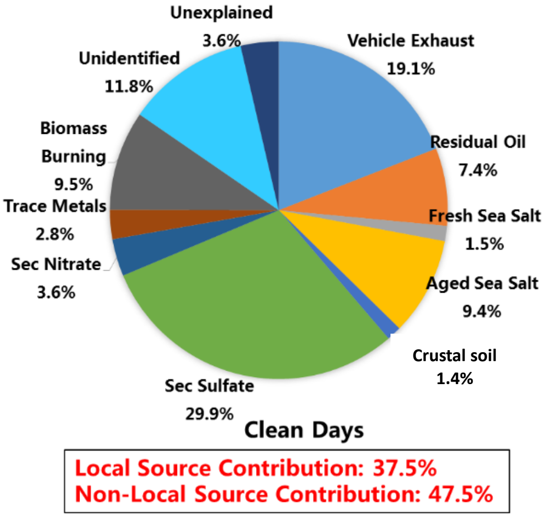
Station		Long-term				Short-term							
		PM_{10}	$PM_{2.5}$	NO_2	Pb	O_3	NO_2	PM_{10}	$PM_{2.5}$	SO_2		CO	
		1-year			1-year	8-hr	1-hr	24-hr	24-hr	10-min	24-hr	1-hr	8-hr
General Station	Central/Western	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	--	--
	Eastern	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	--	--
	Kwun Tong	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	--	--
	Sham Shui Po	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	--	--
	Kwai Chung	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	--	--
	Tsuen Wan	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Tseung Kwan O	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓
	Yuen Long	✓	✓	✗	✓	✗	✓	✓	✓	✓	✓	✓	✓
	Tuen Mun	✓	✓	✗	✓	✗	✓	✓	✓	✓	✓	✓	✓
	Tung Chung	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓
	Tai Po	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	--	--
	Sha Tin	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	--	--
	Tap Mun	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓
Roadside Station	Causeway Bay	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓
	Central	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓
	Mong Kok	✓	✓	✗	✓	✓	✗	✓	✓	✓	✓	✓	✓

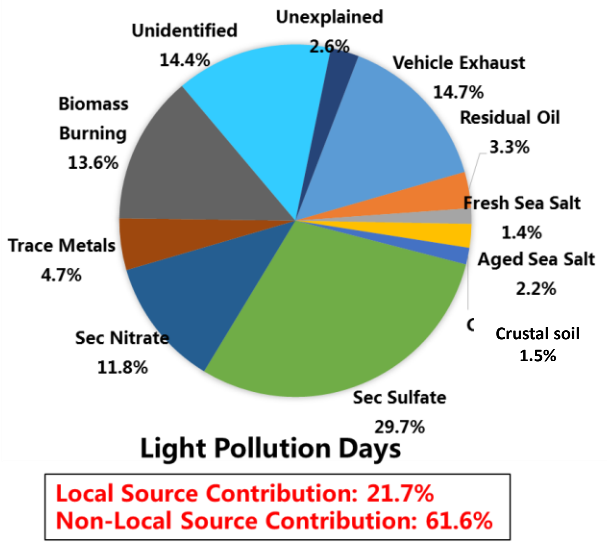
Notes:
"✓" Complied with the AQO
"✗" Not in compliance with the AQO
"--" Not measured

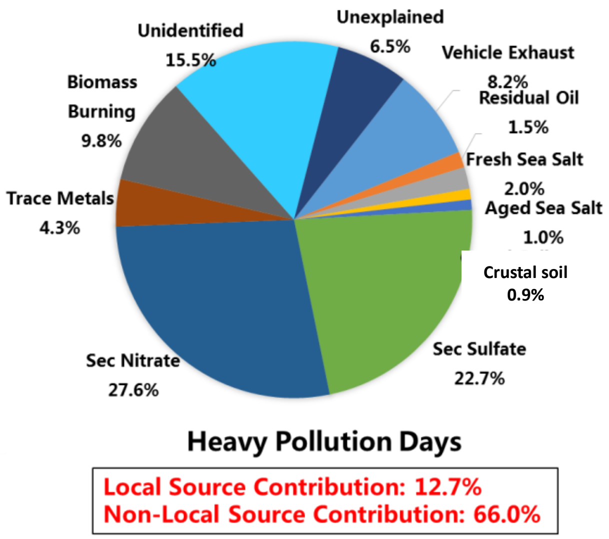
Annex D

Source Contribution Patterns of Ambient $PM_{2.5}$

During Clean days ($PM_{2.5}$ <35µg/m^3), Light Pollution Days ($PM_{2.5}$: 35-50µg/m^3)
and Heavy Pollution Days ($PM_{2.5}$ >50µg/m^3)







Note:

1. 'Unidentified' represents the difference between $PM_{2.5}$ measured mass and reconstructed mass (reconstructed $PM_{2.5}$ mass = [geological material] + [organic mass] + [soot] + [sulphate] + [ammonium] + [nitrate] + [soluble sodium] + [total potassium] + [trace elements], [geological material] = 1.89×[Al] + 2.14×[Si] + 1.4×[Ca] + 1.43×[Fe]).
2. 'Unexplained' represents the difference between the sum of nine factors and reconstructed mass.

Annex E1

PREDICTED AIR QUALITY IN 2020

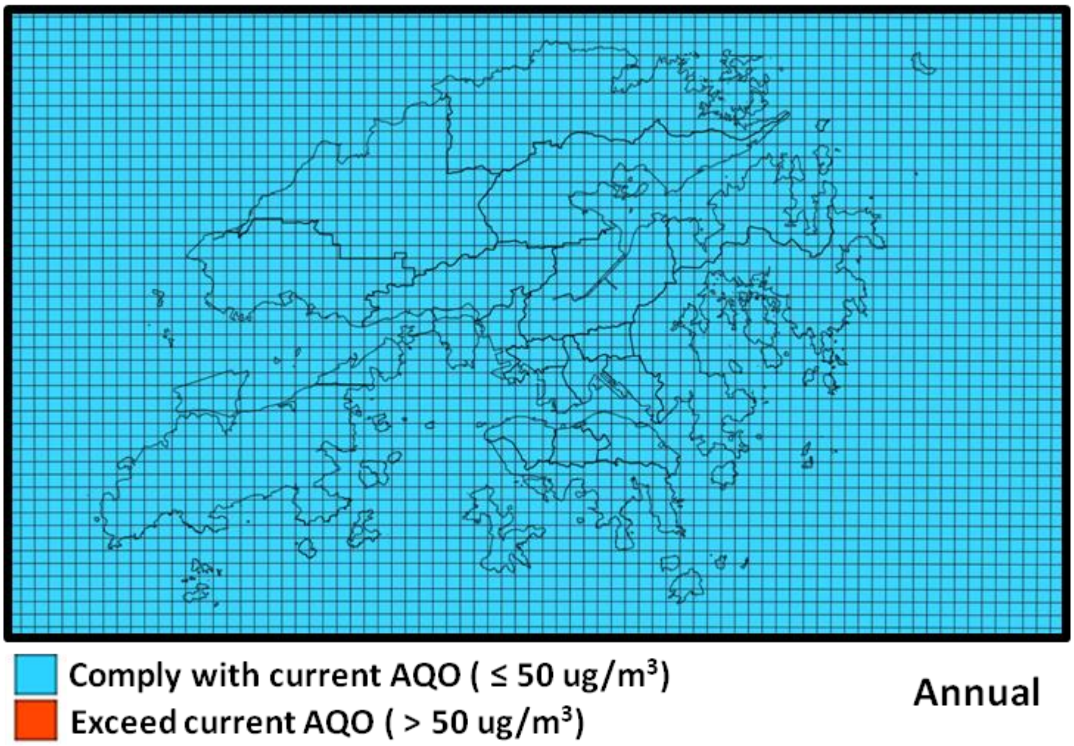


Figure E1 – Annual PM_{10} compliance in 2020

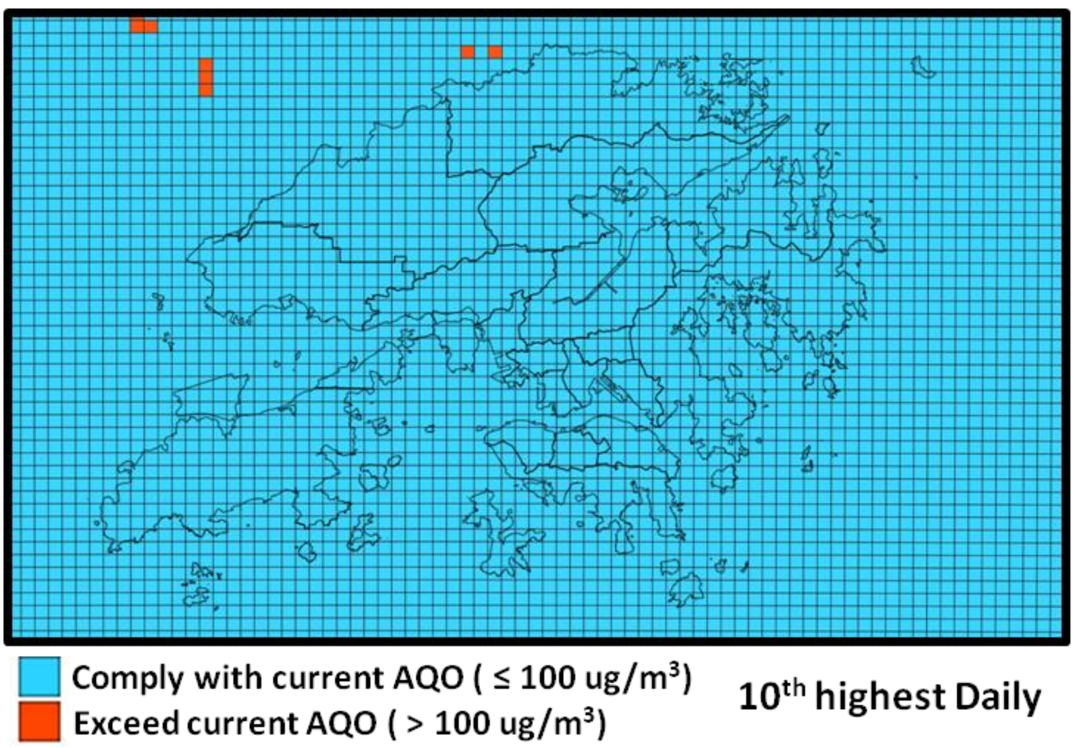


Figure E2 – 10th highest daily PM_{10} compliance in 2020

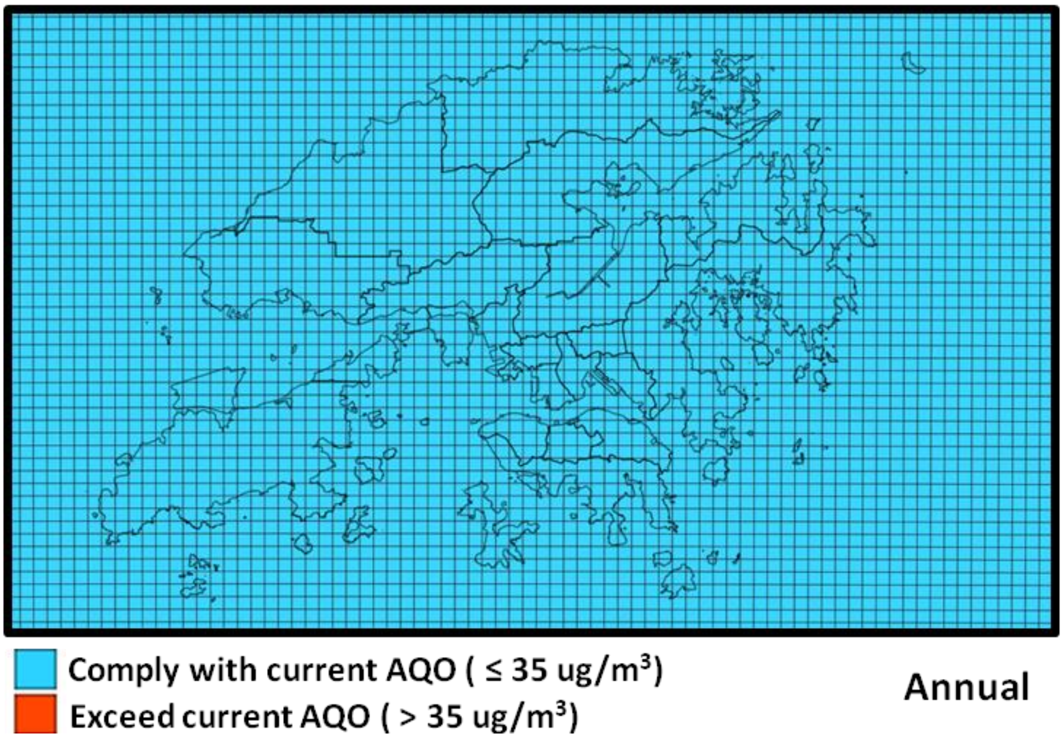


Figure E3 – Annual $PM_{2.5}$ compliance in 2020

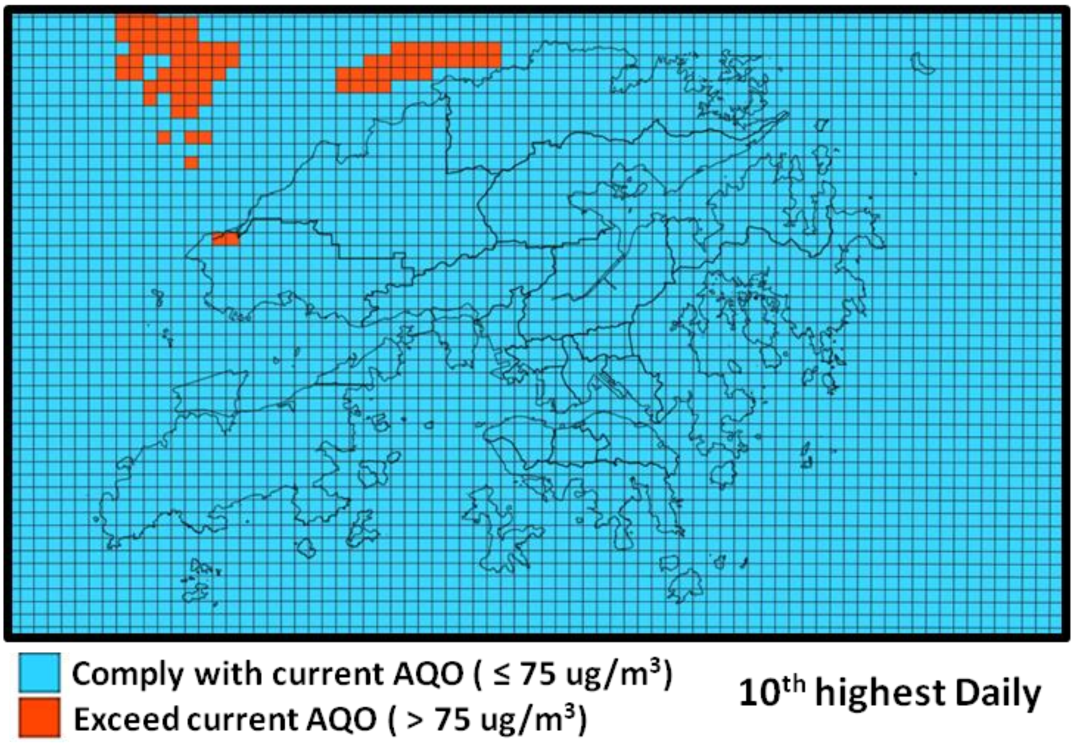


Figure E4 – 10th highest daily $PM_{2.5}$ compliance in 2020

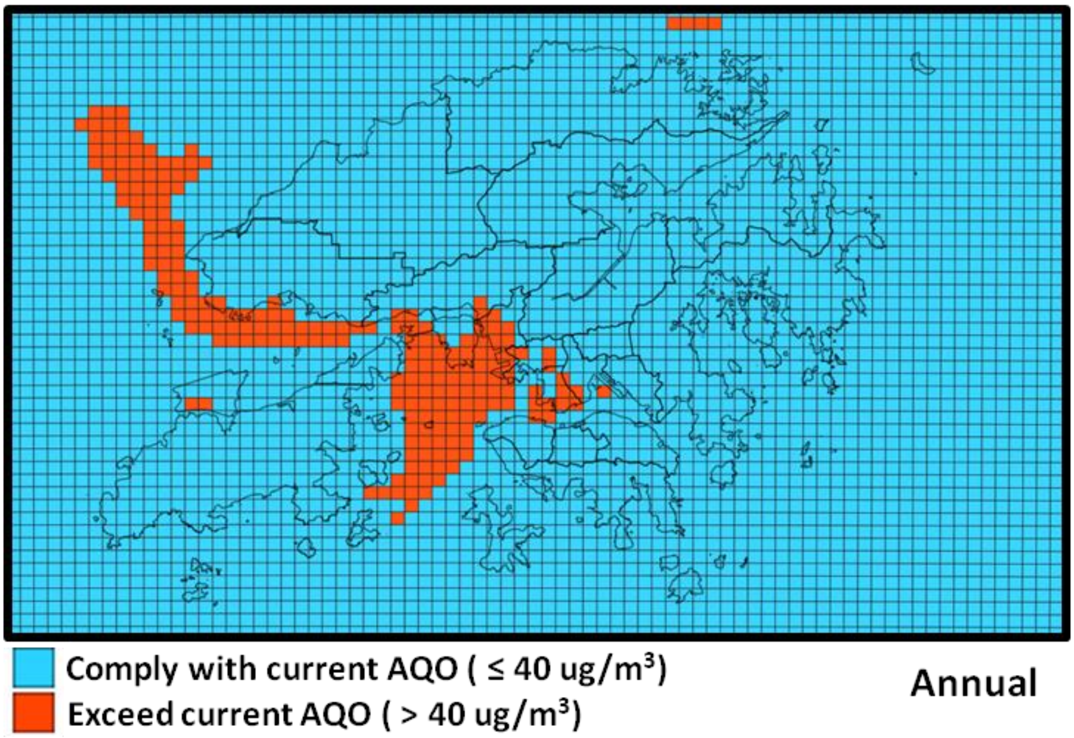


Figure E5 – Annual NO_2 compliance in 2020

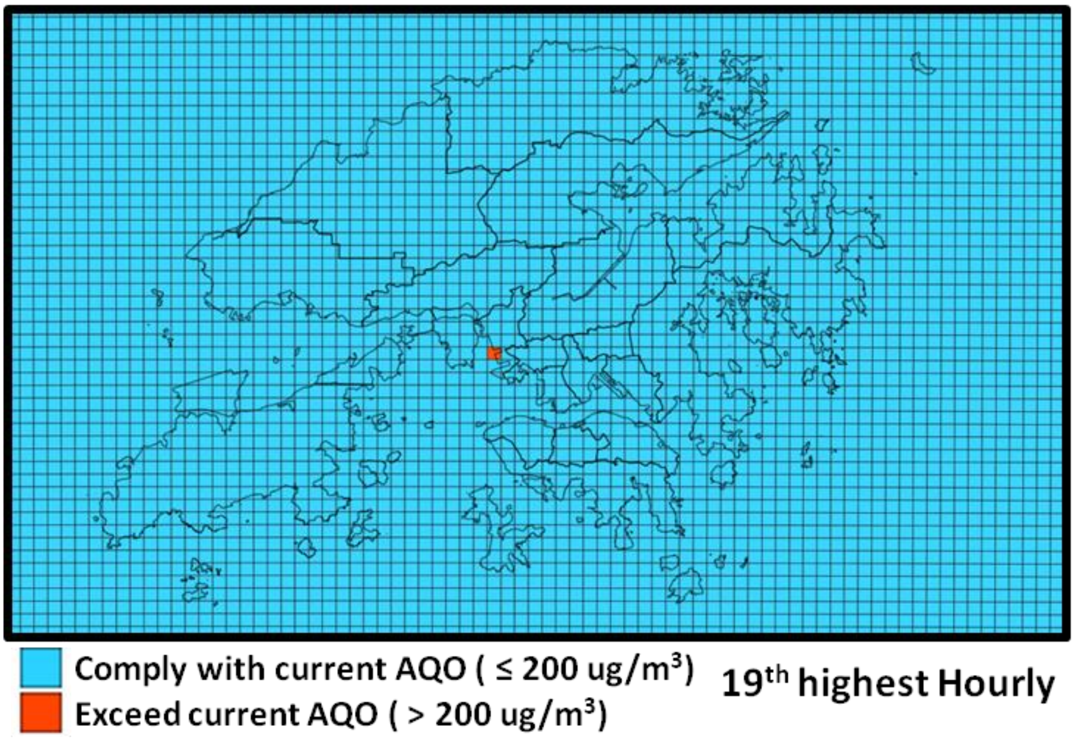


Figure E6 – 19th highest hourly NO_2 compliance in 2020

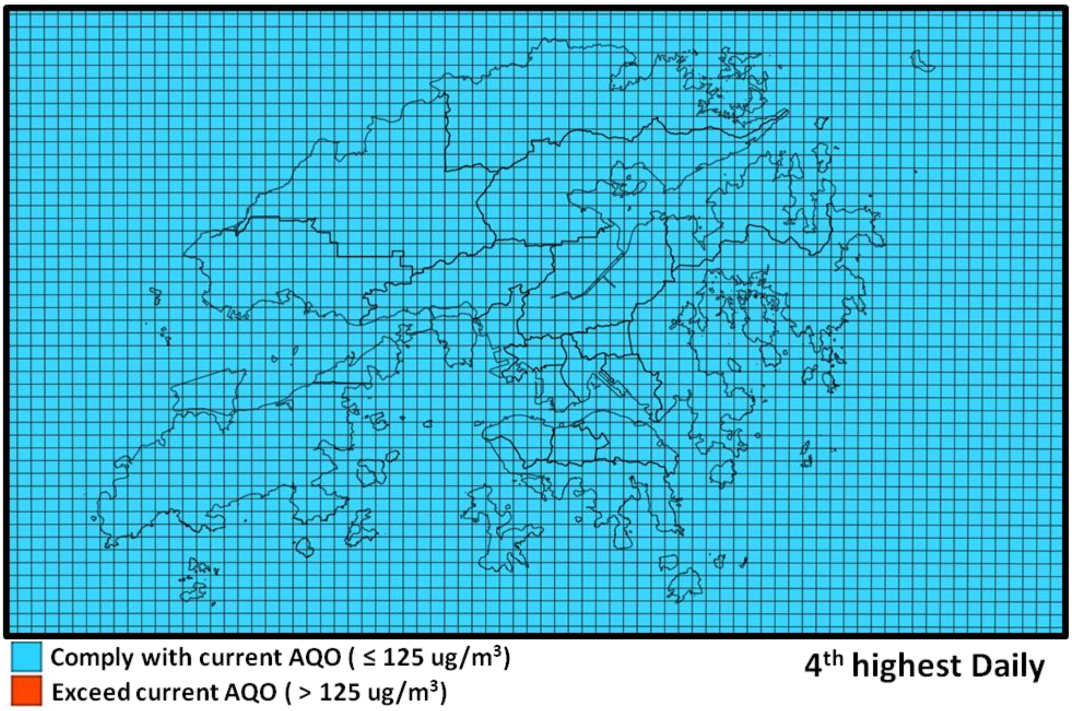


Figure E7 – 4th highest daily SO_2 compliance in 2020

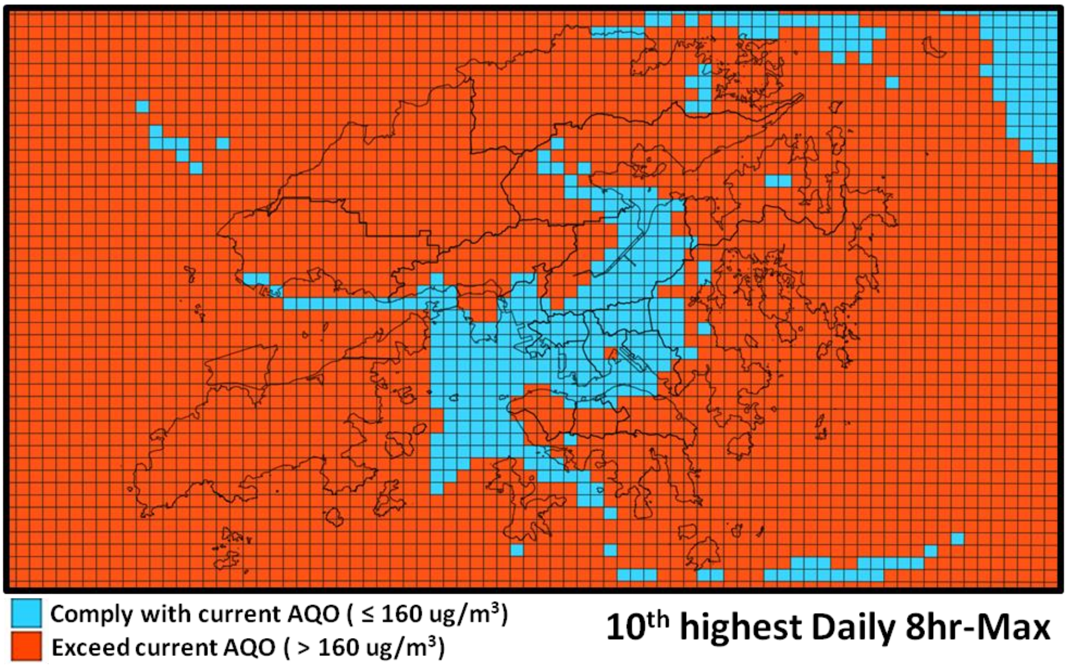


Figure E8 – 10th highest daily maximum 8-hour O_3 compliance in 2020

Predicted air quality in 2025

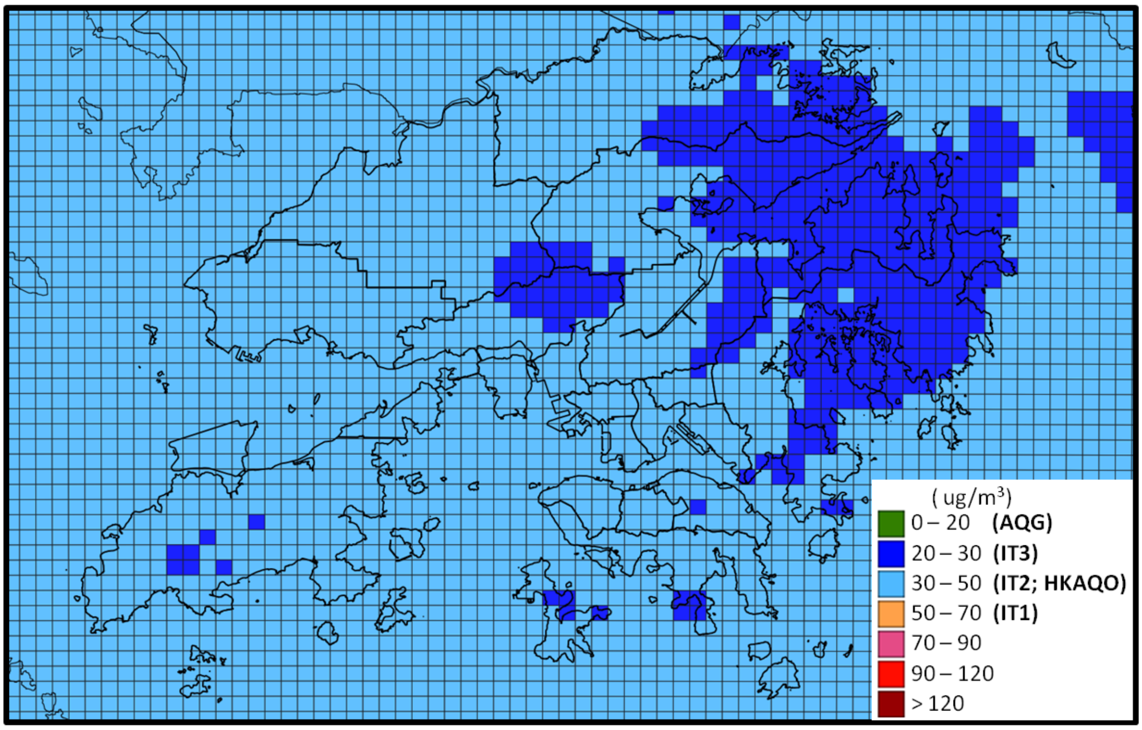


Figure E9 – Annual averaged PM_{10} concentration in 2025

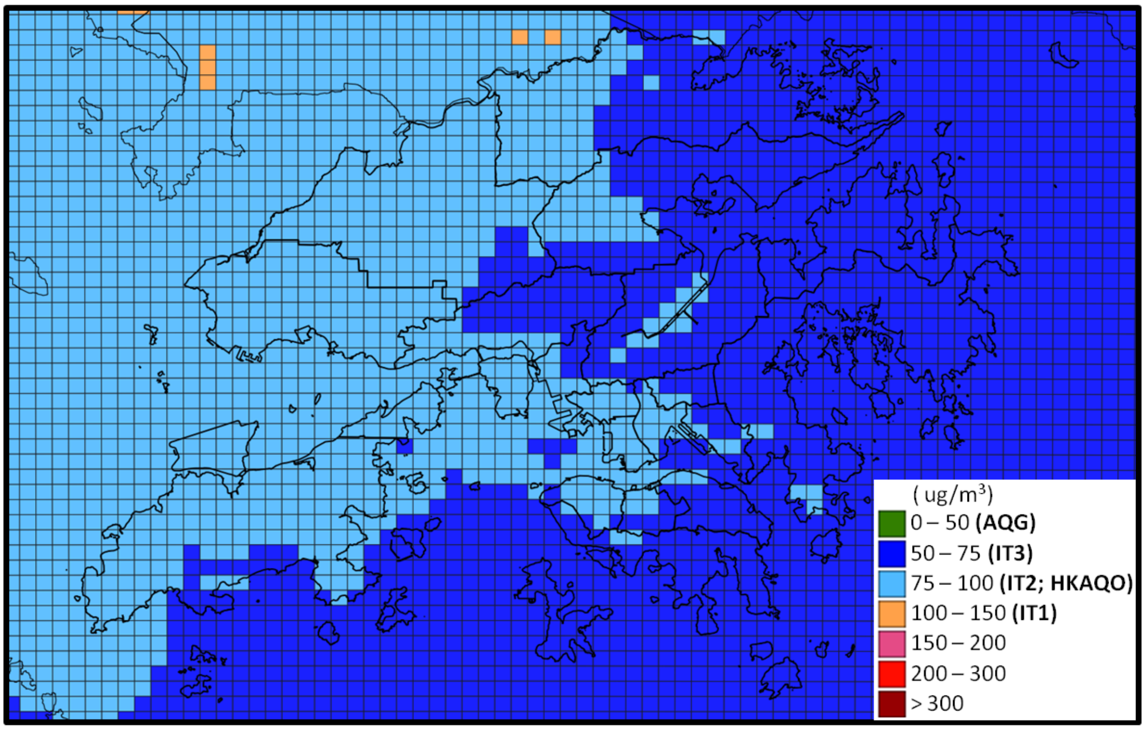


Figure E10 – 10th highest daily PM_{10} concentration in 2025

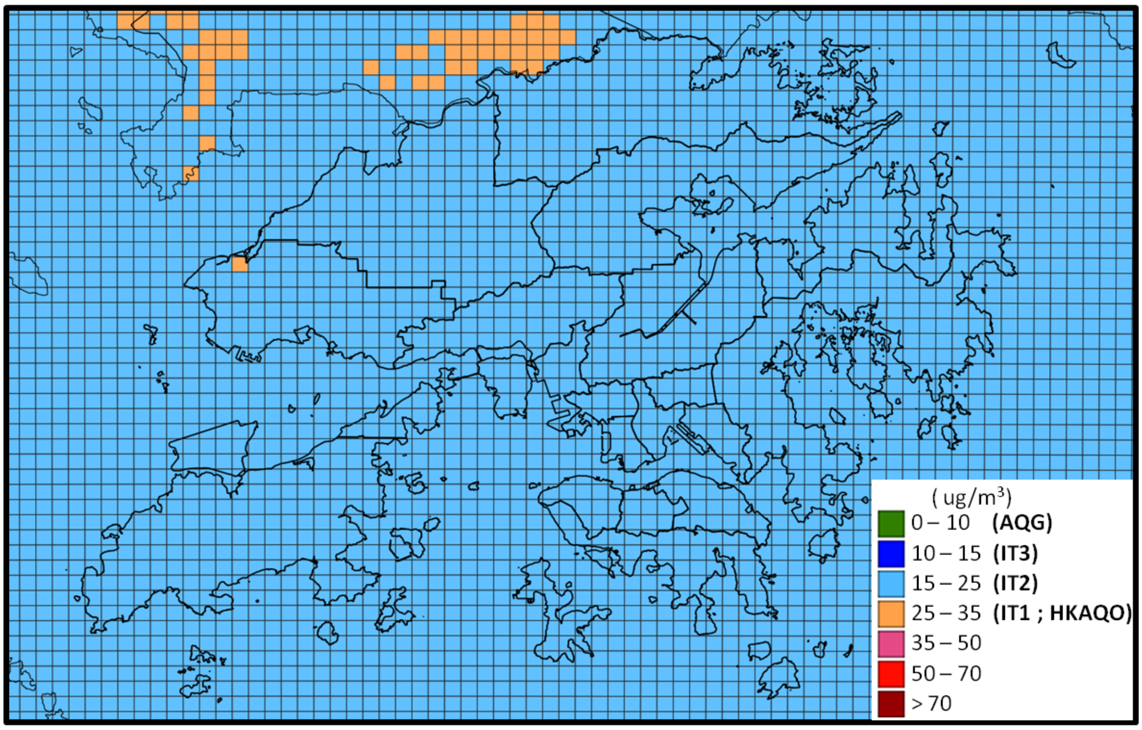


Figure E11 – Annual averaged $PM_{2.5}$ concentration in 2025

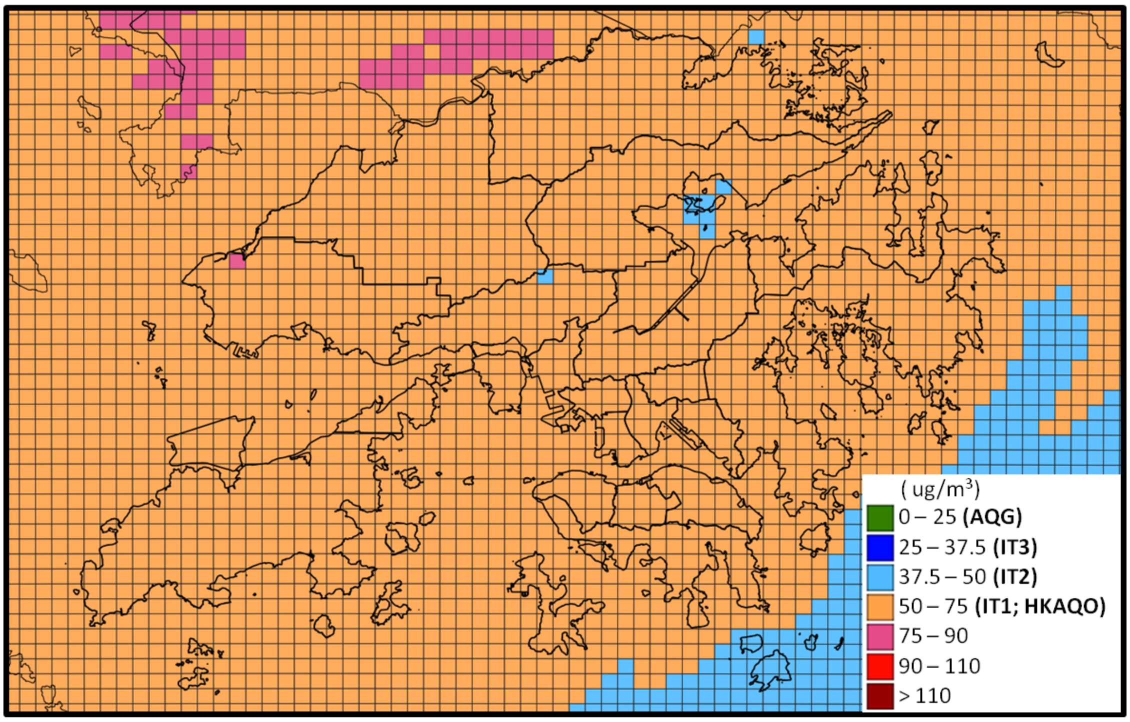


Figure E12 – 10th highest daily $PM_{2.5}$ concentration in 2025

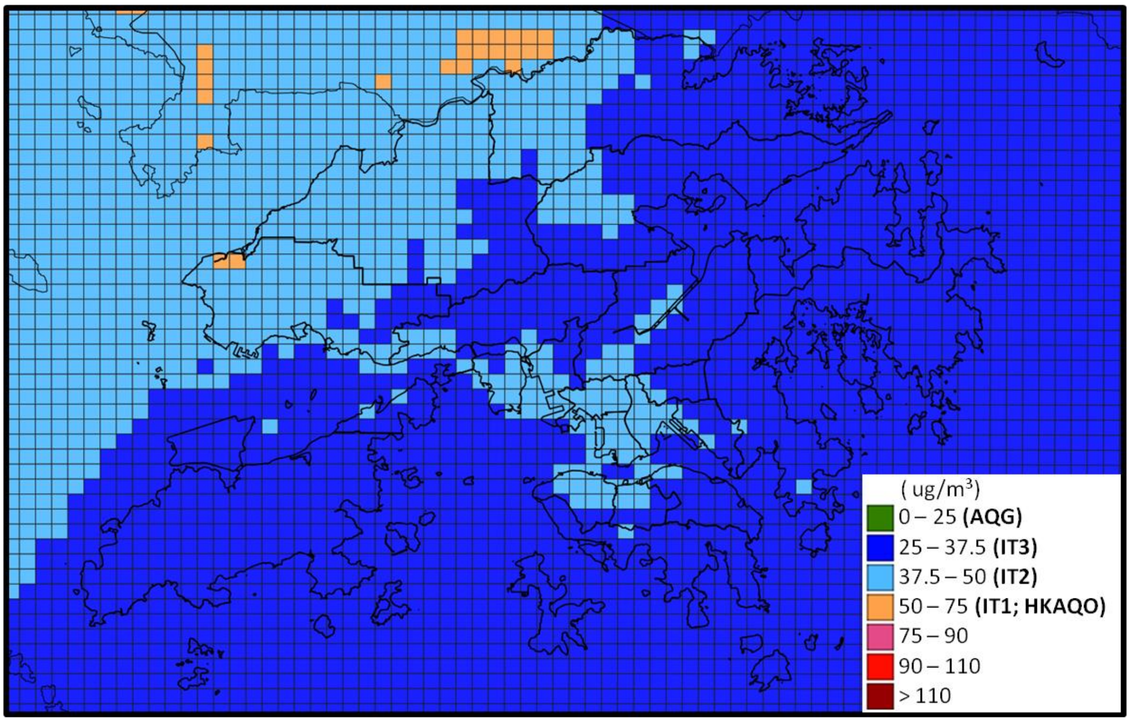


Figure E13 – 36th highest daily $PM_{2.5}$ concentration in 2025

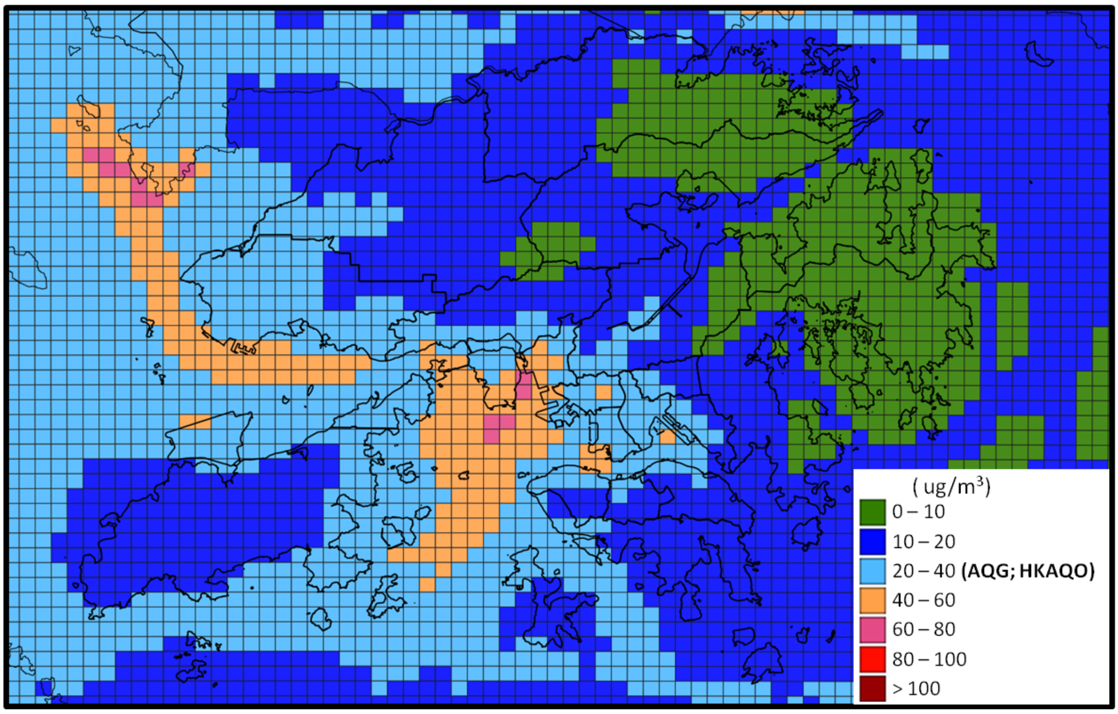


Figure E14 – Annual averaged NO_2 concentration in 2025

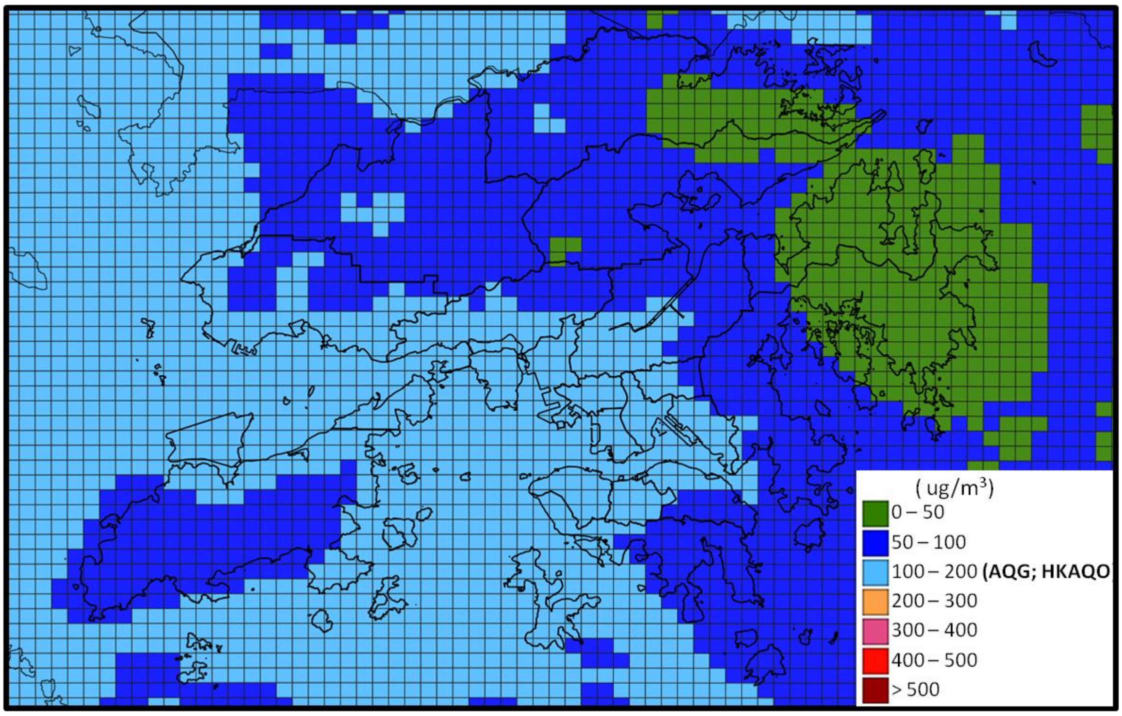


Figure E15 – 19th highest hourly NO_2 concentration in 2025

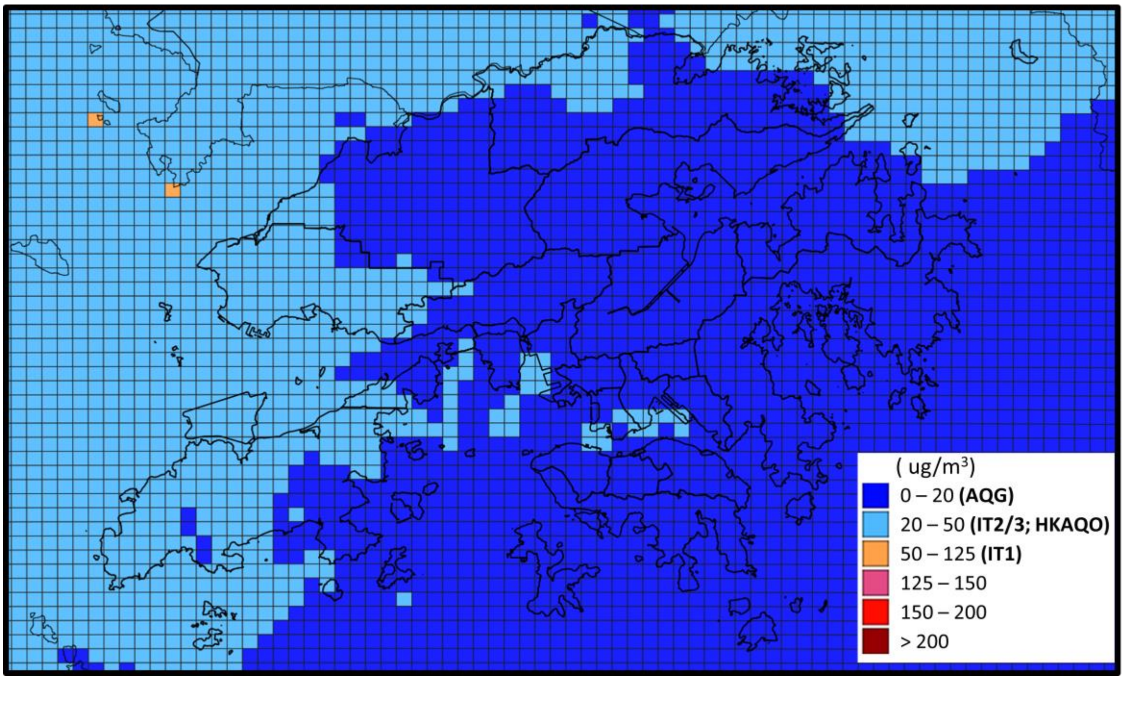


Figure E16 – 4th highest SO_2 concentration in 2025

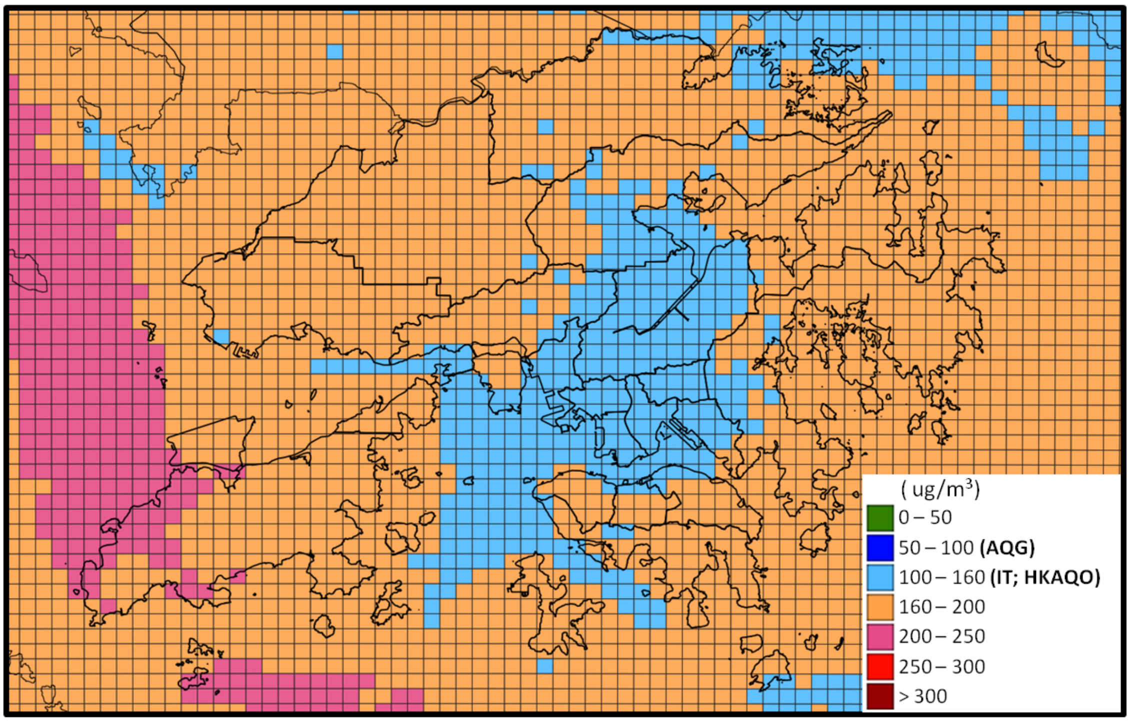


Figure E17 – 10th highest daily maximum 8-hour O_3 concentration in 2025

Annex F

Health outcomes and relative risks to calculate the short-term and long-term exposure to air pollution

A) Relative risks of short-term and long-term exposures of air pollutants

Health Outcomes		Relative Risks per 10μg/m³ (95% Conference Interval)			
		PM2.5 (Daily mean)	**NO2 (Daily Mean)**	**O3 (Daily 8-hr maximum)**	**SO2 [1] (Daily mean)**
Short-term Impact					
Emergency hospital admissions	Cardiovascular diseases (all ages)	1.0066 [2] (1.0036 - 1.0097)	1.0100 [3] (1.0073 - 1.0126)	NA	1.0098 [3] (1.0057 - 1.0139)
	Respiratory diseases (all ages)	1.0097 [4] (1.0065 - 1.0129)	1.0075 [3] (1.0050 - 1.0100)	1.0081 [3] (1.0058 - 1.0104)	NA
	COPD [5]	1.031 (1.026 - 1.036)	1.026 (1.022 - 1.031)	1.034 (1.030 - 1.040)	
	Asthma [6]	1.021 (1.015 - 1.028)	1.028 (1.021 - 1.034)	1.034 (1.029 - 1.039)	
New episodes of URTI	GP visits [7]	1.021 (1.010 - 1.032)	1.030 (1.020 - 1.040)	1.025 (1.012 - 1.038)	
	GOPC visits [8]	1.005 (1.002 - 1.009)	1.010 (1.006 - 1.013)	1.009 (1.006 - 1.012)	
Mortality		1.004097 [9] (1.001806-1.006394)	1.0103 [3] (1.0069-1.0137)	1. 0034 [3] (1.0002-1.0066)	1.0091 [3] (1.0040 -1.0142)
Long-term Impact					
Mortality		1.062 [10] (1.040 - 1.083)	1.039 [11] (1.022 - 1.056)	NA	NA

Notes:

1. The HIA on SO_2 is provided for reference as some of the possible new air quality improvement measures would have emission reduction potential on SO_2. Although the health outcome is comparatively less significant than other air pollutants.
2. Qiu et al, 2013. Differential Effects of Fine and Coarse Particles on Daily Emergency Cardiac Hospitalizations in Hong Kong. Atmospheric Environment *64* 296-302; and personal communications with Dr. H. Qiu. The RR was presented for each interquartile increase in $PM_{2.5}$ in the published paper. Dr. Qiu was requested to provide the RR for each 10 μg/m³ increase in $PM_{2.5}$ concentration, i.e. 1.0066 as quoted above.
3. Wong et al., 2010. Part 4. Interaction between Air Pollution and Respiratory Viruses: Time Series Study of Daily Mortality and Hospital Admissions in Hong Kong. In: Public Health and Air Pollution in Asia (PAPA): Coordinated Studies of Short-Term Exposure to Air Pollution and Daily Mortality in Four Cities. HEI Research Report 154, Health Effects Institute, Boston, MA.
4. RR for respiratory diseases is obtained through the personal communications with Dr. H. Qiu. The excess risk of mortality reported in PAPA Study (Wong et al, 2010) with PM_{10} were 0.63% and 0.69% (equivalent to RRs of 1.0063 and 1.0069) and were somewhat lower than the RR for $PM_{2.5}$, as the effect of PM_{10} on health is smaller than that of $PM_{2.5}$.
5. Ko et al., 2007a. Temporal relationship between air pollutants and hospital admissions for chronic obstructive pulmonary disease in Hong Kong. Thorax *62* 779-784.
6. Ko et al., 2007b. Effects of air pollution on asthma hospitalization rates in different age groups in Hong Kong. Clinical and Experimental Allergy *37* 1312-1319.

7. Wong et al., 2006. Association between Air Pollution and General Practitioner Visits for Respiratory Diseases in Hong Kong. Thorax *61* 585-591.
8. Tam et al., 2014. Association between air pollution and general outpatient clinic consultations for upper respiratory tract infection in Hong Kong. PLOS ONE 9(1) e86913, 1-6. (Note: In Tam's study, only RR for PM_{10} was available. This is used as a proxy of RR for $PM_{2.5}$ in this study. In general, RR for PM_{10} is slightly lower in magnitude than that for $PM_{2.5}$.)
9. Tam, (2016), unpublished data. RR of all-cause, cardiovascular and respiratory mortality from Prof. W. Tam based on time series of PM2.5 on all-cause mortality between 2001 and 2010.
10. Hoek el al., 2013. Long-term air pollution exposure and cardio-respiratory mortality: a review. Environmental Health *12* 43.
11. WHO, 2013. Health risks of air pollution in Europe – HRAPIE project. Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide. Copenhagen: WHO Regional Office for Europe. (Note: the overlapping effect on PM has been considered. The original RR is 1.055 (1.031 – 1.080) per 10μg/m^3).

B) The assessment on health impact is based on the tool developed by the Chinese University of Hong Kong Study and is estimated by:

Attributable health outcomes = Baseline health outcome data x AF

where "AF" is the attributable fraction, RR is the relative risk estimated by the formulae below:

Equation 1: $\mathrm{AF} = (\mathrm{RR} - 1)/\mathrm{RR}$

Equation 2: $\mathrm{RR} = \mathrm{e}^{\frac{\ln(\mathrm{RR\ per\ 10\ ug/m^3})}{10} * (x-y)}$ *where "x" is referred to air pollutant concentration at a specific year (in μg/m^3), and "y" as counterfactual/target/desired level is referred to the WHO AQG (in μg/m^3)*

Annex G

Summary of the health and economic benefits due to the projected air quality improvements in 2025

Table 1: Health outcomes attributable to short-term and long-term exposure to air pollution owing to changes in air quality, as compared with 2015

Health Outcomes		Air Pollutants				Max. Short-term Impact / Total Mortality
		$PM_{2.5}$	**NO_2**	**O_3**	**SO_2**	
Reductions in number of hospital admissions and clinic visits						
Emergency hospital admissions saved	Cardiovascular diseases	92	704	NA[b]	25	1,528
	Respiratory diseases	213	*824*	-25 [d]	NA [b]	
	COPD [a]	158	686	-27 [d]		--
	Asthma	72	470	-17 [d]		--
Clinic visits saved (for new episodes of URTI)	GOPC visits	858	8,226	-293 [d]		262,577
	GP visits	104,895	254,351	-7,921 [d]		
Reductions in number of premature deaths						
Mortality (Short-term exposure, all ages)		28	350	-3 [d]	12	*c*
Mortality (Long-term, aged 30 and above)		865	983	NA[b]	NA[b]	1,848

Notes:
COPD = Chronic Obstructive Pulmonary Disease
GOPC = General Outpatient Clinic
GP = General Practitioner
URTI = Upper Respiratory Tract Infections
To avoid double-counting of health effects, short-term impacts of different air pollutants are not added up, the maximum value among the air pollutants is taken.

a. COPD, influenza and pneumonia are examples of respiratory diseases. Asthma is a sub-class of COPD. While separate quantification was performed for COPD and asthma (both belong to the class of respiratory diseases). , influenza and pneumonia could not be assessed due to the lack of reliable local concentration-response functions.
b. The health outcome is not assessed as the relative risk for the respective air pollutant is either statistically not significant or available.
c. Short-term premature death is covered in the long-term premature death.

d. The negative (-) sign indicates the air pollutant exerts negative impact.

Table 2: Economic benefits due to savings in hospital admissions, clinic visits and associated productivity loss in 2025 compared with 2015

Air Pollutants	Economic Costs Saved (HK$)			
	Hospital Admissions [a]	Clinic Visits [b]	*Productivity Loss* [c]	Total [d]
$PM_{2.5}$	5,510,850	26,605,560	*59,785,600*	91,902,010
NO_2	28,848,240	67,248,320	*150,004,400*	**246,100,960**
SO_2	540,750	--	*56,000*	596,750
O_3	-413,250 [e]	-2,110,635 [e]	*-4,641,840* [e]	-7,165,725 [e]

Notes:

a. The cost of hospital admissions relates to Accidents and Emergency (A&E) attendance due to cardiovascular and respiratory diseases and cost of hospital beds.

b. The cost of clinic visits includes doctor consultation of both public and private practitioners due to new episodes of upper respiratory tract infections (URTIs).

c. The cost of productivity loss is due to time lost from hospital admissions and clinic visits. The costs provided are for reference only. Please also refer to footnote 12 to the para. 15.

d. To avoid double-counting of economic benefits, short-term impacts of different air pollutants are not added up, the maximum cost benefits among the air pollutants (i.e. NO_2) is taken as representative figures, which marked in **bold**.

e. The negative (-) sign means there could be additional costs incurred.

Table 3: Economic benefits due to avoided premature deaths in 2025 compared with 2015

Air Pollutants	Economic Costs Saved (HK$) [a]	
	Long-term premature deaths expressed in VOSL [b]	Total [c]
$PM_{2.5}$	15,659,273,600	**33,454,725,500**
NO_2	17,795,451,900	

Notes:

a. Figures are rounded to the nearest hundred.

b. The VOSL is derived from the value used in Tool Study, which was based on the average of VOSL from European WHO Regional Office Report and VOSL in China from a World Bank reference and then adjusted to the price in 2017, at about HK$18,103,200. These two references entailed the upper and lower bounds of the VOSL. Please also refer to footnotes 10 and 11 to the paragraph 15.

c. The long-term impacts can be added up as the overlapping effects of the two pollutants (i.e. $PM_{2.5}$ and NO_2).