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Association between energy use and poor visibility in Hong Kong SAR, China

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A city’s reliance on energy increases when it is developed. Moreover, the combustion of fossil fuels inevitably generates air pollutants including carbon dioxide, nitrogen oxides, sulfur dioxide, particulate matter, and others. Combining with other anthropogenic air pollutants, visibility in many Asian cities including Hong Kong have deteriorated rapidly in the past decades. This paper explores the relationships between energy use, meteorological factors, and change in visibility in Hong Kong using long-term time-series data. The total use of primary energy increased from 146,700 TJ in 1971 to 1,270,865 TJ in 2011 while the number of hours of reduced visibility increased from 184 h to 1398 h during the same period of time. Bivariate correlations show that poor visibility was significantly associated with energy use and annual mean air temperature. Multiple regression analysis indicates that the burning of aviation gasoline significantly, adversely affect visibility. Results illustrate that the number of clear days in Hong Kong will decrease, in particular due to the increase in air traffic.

1. Introduction

Urbanization forces Asian cities to develop and expand rapidly. Indeed, many cities have followed a similar development process, i.e. from a manufacturing-based economy in the 1960s and 1970s to a service-based economy in recent years. Although the World Development Report [1] argues that air pollution level normally rises with income per capita but it should start to decline when income per capita exceeds a threshold level, for example, particulate matter should decrease when income per capita exceeds US$ 250. This inverted U-shape curve is known as Environmental Kuznets Curve [2,3]. Unfortunately, this argument is not applicable to Asia. For example, annual income per capita in Hong Kong was US$ 9096 in 1985 and reached US$17,023 in 2011. However, the total mass concentration of particulate matter, i.e. ultrafine particles, PM$_{2.5}$ and PM$_{10}$, in fact was much higher in 2011 than that in 1971 which in turn affects visibility in Hong Kong [4–6]. Air pollution is still one of main concerns for people living and working here [6]. Researchers reported that poor air quality was found to be significantly associated with severe respiratory and cardiovascular diseases [7], might cause cancers [8] and mortality [6,7]. The impact on human health is even more severe when air pollutants are in the form of gaseous [7] or aerosols [9,10]. In recent years, most Asian cities including Hong Kong have been covered by haze almost continuously between October and April [6,11–15]. Poor visibility, an integral form of air pollution in the dry season, may cause substantial psychological and physiological pressure on people.

In recognizing the close link between energy use and its impact on environment, this paper is one of the first to systematically obtain the different energy uses in the form of time-series and explore their influences on visibility in Hong Kong SAR, China. The effects of meteorological variables on visibility are also explored. Visibility here is defined as the greatest horizontal distance at which a specified object can be seen in normal daylight condition. That is not the same as vertical visibility that can be determined by measuring aerosol optical depth from satellite images [15].

1.1. Hong Kong’s economic development

Before discussing the relationships between energy use, meteorological factors, and visibility, it is necessary to gain a background on the economic development of Hong Kong. In fact, Hong Kong has developed earlier than all other cities in China and its success has been duplicated in many parts of China such as Guangzhou, Suzhou, Shanghai, Tianjin, and others.

Shortly after the Second World War and the civil war in China, Hong Kong evolved as one of Four Asian Tigers (also known as Four Asian Dragons) along with Singapore, South Korea and Taiwan. It was because Hong Kong had attracted many entrepreneurs from...
Shanghai and a large number of migrants from Guangdong. According to Ho and Liu [16], Hong Kong’s population increased from around 600,000 in 1945 to 2.2 million in the mid of 1950s. The population figure increased to 4.1 million in 1971 and to 7.1 million in 2011 respectively [17].

In the 1960s, Hong Kong became a light-industrial center in Asia. With a large number of unskilled workers from nearby Guangdong, local entrepreneurs, and rich families fled from Shanghai in the 1950s, many light-metal, plastic, toys, textile, and garment factories were established. These factories employed hundreds of thousands of laborers [18]. The manufacturing sector had expanded steadily until early 1980s under a favorable environment, i.e. relatively low rent, low transportation cost, and low labor cost because of the abundant of unskilled workers. For example, more than 0.3 million unskilled migrants found their way either legally or illegally into Hong Kong’s labor market between 1978 and 1980. However, as land price and labor cost increased substantially in early 1980s, Hong Kong’s manufacturing sector shrank rapidly and many industrialists relocated their factories to mainland China in which the “open-door policy” has been implemented since 1978. Hong Kong started transforming itself to a logistic hub and its finance and service sector expanded rapidly in the 1980s and 1990s. After almost two decades of transformation, Hong Kong in the future will change itself from a manufacturing-based city to the busiest port in the world [19] as well as one of the world’s financial centers. Hong Kong’s container terminals handled less than 0.7 million TEU (twenty-foot equivalent unit) in 1970 and steadily increased to handle 24.4 million TEU in 2011 [17]. Nevertheless, Hong Kong’s economic development was once badly hit by the outbreak of SARS (Severe Acute Respiratory Syndrome) in early 2003. In order to reboot Hong Kong’s economy, the Central Government of the People’s Republic of China decided to offer favorable treatments to Hong Kong under the CEPA (Closer Economic Partnership Arrangement). The CEPA agreement allows mainland visitors traveling to Hong Kong under the new Individual Visitor Scheme and encourages mainland companies to be listed in the Hong Kong Stock Exchange. The number of mainland visitors surged rapidly to 18 million in 2009 and they spent HK$ 26 billion in that year [20]. In 2011, Hong Kong attracted 37.8 million visitors and 28 percent of visitors traveled to Hong Kong by flights [17]. Hong Kong becomes a tourist center and the world financial center in Asia. In aviation, the passenger throughput increased from 1.2 million to 46.3 million while the cargo throughput increased from 26.5 thousand tonnes to 3.742 million tonnes between 1967 and 2007 [21]. In 2011, the number of flights arriving and departing from the Hong Kong International Airport was 334,000. On road surfaces, the number of vehicles increased from 162,000 in 1971 to 630,281 in 2011 [22]. The number of private vehicles alone increased from 93,000 to 434,843 during this period.

2. Energy use in Hong Kong

The preceding section briefly describes the economic development of Hong Kong. It shows that Hong Kong has transformed from a manufacturing-based economy to a service-based economy in the past forty years. At the same time, Hong Kong’s population increases at an average annual growth rate between 0.8 and 1.8 percent from 4.1 million in 1971 to 7.1 million in 2011. However, increase in population mostly comes from the net immigration rather than the number of new borne babies in Hong Kong [17]. This situation is expected to prevail in the future. As there are over 7.1 million living in Hong Kong and Hong Kong welcomes over 30 million visitors a year, their residential, social, business, and commercial activities consume a significant amount of energy [23–25]. Besides, Hong Kong is still one of the busiest ports in the world. All road, sea and air traffic consume a large amount of oil products and gas products. Table 1 summarizes the retained import of primary energy in 1971, 1976, 1981, 1986, 1991, 1996, 2001, 2006, and 2011 respectively [26]. It also shows the consumption of electricity—a secondary energy in those years.

The amounts of fossil fuels imported were then converted into thermal unit in terms of TJ by using the calorific value of each fuel. Fig. 1 shows the energy use of Hong Kong from 1971 to 2011 based on the annual net import of fossil fuels and the net electricity imported from Shenzhen’s Daya Bay Power Station in China after 1995 [14]. It illustrated that the total energy use increases continuously except in 1997, 2008 and 2011. The sudden drops of energy use in these three years can be understood because as an open economy Hong Kong was significantly affected by the Asian financial crisis in 1997 and the world financial crisis triggered by sub-prime mortgage problems in the United States in 2007–08 and 2010–11.

Figs. 2 and 3 show the imported energy of each fossil fuel from 1971 to 2011. It should be noted that aviation gasoline and kerosene are primarily consumed by aircrafts, motor gasoline by private vehicles, diesel oil by buses, trucks and industrial boilers, fuel oil by ships (and by power companies before 1982), LNG (liquefied natural gas) by power companies after 1995, and coal by power companies [14].

Fig. 4 shows the percentage of thermal unit (i.e. using TJ) for oil products, gas products, and coal products from 1971 to 2011. It illustrates that Hong Kong predominately used oil products before 1982. Between 1971 and 1981, over 97 percent of the energy use of Hong Kong came from oil products. Heavy fuel oil was the main source of energy to generate electricity and to produce thermal energy in factories, hotels, hospitals, etc. From 1982 to 1995, Hong Kong’s power companies consumed a significant amount of coals to generate electricity. In order to diversify the source of primary energy and to discharge less air pollutant to the environment, the Government of Hong Kong requested Hong Kong’s power companies to use LNG in generating around 35 percent of electricity locally. Since 1995, a portion of electricity has been generated using LNG and has been imported from Shenzhen’s Daya Bay Power Station.

3. Visibility and other meteorological parameters

Visibility is an integrative parameter that refers to the ability to see a distant object. It depends on the characteristics of the object, its surrounding, air quality and the illumination of the sight path. More specifically, it is affected by all types of particulate matter and aerosols in the atmosphere [27]. In Hong Kong, the visibility readings have been recorded by the Hong Kong Observatory at its headquarters located at the city’s center [28]. Reduced visibility is defined as visibility below 8 km when there is no fog, mist, or precipitation [29]. The readings have been recorded based on hourly measurements using a forward scatter visibility meter. Fig. 5 shows the number of hours of reduced visibility observed at the Hong Kong Observatory from 1971 to 2011.

Fig. 5 shows that there was no substantial change in visibility between 1971 and 1990. However, there was an upward trend after 1991. Fig. 6 shows the number of hours of reduced visibility observed at the same location on a monthly basis. It indicates that visibility in Hong Kong deteriorates; especially in autumn and winter that Hong Kong has been covered by haze continuously between October and April in recent years. It should be noted that the distance between the Hong Kong Observatory located in Tsim Sha Tsui and the old Hong Kong International Airport (also known as Kai Tak Airport; see Fig. 7a) was 2 km.

The Hong Kong Observatory has also recorded the number of hours of reduced visibility at the Hong Kong International Airport.
after it was relocated to an artificial island at Chek Lap Kok in 1997
as shown in Fig. 7b. The numbers of hours of reduced visibility
observed at the Airport on a monthly basis are shown in Fig. 8.
However, there was no visibility data at Chek Lap Kok before 1997.

By comparing the number of hours of reduced visibility at the Hong
Kong Observatory and that at the Hong Kong International Airport
between 1997 and 2011, the correlations, i.e. the \( R \)-values between
these two sets of data were 0.77 using the annual data and 0.82
using the monthly data respectively. Besides, the distance between
the Hong Kong International Airport and the Hong Kong Observa-
tory is 25 km and a significant number of flights fly over the
Kowloon Peninsula and Victoria Harbour (see Fig. 7b). Hence, only

Table 1
Import of fossil fuels (primary source of energy) in 1971, 1976, 1981, 1986, 1991, 1996, 2001, 2006, and 2011.

| Year | Primary energy\(^a\) | Secondary energy |
|------|----------------------|------------------|
|      | Aviation gasoline and kerosene (million kiloliters) | Motor gasoline\(^a\) (million kiloliters) | Gas oil, diesel oil and naphtha (million kiloliters) | Fuel oil (million kiloliters) | Liquefied petroleum gas and natural gas (kilolitres) | Coal\(^b\) products (kilotonnes) | Electricity net imported (TJ) | Local electricity consumed (TJ) |
| 1971 | 0.82 | 0.15 | 0.62 | 2.21 | 45.4 | – | 0 | 17,609 |
| 1976 | 1.05 | 0.17 | 0.93 | 2.96 | 86.4 | – | 0 | 26,190 |
| 1981 | 1.16 | 0.34 | 1.41 | 4.40 | 114.0 | 78.0 | 0 | 41,620 |
| 1986 | 1.51 | 0.25 | 2.12 | 2.27 | 161.8 | 6433.2 | 0 | 63,592 |
| 1991 | 2.11 | 0.35 | 2.89 | 1.15 | 163.4 | 9652.8 | 0 | 91,140 |
| 1996 | 3.67 | 0.49 | 4.41 | 1.74 | 1671.1 | 6784.8 | 0 | 113,880 |
| 2001 | 4.20 | 0.52 | 6.92 | 2.39 | 2459.1 | 8028.8 | 31,586 | 134,138 |
| 2006 | 5.54 | 0.43 | 5.08 | 5.92 | 2592.1 | 11,410.0 | 22,930 | 145,204 |
| 2011 | 6.99 | 0.54 | 5.35 | 7.72 | 2644.9 | 12,535.0 | 30,177 | 15,1432 |

\(^a\) Hong Kong started banning the use of leaded petrol/motor gasoline in 2000.
\(^b\) Hong Kong’s power companies started using coal as the major fuel to generate electricity in 1982.
\(^c\) Calorific values of various fuels: aviation gasoline – 33.52 GJ/kl; motor gasoline – 35 GJ/kl; gas oil/diesel oil – 38.6 GJ/kl; fuel oil – 39.7 GJ/kl; liquefied petroleum gas and natural gas – 54.4 GJ/T; coal – 26.4 GJ/T.

Fig. 1. Imported energy of Hong Kong from 1971 to 2011.

Fig. 2. The imported energy of aviation gasoline, motor gasoline, and gas/diesel oil from 1971 to 2011.

Fig. 3. The imported energy of fuel oil, LPG/NG, and coal from 1971 to 2011.
the number of hours of reduced visibility at the Hong Kong Observatory will be used to correlate with fuel uses and in multiple regression analysis because this dataset has a much longer history of forty-one years.

In addition to visibility data, the Hong Kong Observatory also published the annual mean air temperature in °C, annual mean atmospheric pressure in hPa, annual mean relative humidity in percent, annual total rainfall in mm recorded at the Hong Kong Observatory, and the annual mean wind speed in km/hr recorded at an outlying island (Waglan Island) of Hong Kong between 1971 and 2011. The Hong Kong Observatory also indicated that the prevailing wind direction is 070° (ENE (east-northeast)) in winter and 230° (SW (southwest)) in summer.

### 4. Correlation and multiple regression analysis

Bivariate correlation was performed between the visibility data recorded at the Hong Kong Observatory, the imported energy of each fossil fuel, and meteorological variables including the annual mean air temperature in °C, annual mean atmospheric pressure in hPa, annual mean relative humidity in percent, annual total rainfall in mm, and the annual mean wind speed in km/hr. The analyzed results are shown in Table 2 and Table 3.

**Fig. 5** and **Fig. 10** show scatter diagrams between visibility and each of fossil fuel. They show that there was a very strong, significant simple linear relationship between visibility and the consumption of aviation gasoline ($R = 0.92$, $p < 0.001$ for 39 degrees of freedom). Data were scattered on the other plots with the $R$ value ranging from 0.56 to 0.86 ($p < 0.001$ for 39 degrees of freedom).

**Fig. 11** shows scatter diagrams between visibility and meteorological variables and trend lines. They show that only annual mean air temperature was moderately, significantly associated with visibility ($R = 0.52$, $p < 0.01$ for 39 degrees of freedom).

Multiple regression analysis was then applied to identify the contribution of the consumption of fossil fuels to the number of hours of reduced visibility. All meteorological variables were also entered as independent variables to explore whether they have any effect on visibility. Stepwise procedure was employed because this procedure combines both forward and backward procedures and produces the optimal solution [31]. At the first step, the independent variable, i.e. a fuel type or meteorological variable, with the largest correlation with visibility entered the equation. In the next step, another variable was selected according to the highest partial correlation. If this variable passed the stepping method criteria, i.e.
$F < 0.05$, it entered the regression equation. The $F$ probability of each variable in the regression equation was then checked. The variable was removed from the equation when $F > 0.10$. The process continued until no variable was entered or removed from the regression equation. Theoretically speaking, the final form of multiple regression equation is given as below. The resulting multiple regression equation can be expressed as follows:

\[
\text{Visib} = C + \sum_{i=1}^{6} a_i \text{Fuel}_i + \sum_{j=1}^{5} \beta_j \text{Meterological}_j
\]

(1)

where $\text{Visib}$ is the number of hours of reduced visibility, $C$ is a constant, $a_i$ is the unstandardized coefficient of the $i$th fuel, Fuel, is the quantity of the $i$th type of fuel in GJ, $\beta_j$ is the unstandardized coefficient of the $j$th meteorological variable, and Meterological$_j$ is the quantity of the $j$th type of meteorological variables.

After running the multiple regression analysis in SPSS17.0 software, only one independent variable, i.e. aviation gasoline and kerosene, was entered in the stepwise procedure. Multiple regression analyses, using the forward selection method and the backward elimination method, produced the same result. The final form of the regression equation is given as below.

\[
\text{Visib} = 17.63 + 6.107 \times \text{Fuel}_{\text{aviation gasoline and kerosene}}
\]

(2)

where figures underneath the coefficients are values for $t$-statistics and figures in brackets are $p$-values.

The $R^2$-value of Equation (2) is 0.85. This $R^2$-value indicates that 85 percent of the variance in visibility is explained by the consumption of aviation gasoline and kerosene. The relationship...
between these two variables is very strong and significant as $p < 0.001$. The $\alpha$ value indicates that the relative influence of the independent variable on dependent variable. That is, a unit increase of aviation gasoline and kerosene in GJ increases the number of hours of reduced visibility by 6.107 per year. The 95% confidence intervals of $C$ and $\alpha$ are $[76.596, 118.853]$, and $[5.281, 6.934]$ respectively. When criteria for stepwise multiple regression were changed (the variable was entered to the regression equation for $F < 0.08$ while the variable was removed from the equation for $F > 0.10$), the result shows that visibility was significantly affected by aviation gasoline and kerosene ($p < 0.001$) and moderately affected by burning of LPG (liquefied petroleum gas) and LNG ($p = 0.085$) as shown in Equation (3).

$$\text{Visib} = 61.28 + 4.750 \times \text{Fuel}_{\text{aviation gasoline and kerosene}} + 1.538 \times \text{Fuel}_{\text{LPG and LNG}}$$

\[ (3) \]

\[ \text{1.187} \quad 5.495 \quad 1.768 \]

\[ [0.243] \quad [0.000] \quad [0.085] \]

where figures underneath the coefficients are values for $t$-statistics and figures in brackets are $p$-values. The $R^2$-value of Equation (3) is 0.86. Nevertheless, the most parsimonious multiple-regression model would be the one given in Equation (2). Fig. 12 shows the comparison between the number of hours of reduced visibility using Equation (2) and the actual data. It also provides the band of predicted values using the 95% confidence intervals of $C$ and $\alpha$.

### 4.1. Associations between visibility and meteorological variables

Fig. 11 indicates that there was a positive, moderate, significant relationship between annual mean air temperature and visibility for the period 1971–2011 while the relationships between visibility and other meteorological variables were weak and non-significant. It was because an increase in the combustion of aviation gasoline and kerosene increased the number of hours of reduced visibility while an increase in the combustion of fossil fuels including oil products, coal and natural gas increased local annual mean air temperature. In fact, the increase in local annual mean air temperature due to the combustion of fossil fuels was also reported by Stone [32] in large US cities.

The monthly data of mean air temperature, mean atmospheric pressure, mean relative humidity, total rainfall recorded at the Hong Kong Observatory and mean wind speed recorded at Waglan
Island of Hong Kong were also collected [30]. Correlation analyses indicated that monthly mean air temperature was lower, monthly mean atmospheric pressure was higher, and the amount of monthly total rainfall was much less during the winter months from December to March.

Pair-wise correlation was performed between visibility and each of meteorological variables on monthly basis for each year. The value of average pair-wise correlation was then determined using Equation (4).

\[
R = \frac{1}{N} \sum_{j=1}^{N} R_j = \frac{1}{N} \sum_{j=1}^{N} \frac{\sum_{i=1}^{12} (X_i - \bar{X})(Y_j - \bar{Y})}{\sqrt{\sum_{i=1}^{12} (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{12} (Y_j - \bar{Y})^2}}
\]

where \( R \) is the average pair-wise correlation [33], \( N \) is the total number of years i.e. 41 from 1971 to 2011, \( X_i \) is the number of hours of reduced visibility on monthly basis and \( Y_j \) is the corresponding value of a meteorological parameter on monthly basis for a particular year.

Table 4 shows the values of average pair-wise correlation and standard deviation between visibility and each meteorological variable. Results show that only monthly mean air temperature was negatively, moderately, significantly associated with visibility because the \( R \) value must be greater than 0.576 (\( p < 0.05 \)) for 10 degrees of freedom. In other words, the number of hours of reduced visibility was associated with lower air temperature, supporting that severe haze was observed during the winter months from December to March in Hong Kong.

5. Conclusion

This paper is one of the first to employ long-term time-series data in investigating the relationships between poor visibility (i.e. the integral form of air pollution in the dry season), energy use, and meteorological variables in Hong Kong SAR, China. Visibility in Hong Kong has deteriorated continuously in the past decades while the net import of fossil fuel energy has increased by 10 times. Multiple regression analysis shows that the burning of aviation gasoline and kerosene significantly adversely affects visibility in Hong Kong, and burning of LPG and LNG moderately affects visibility. The effect of burning of other fossil fuels and meteorological factors on visibility on annual basis was not statistically significant. Nevertheless, correlation analysis between monthly visibility readings and monthly records of meteorological variables indicates that poor visibility was in general associated with lower air temperature i.e. the winter months in Hong Kong with higher mean

| Table 4 Avera{

| Visibility |
|----------------|
| Monthly mean temperature | 0.505 (0.196) |
| Monthly mean atmospheric pressure | 0.076 (0.312) |
| Monthly mean relative humidity | 0.042 (0.199) |
| Monthly total rainfall | 0.072 (0.269) |
| Monthly mean wind speed | 0.600* (0.173) |

(i) The sample size of each pair is 12 i.e. 12 months. (Average values from 1971 to 2011).
(ii) * for \( p < 0.05 \); ** for \( p < 0.01 \); *** for \( p < 0.001 \).
(iii) The values of standard deviations are shown in bracket.
atmospheric pressure and less or no rainfall. The findings of this study is consistent with the research works conducted recently in the United States and England [34–36] in which a significant amount (in terms of the number concentrations) of ultrafine particles were observed due to jet departures, jet landing, jet taxi and idle. Aircraft operations also produce a large amount of NOx (nitrogen oxides) and VOC (volatile organic compound) [35,37].

In fact, it has been known that for an aircraft operating over on 800 km range approximately 25% of the emissions are produced during the take-off/landing cycle [38,39]. As there are over a thousand commercial aircrafts departing and landing at the Hong Kong International Airport per day as reported by the China Daily [40], many aircrafts taxi above Hong Kong and produce a significant amount of particulate matter in low troposphere. The aged particles with a mode diameter of 90 nm [34] will collide and grow to form the accumulation mode ultrafine particles. These accumulation mode particles will stay and disperse in low troposphere. They block and scatter the reflected visible light with a wavelength between 380 nm and 750 nm, causing a substantial reduction in visibility.

LPG is one of the main types of fuel gas used in Hong Kong for water heating in domestic, commercial, and industrial buildings. It is also used as a fuel by nearly all taxis and over 50 percent of public light buses. The consumption of LPG increases significantly during the autumn and winter, hence, the amount of fine particulate matter emitted from burning of LPG from about 0.5 million domestic, commercial and industrial users in Hong Kong also increases. LNG is primarily used by local power companies for producing electricity. It is a form of ‘cleaner energy’ and can reduce the total amount of particulate matter emitted from power plants by reducing the amount of coal burnt.

6. Implications

Visibility is an indicator of air quality [27,41]. Poor visibility can adversely affect human physiologically as well as psychologically [42,43]. It has primarily caused by the burning of aviation gasoline and kerosene in Hong Kong SAR, China. According to the Report from the Hong Kong Civil Aviation Department, the total number of flights landing and departing from Hong Kong increased from 166,223 in 1998 to 334,000 in 2011. Recently, there are more than a thousand flights landing and departing from Hong Kong per day. It is no doubt that air transport plays an important role in local economic development such as Hong Kong – one of the world finance centers, a regional tourism center, and the world’s logistic hub. The Government of Hong Kong projects that traffic at the Hong Kong International Airport will increase to 490,000 in 2025 and planned to build the third runway to cope with the increased demand. However, it is expected that the number of hours of reduced visibility will increase to around 2177 by the Year 2025 (using Equation 2 and assuming the fuel consumption to be linearly proportional to the number of flights). It is almost impossible to Hong Kong to have a “clear sky” in future, especially between October and April, a period without high humidity, rains and storms to flush out ultrafine particulate pollutants.

Past research [35] shows that aircraft operations would have no discernible elevation of 24-averaged PM$_{2.5}$ (or PM$_{10}$) mass, but highly elevated total suspended particulates, especially in the form of ultrafine particles. Hence, it is necessary for the Government of Hong Kong to monitor ultrafine particles and PM$_{2.5}$ both in terms of the number and mass concentrations, rather than relying on the PM$_{10}$ mass concentration measurements in the existing air quality monitoring networks. In addition, some of the monitoring stations shall be located at a higher level from the ground, rather than the existing ones that are located at the ground levels and/or the road sides. The correlation and multiple regression analyses show that visibility would be moderately affected by burning of LPG and LNG. As the consumption of LPG increases substantially during the autumn and winter, the amount of fine particulate matter emitted from gas-fired boilers and heaters in buildings increases. It is suggested that more energy-efficiency buildings shall be designed [44,45] and the use of renewable energy [46] such as photovoltaic [47] and wind power [48] should be explored.

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