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Effectiveness of replacing catalytic converters in LPG-fueled vehicles in Hong Kong

Xiaopu Lyu et al.

Correspondence to: Hai Guo (ceguohai@polyu.edu.hk)

Supplementary material for the manuscript "Effectiveness of replacing catalytic converters in LPG-fueled vehicles in Hong Kong"

Table S1 Average 'pre-converter' (*i.e.*, before catalytic converter replacement) and 'post-converter' (*i.e.*, after catalytic converter replacement) mixing ratios of CO, NO_x and the top 10 most abundant NMHCs emitted from the exhaust of 20 LPG-fueled taxis and 5 public light buses (PLBs). The results are based on chassis dynamometer tests in a controlled vehicle testing facility in Hong Kong. Error bars represent one standard error. Mixing ratios are in ppmv.

Compound	LPG taxi pre-converter mixing ratio (n=39)	LPG taxi post-converter mixing ratio (n=38)	LPG taxi decrease (%)	LPG PLB pre-converter mixing ratio (n=10)	LPG PLB post-converter mixing ratio (n=10)	LPG PLB decrease (%)
CO	5807 ± 520	481 ± 104	98.2%	5208 ± 1094	1097 ± 439	78.9%
NO_x	~800	~80	~90.0%	-	-	-
n-Butane	180 ± 20	6.1 ± 1.1	99.4%	133 ± 35	9.8 ± 2.0	92.6%
Propane	122 ± 11	4.6 ± 0.9	99.3%	114 ± 31	10.3 ± 2.3	91.0%
i-Butane	85.1 ± 8.8	3.1 ± 0.6	99.3%	70 ± 18	6.0 ± 1.3	91.5%
Ethene	44.4 ± 5.8	0.36 ± 0.05	99.9%	26 ± 13	0.28 ± 0.03	98.9%
Propene	17.8 ± 2.7	0.57 ± 0.32	98.2%	8.8 ± 4.6	0.13 ± 0.02	98.5%
Ethyne	14.2 ± 2.3	0.07 ± 0.01	99.9%	12.7 ± 8.0	0.08 ± 0.01	99.4%
Ethane	11.2 ± 0.7	0.36 ± 0.05	99.9%	8.7 ± 1.3	4.6 ± 1.2	46.9%
i-Pentane	1.6 ± 0.2	0.05 ± 0.01	99.4%	1.3 ± 0.3	0.08 ± 0.02	93.4%
i-Butene	1.0 ± 0.2	0.09 ± 0.01	98.8%	0.63 ± 0.15	0.05 ± 0.01	91.7%
1-Butene	1.0 ± 0.1	0.04 ± 0.01	99.3%	0.51 ± 0.24	0.01 ± 0.00	97.5%
Sum of NMHCs	479 ± 49	16.1 ± 2.9	99.4%	377 ± 94	32 ± 6	91.6%

Table S2 Mixing ratios (ppbv unless otherwise specified) and OH-reactivity (s^{-1}) of VOCs and trace gases at the roadside site (MK) and background site (HT) before and during the program. The reaction rates between OH and air pollutants are extracted from the Master Chemical Mechanism (http://mcm.leeds.ac.uk/MCM/).

Species	"before"				"during"			
	Concentration		Reactivity		Concentration		Reactivity	
	MK	HT	MK	HT	MK	HT	MK	HT
CO	922.0±26.8	289.3±1.9	5.2±0.2	1.7±0.02	917.0±35.3	252.2±1.8	5.2±0.3	1.4±0.01
NO	173.7±22.1	0.63±0.24	58.2±4.4	0.28±0.10	141.3±21.8	3.0±0.2	49.6±4.3	1.0±0.1
NO_2	61.9±6.4	6.9±0.1	17.1±1.4	1.7±0.01	63.2±7.1	6.6±0.2	17.7±1.6	1.6±0.1
O_3	5.5±0.9	17.2±1.1	0.01±0.001	0.03±0.003	9.0±1.7	26.6±1.7	0.01±0.002	0.05±0.01
SO_2	4.0±0.1	-	0.08±0.002	-	4.7±0.2	-	0.09±0.004	-
Ethane	4.6±0.3	2.2±0.04	0.02±0.001	0.01±0.001	4.8±0.3	2.5±0.1	0.03±0.001	0.02±0.001
Ethene	5.2±0.3	0.47±0.03	1.1±0.05	0.09±0.01	6.4±0.4	0.22±0.01	1.4±0.1	0.04±0.004
Ethyne	2.8±0.2	1.1±0.03	0.06±0.003	0.02±0.001	5.3±0.4	1.2±0.02	0.11±0.01	0.02±0.001
Propane	**9.2±1.0**	**0.75±0.02**	**0.20±0.01**	**0.02±0.001**	**6.9±0.6**	**1.0±0.02**	**0.15±0.003**	**0.03±0.0005**
Propene	1.9±0.1	0.10±0.01	1.2±0.04	0.07±0.01	1.3±0.1	0.08±0.01	0.88±0.05	0.05±0.01
***i*-Butane**	**6.8±0.7**	**0.33±0.01**	**0.30±0.01**	**0.02±0.001**	**5.1±0.6**	**0.34±0.01**	**0.22±0.01**	**0.02±0.001**
***n*-Butane**	**13.4±1.6**	**0.42±0.02**	**0.62±0.02**	**0.02±0.002**	**9.0±1.0**	**0.45±0.02**	**0.42±0.01**	**0.03±0.001**
trans-2-Butene	0.12±0.004	0.01±0.001	0.18±0.01	0.02±0.003	0.3±0.01	0.003±0.0004	0.47±0.02	0.005±0.001
1-Butene	0.44±0.02	0.02±0.001	0.32±0.01	0.01±0.002	0.09±0.01	0.01±0.001	0.06±0.01	0.01±0.0005
cis-2-Butane	0.10±0.01	0.01±0.001	0.13±0.01	0.01±0.002	0.05±0.01	0.02±0.001	0.06±0.01	0.03±0.002
i-Pentane	0.97±0.06	0.25±0.02	0.09±0.01	0.02±0.003	0.91±0.06	0.21±0.01	0.08±0.01	0.02±0.001
n-Pentane	0.54±0.04	0.15±0.02	0.06±0.004	0.02±0.003	0.51±0.03	0.11±0.01	0.05±0.003	0.01±0.001
1,3-Butadiene	0.13±0.01	0.02±0.001	0.21±0.01	0.03±0.002	0.07±0.01	0.003±0.01	0.12±0.01	0.01±0.001
1-Pentene	0.12±0.02	0.01±0.001	0.10±0.02	0.01±0.002	0.02±0.003	0.002±0.01	0.02±0.004	0.002±0.001
2-methyl Pentane	0.27±0.03	0.07±0.01	0.04±0.005	0.01±0.002	0.29±0.03	0.03±0.003	0.04±0.01	0.004±0.001
Isoprene	0.13±0.01	0.16±0.08	0.32±0.02	0.70±0.25	0.14±0.01	0.05±0.02	0.34±0.02	0.19±0.08

n-Hexane	0.42±0.03	0.09±0.003	0.06±0.01	0.01±0.001	0.34±0.04	0.27±0.01	0.05±0.01	0.03±0.001
Benzene	0.53±0.02	0.36±0.01	0.02±0.001	0.01±0.001	0.53±0.02	0.60±0.01	0.02±0.001	0.02±0.0005
n-Heptane	0.12±0.01	0.02±0.004	0.02±0.003	0.005±0.001	0.09±0.01	0.03±0.003	0.02±0.003	0.01±0.001
Toluene	1.9±0.2	0.60±0.03	0.28±0.03	0.09±0.01	2.0±0.2	0.94±0.04	0.28±0.04	0.12±0.01
n-Octane	0.05±0.01	0.03±0.002	0.01±0.002	0.01±0.0005	0.02±0.004	0.01±0.001	0.01±0.001	0.002±0.0002
Ethylbenzene	0.37±0.05	0.11±0.003	0.07±0.01	0.02±0.001	0.26±0.04	0.17±0.02	0.05±0.01	0.03±0.002
m,p-Xylenes	0.67±0.07	0.11±0.01	0.42±0.06	0.06±0.01	0.58±0.07	0.24±0.03	0.34±0.06	0.11±0.02
o-Xylene	0.18±0.02	0.04±0.002	0.07±0.01	0.01±0.001	0.13±0.02	0.06±0.01	0.04±0.01	0.02±0.003
1,3,5-TMB	0.03±0.01	0.002±0.001	0.04±0.01	0.004±0.001	0.01±0.002	0.002±0.0001	0.02±0.005	0.002±0.0002
1,2,4-TMB	0.11±0.01	0.01±0.002	0.10±0.02	0.005±0.003	0.08±0.01	0.01±0.001	0.07±0.02	0.004±0.001
1,2,3-TMB	0.03±0.004	0.003±0.001	0.03±0.004	0.003±0.001	0.01±0.002	0.002±0.0003	0.01±0.002	0.001±0.0004
Sum 1	51.3±3.2	7.5±0.2	-	-	45.1±1.9	8.6±0.1	-	-
Sum 2	-	-	6.0±0.3	1.3±0.2	-	-	5.3±0.3	0.8±0.05
Sum 3	-	-	86.6±6.0	5.0±0.3	-	-	77.9±6.1	4.9±0.1

TMB represents trimethylbenzene; Sum 1, 2 and 3 are the sum of mixing ratios of VOCs, of OH-reactivity of VOCs, and of OH-reactivity of all the air pollutants.

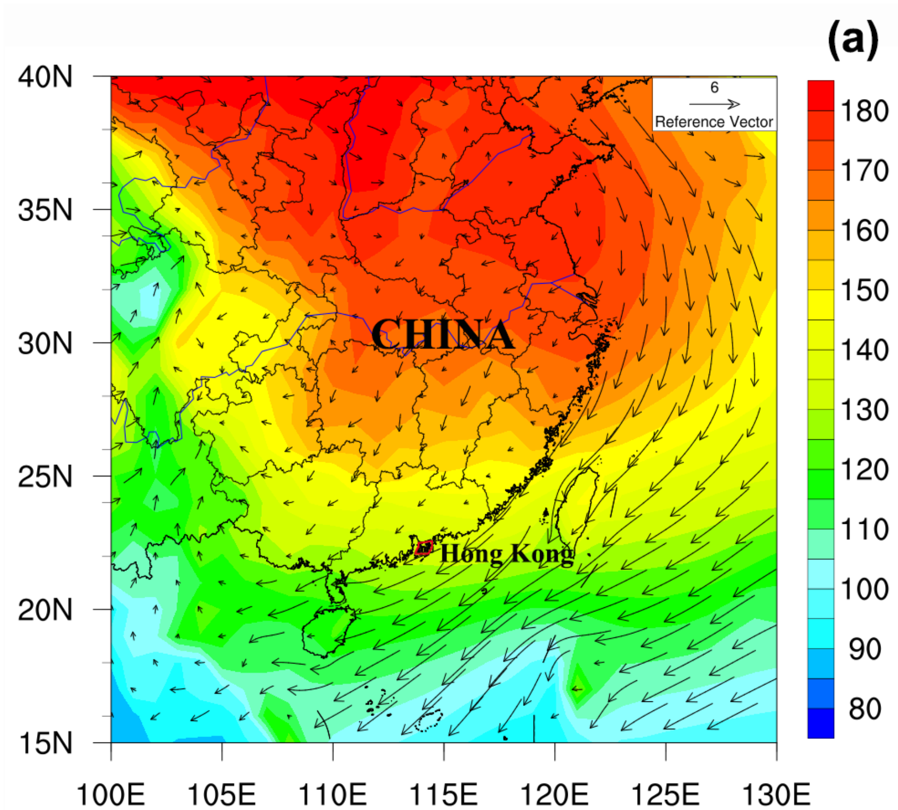
Table S3 Configuration for the model inputs of the base run and three constrained runs.

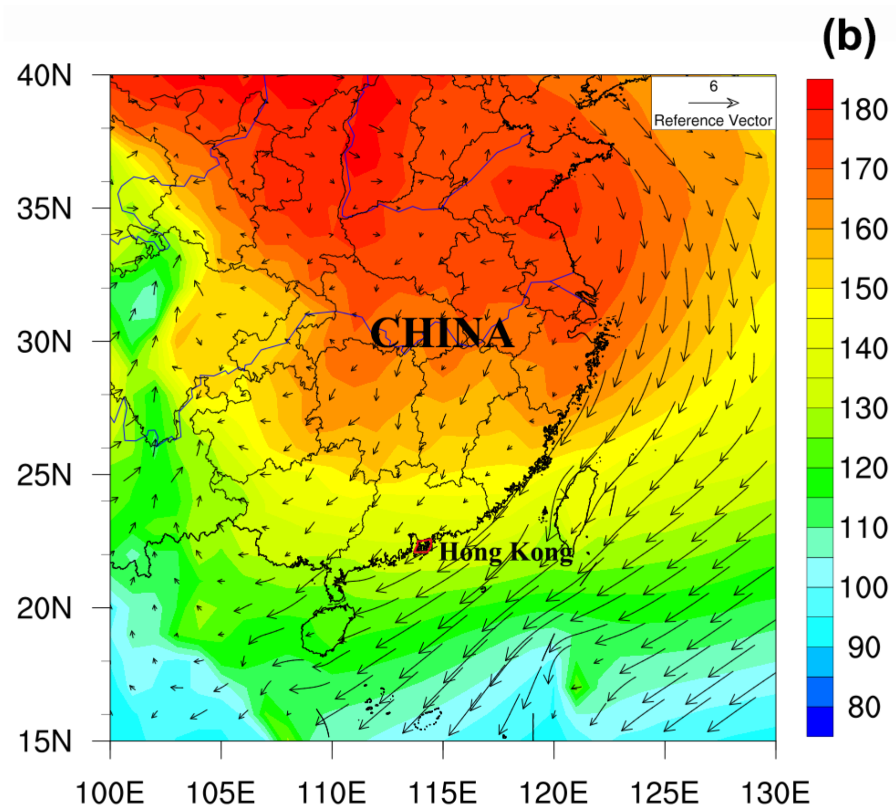
	Base run	Constrained run 1	Constrained run 2	Constrained run 3
VOCs	Observation	**Observation × (1-x)**	Observation	**Observation × (1-x)**
NO_x	Observation	Observation	**Observation × (1-y)**	**Observation × (1-y)**
CO	Observation	Observation	Observation	Observation
SO_2	Observation	Observation	Observation	Observation

"Observation" represents the observed whole-air ambient concentrations; x and y are the percentage contributions of LPG-fueled vehicle exhaust to ambient VOCs and NO_x, respectively, which are extracted from PMF simulations (x= 0.238/0.212 (before/ during the program) for ethane, ethene (0.206/0.061), ethyne (0.000/0.000), propane (0.703/0.574), propene(0.496/0.415), *n*-butane (0.769/0.641), *i*-butane (0.711/0.639), *n*-pentane (0.055/0.011), *i*-pentane (0.130/0.116), benzene (0.000/0.000), toluene (0.033/0.026), ethylbenzene (0.000/0.000), *m,p*-xylene (0.037/0.000) and *o*-xylene (0.048/0.003), and y= 0.073/0.011 and 0.003/0.000 for NO and NO_2, respectively)

Table S4 Number of registered vehicles in Hong Kong by the end of 2013 categorized by the fuel types.

Fuel type	Class of vehicles	No.
Gasoline	Private cars	475,752
Diesel	Single decked Public buses	7,162
	Double decked Public buses	5,619
	Public light buses	3,151
	Single decked Private buses	511
	Double decked Private buses	61
	Private light buses	2,757
	Light goods vehicles	74,399
	Media goods vehicles	37,902
	Heavy goods vehicles	4,755
LPG	Taxis	17,950
	Public light buses	3,280
Electricity	Motor cycles (including motor tricycles)	41,766
Total	675,065	


(a)
40N
35N
30N
25N
20N
15N
100E
105E
110E
115E
120E
125E
130E
6
Reference Vector
CHINA
Hong Kong
180
170
160
150
140
130
120
110
100
90
80



(b)
6
Reference Vector
CHINA
Hong Kong
40N
35N
30N
25N
20N
15N
100E
105E
110E
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120
110
100
90
80

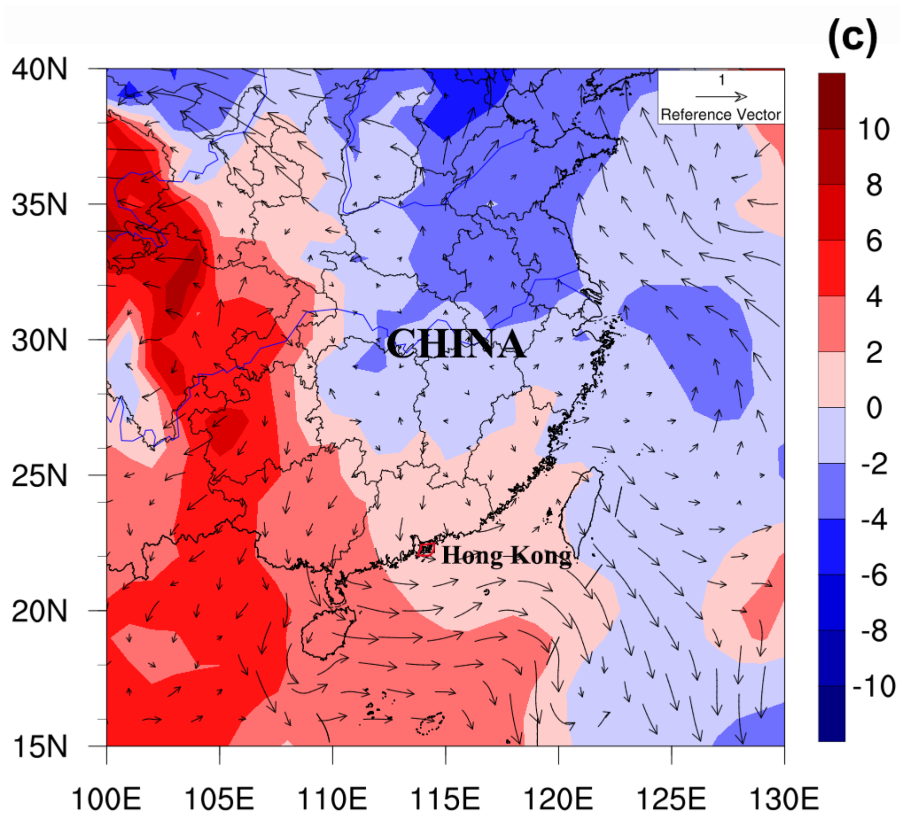
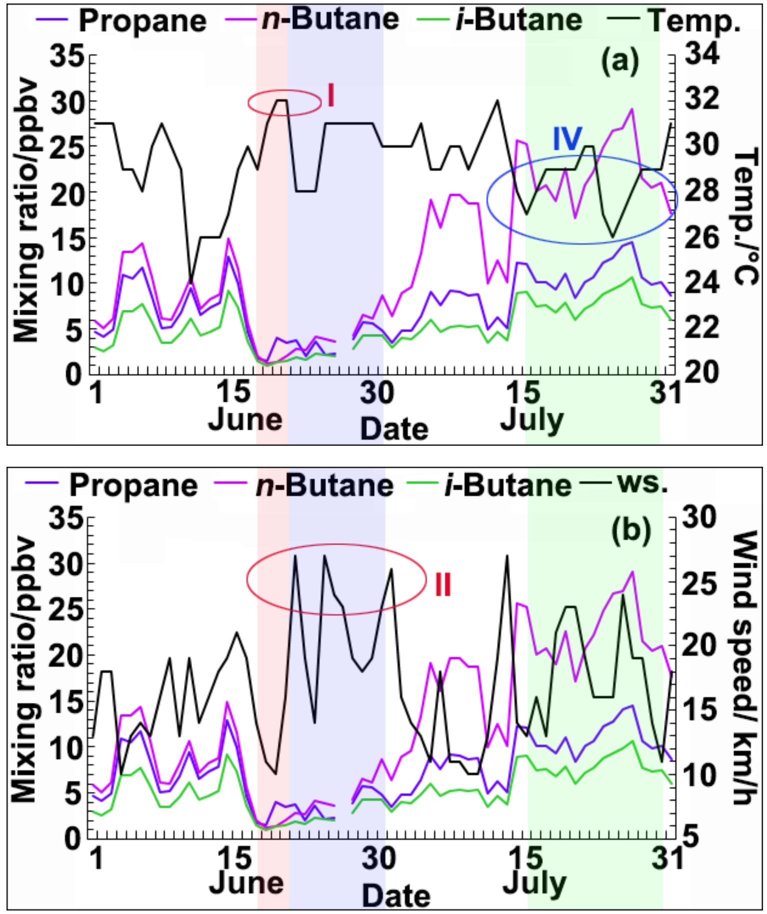


Figure S1 Average geopotential height (HGT) and wind field during the periods of (a) "matched" (1/10/2012-31/05/2013) and (b) "during" (1/10/2013-31/05/2014). (c) shows the differences in HGT and wind field between the periods of "matched" and "during". The red circle represents the border line of Hong Kong. The figures were made using NCEP FNL (final) data with a horizontal resolution of $1^{\circ}\times1^{\circ}$.



Propane
n-Butane
i-Butane
Temp.
(a)
I
IV
Mixing ratio/ppbv
Temp./°C
35
30
25
20
15
10
5
0
34
32
30
28
26
24
22
20
1
15
30
15
31
June
Date
July
Propane
n-Butane
i-Butane
ws.
(b)
II
Mixing ratio/ppbv
Wind speed/ km/h
35
30
25
20
15
10
5
0
30
25
20
15
10
5
1
15
30
15
31
June
Date
July

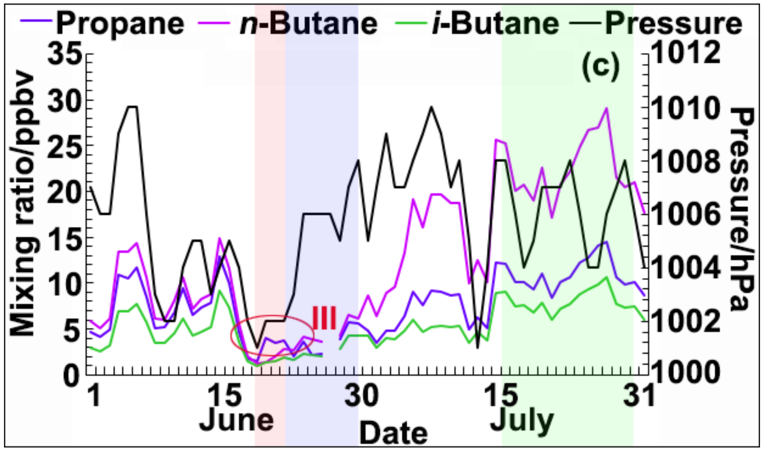
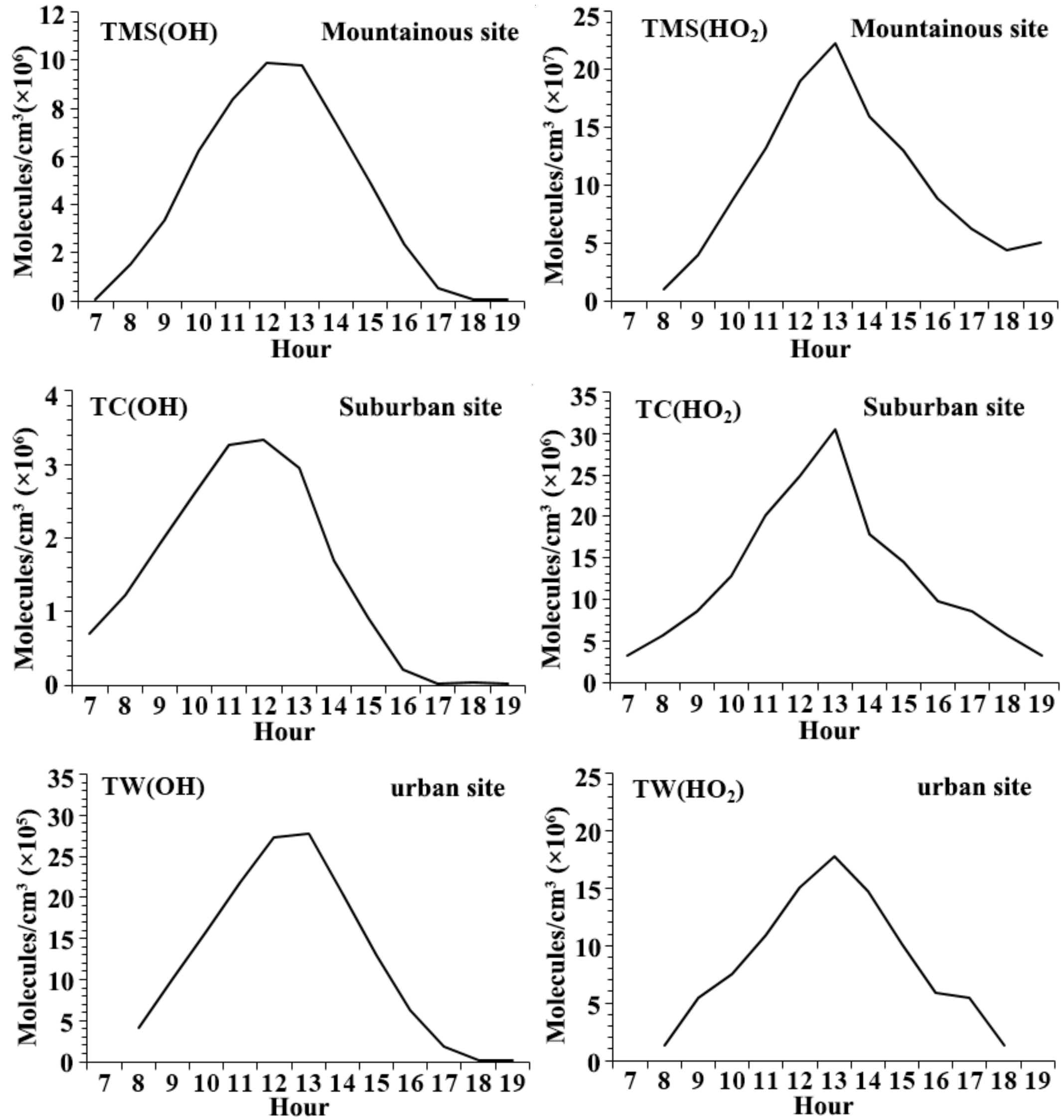


Figure S2 Relationships between the LPG-related VOCs with (a) temperature, (b) wind speed and (c) pressure (I. the high temperature caused by the anti-cyclone over South China (highlighted with red color); II. the high wind speed caused by the tropical storm over SCS (highlighted with blue color); III. the low pressure. IV. the low temperature caused by an active ocean flow and a low pressure trough over SCS (highlighted with green color).


TMS(OH)
Mountainous site
Molecules/cm³(×10⁶)
Hour
TMS(HO₂)
Mountainous site
Molecules/cm³ (×10⁷)
Hour
TC(OH)
Suburban site
Molecules/cm³ (×10⁶)
Hour
TC(HO₂)
Suburban site
Molecules/cm³ (×10⁶)
Hour
TW(OH)
urban site
Molecules/cm³ (×10⁵)
Hour
TW(HO₂)
urban site
Molecules/cm³ (×10⁶)
Hour

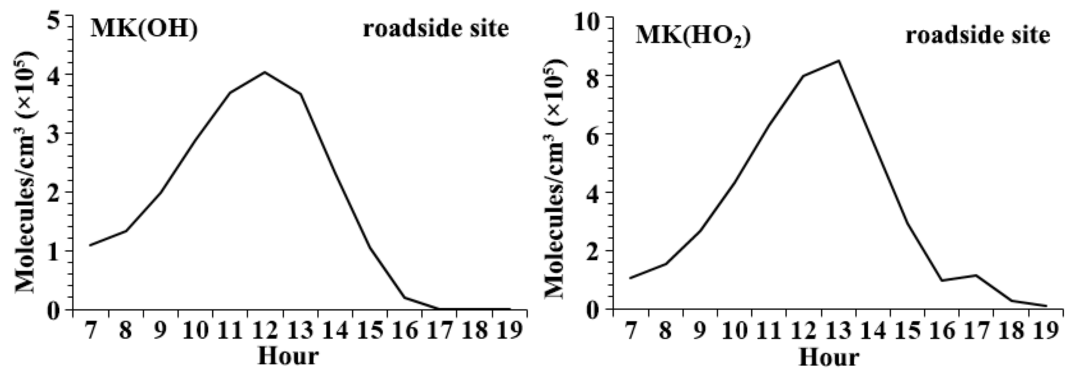


Figure S3 Daytime patterns of OH and HO_2 at different sites in Hong Kong simulated by the PBM-MCM model. TMS, TC, TW and MK are the mountainous, suburban, urban and roadside sites, respectively.