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Supplementary Materials

Evaluating Real Driving Emissions of Compressed Natural Gas Taxis in Chongqing, China—A Typical Mountain Cities

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Table S1 Information on taxis fueled by compressed natural gas.

Vehicle ID	Model year	Cross vehicle weight	Emission standard	Fuel type	Mileage traveled (×1000 km)	Engine displacement (ml)	Engine type	Power
1	2015	1265	China IV	CNG	650	1600	M16A4	80 kW
2	2015	1265	China IV	CNG	565	1600	M16A4	80 kW
3	2015	1265	China IV	CNG	551	1600	M16A4	80 kW
4	2016	1120	China V	CNG	456	1600	CAS16	90 kW
5	2016	1120	China V	CNG	327	1600	CAS16	90 kW

Table S2 Driving condition parameters used in the testing of each taxi fueled by compressed natural gas.

Vehicle	Test distance (km)			Average speed (km/h)			Duration (s)		
ID	UF	PR	SR	UF	PR	SR	UF	PR	SR
1-a				60.8	27.0	30.2	1434	3102	712
1-b				49.1	31.4	33.2	2082	1168	1477
2-a				57.4	30.1	29.8	1520	2784	718
2-b	24.2	23.3	5.9	62.4	35.4	34.6	1397	2266	590
3-a				54.1	29.3	29.6	1614	2871	720
3-b				60.8	27.0	30.2	1636	2453	529
4-a				61.3	32.6	27.8	1421	2559	777

4-b	50.5	30.2	29.3	1274	2575	591
5-a	48.3	30.5	32.7	1801	2753	658
5-b	59.9	36.9	27.7	1460	2267	619

[a]CNG taxis without TWC replacement
[b]CNG taxis with TWC replacement

Table S3 The precision of measurements.

Pollutants	Range	Maximum Allowable Deviation/Accuracy Grade	Manufacturer
CO	(0-10) vol%	<±2.0% of reading or ±0.3% of full scale, whichever is greater	Japan, Horiba
CO_2	(0-20) vol%		
NOx	(0-3000)ppm		
THC	(0-10000)ppm		
PM	--		
Flow rate	(0-45) m^3/min	<±2.0% of reading or ±0.5% of full scale, whichever is greater	

Table S4 The parameters of the replaced three-way catalytic converter.

Parameter	Diameter	Length	Cell density	Wall thickness	Carrier material	Precious metals
Feature/Value	110 mm	130 mm	400	0.05 mm	CeO_2-Al_2O_3	Pd-based-60g/ft^3

Table S5 Definition of operating mode bins by using vehicle specific power (VSP) and vehicle speed (v).

VSP (kW t^{-1})		Vehicle Speed (km h^{-1})			
		v<1.6	1.6≤v<40	40≤v<80	v>80
VSP<-4	Bin 0 Deceleration or braking	Bin 1 Idle	Bin 11	Bin 21	Bin 35
-4≤VSP<2			Bin 12	Bin 22	
-2≤VSP<0			Bin 13	Bin 23	
0≤VSP<2			Bin 14	Bin 24	
2≤VSP<4			Bin 15	Bin 25	
4≤VSP<6			Bin 16	Bin 26	Bin 36
6≤VSP<8			Bin 17	Bin 27	Bin 37
VSP≥8			Bin 18	Bin 28	Bin 38

Table S6 The average distance-specific emission factors of NO, NO_2 and CO_2 for taxis with/without TWC replacement.

Fuel type	Criteria	Average distance-specific emission factors (g/km)		
		NO	NO_2	CO_2
CNG	China IV(without TWC replacement)	1.13 ± 0.44	0.68 ± 0.34	115.60 ± 9.53
	China V(without TWC replacement)	0.71 ± 0.18	0.39 ± 0.11	109.35 ± 0.95
	China IV(with TWC replacement)	0.22 ± 0.13	0.12 ± 0.07	119.00 ± 4.17
	China V(with TWC replacement)	0.27 ± 0.12	0.16 ± 0.13	119.60 ± 14.10

Table S7 The results of ASM mode testing.

Vehicles ID	**THC(ppm)**	**CO(%)**	**NOx(ppm)**
Taxi 1# without TWC replacement	128	0.03	2766
Taxi 1# with TWC replacement	2	0.02	172
Taxi 2# without TWC replacement	63	0.02	1645
Taxi 2# with TWC replacement	2	0.02	56

Taxi 3# without TWC replacement	69	0.02	2108
Taxi 3# with TWC replacement	2	0.03	28
Taxi 4# without TWC replacement	76	0.02	1146
Taxi 4# with TWC replacement	2	0.01	44
Taxi 5# without TWC replacement	89	0.25	2109
Taxi 5# with TWC replacement	1	0.03	76
Emission limits	90	0.5	700

Table S8 The average distance-specific emission factors of passenger car fueled by gasoline.

Fuel type	Mileage traveled (km)	Engine displacement (ml)	Engine type	Emission standard	Average distance-specific emission factors (g/km)		
					CO (g/km)	NO_x (g/km)	PN (#/km×10^{11})
Gasoline	210039	2300	VQ23DE	China II	31.47	1.06	100
Gasoline	529024	2700	2TR-FE	China II	5.00	0.28	70
Gasoline	120073	2400	4G64S4M	China III	2.28	0.07	4
Gasoline	135871	1800	EA113	China III	2.71	0.33	70
Gasoline	165950	1000	JL466Q9	China III	1.02	0.39	30
Gasoline	134428	1600	N6A	China III	1.48	0.14	9
Gasoline	215046	1600	EA113	China III	1.00	0.26	9
Gasoline	122570	1500	4G15M	China IV	0.70	0.019	2

Gasoline	115170	2000	LFX	China IV	6.10	0.036	3
Gasoline	169003	1600	M16A4	China IV	0.47	1.22	10
Gasoline	163330	2000	LFX	China IV	3.26	0.16	2
Gasoline	146744	1497	SQR477F	China IV	1.60	0.21	4
Gasoline	60156	1798	DBH	China V	0.17	0.013	2
Gasoline	96110	1997	9B335108	China V	0.28	0.004	9
Gasoline	100220	1598	1ZR	China V	0.16	0.016	33

Table S9 Road grade distribution ratio of test route.

Road grade (%)	<-8	[-8,-6)	[-6,-4)	[-4,-2)	[-2,2]	(2,4]	(4,6]	(6,8]	>8
Ratio	7.51	1.96	7.98	11.58	38.78	12.61	8.20	2.10	9.28

Table S10 The acceleration patterns on different road gradients.

Range	Without TWC replacement			With TWC replacement		
	Average	Max	Mix	Average	Max	Mix
(-∞,-8%)	-0.018	5.59	-3.63	-0.013	9.34	-4.68
[-8%,-6%)	0.047	3.54	-2.39	0.041	2.24	-4.09
[-6%,-4%)	0.018	4.94	-3.49	0.0078	3.14	-3.53
[-4%,-2%)	0.013	3.14	-3.47	0.0026	6.50	-5.55
[-2%,2%]	-0.0036	8.47	-7.03	0.0019	5.65	-7.70
(2%,4%)	0.011	5.54	-2.47	0.0022	1.92	-5.40
[4%,6%)	-0.035	3.79	-6.65	-0.092	1.67	-3.80
[6%,8%)	-0.012	3.97	-3.25	-0.054	2.74	-3.15
[8%,+∞)	-0.013	8.68	-7.03	-0.012	8.72	-3.56

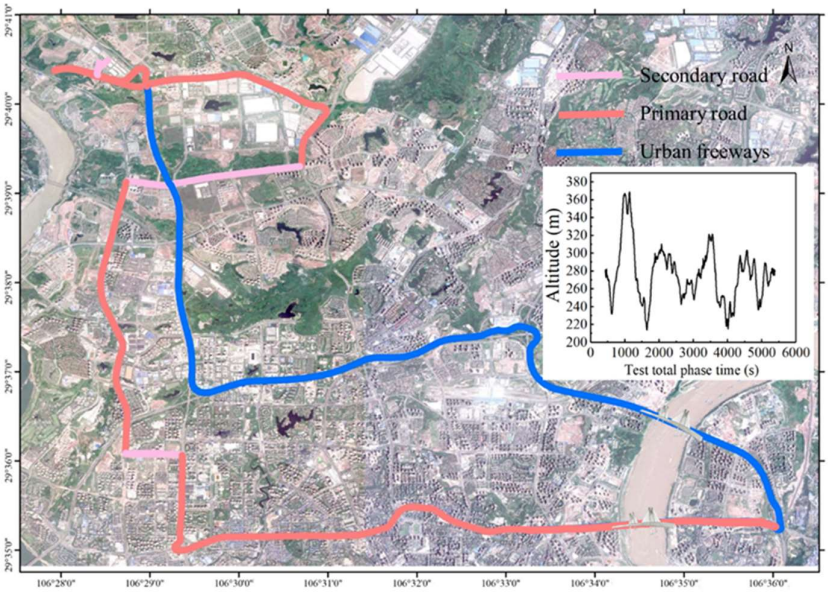


Figure S1. The test routes for the CNG taxis in Chongqing.

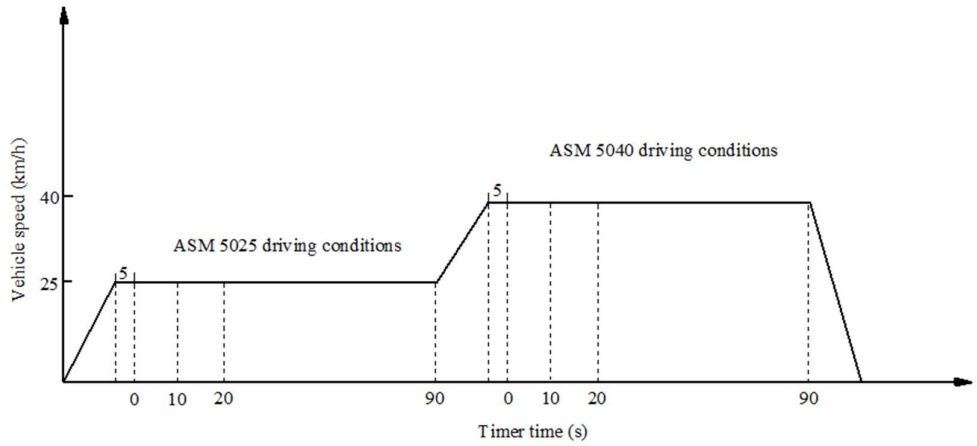


Figure S2. ASM test operating cycle.



Figure S3. The portable emissions measurement system used to test the CNG taxis.

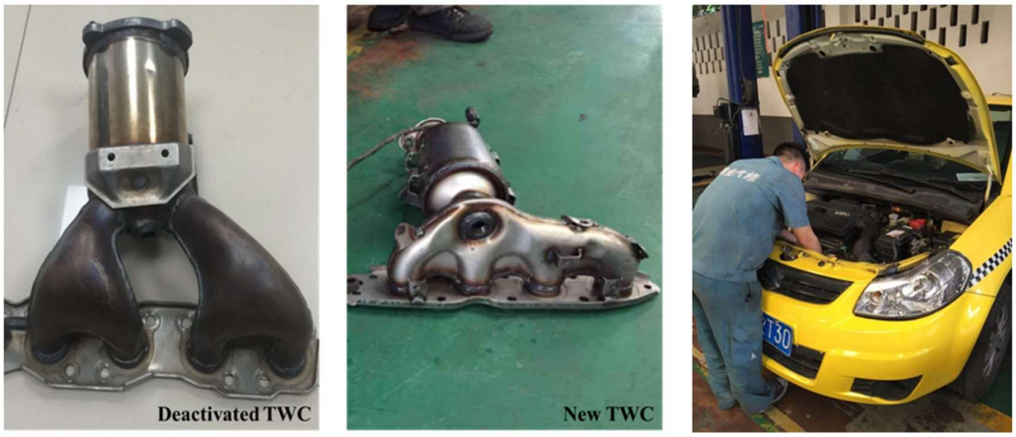
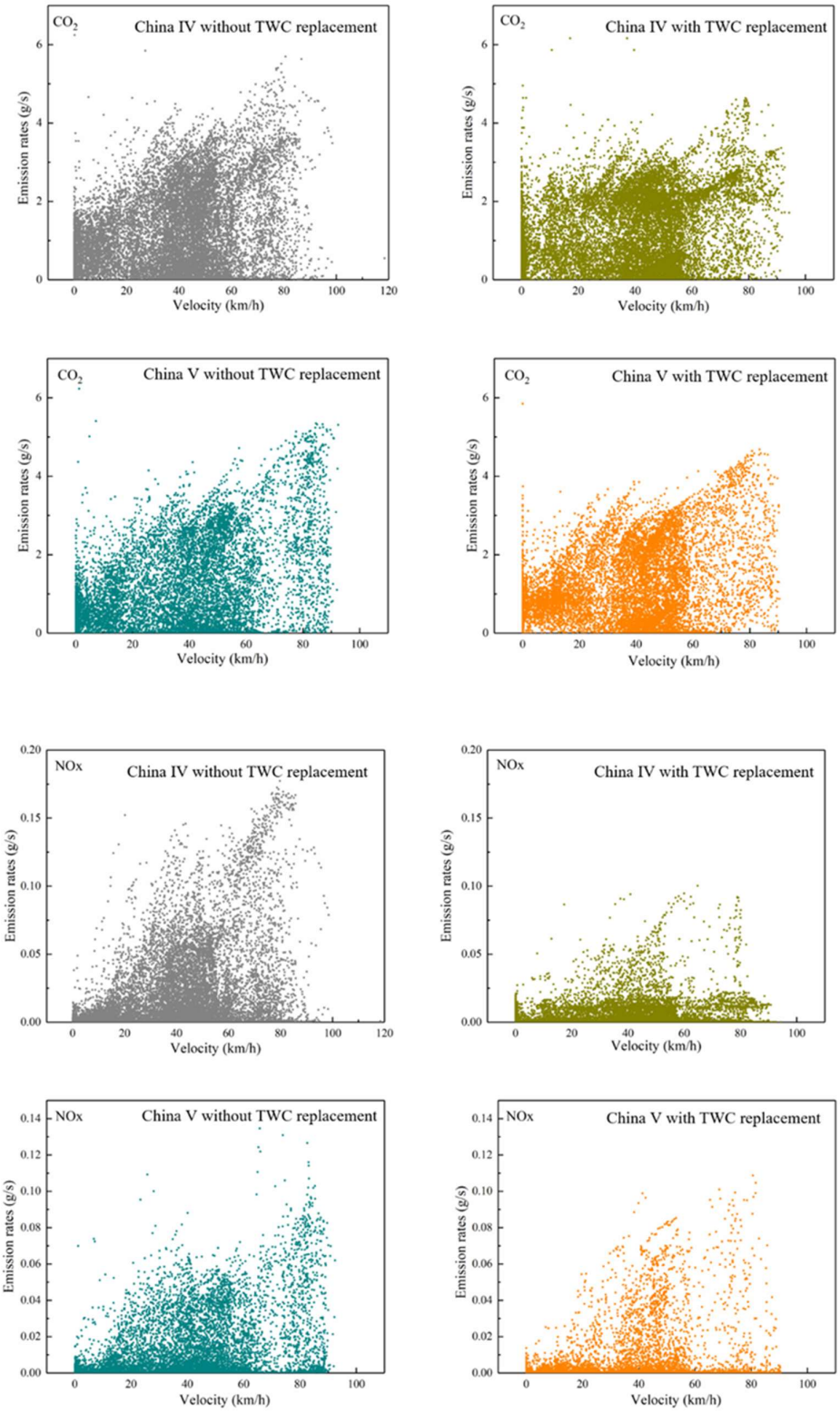
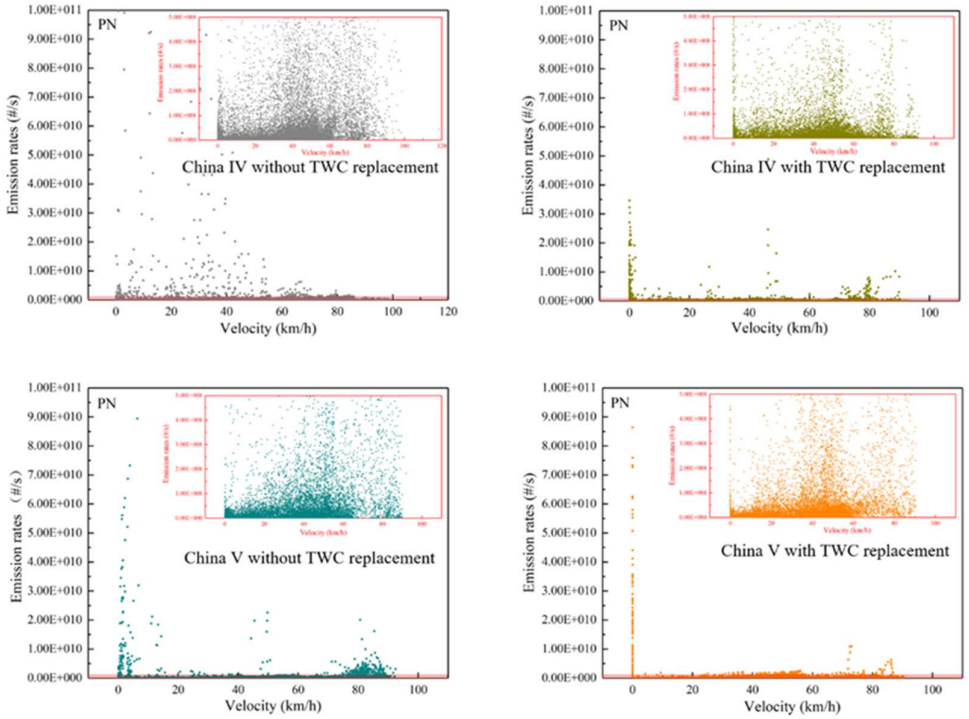
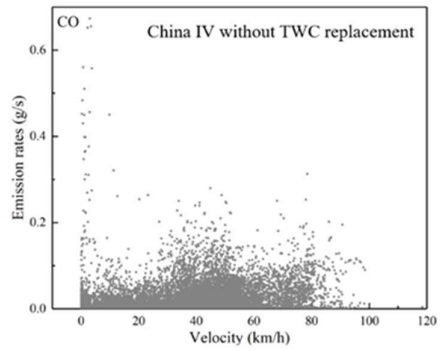
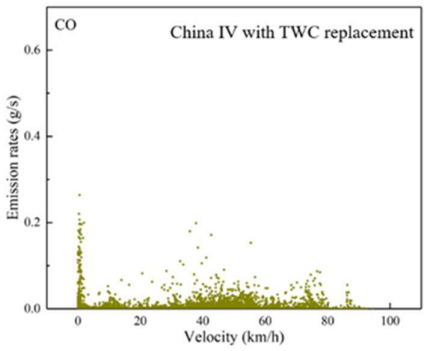


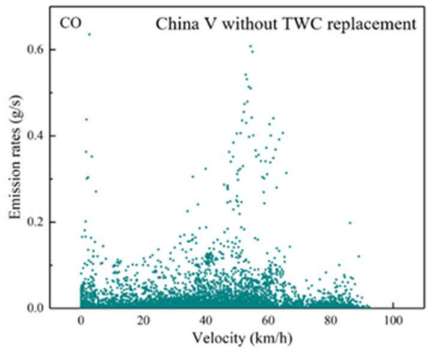
Figure S4. The deactivated and new TWCs.

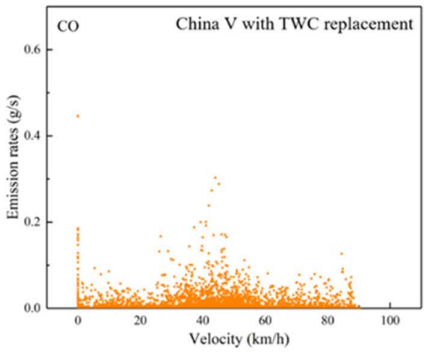

CO2
China IV without TWC replacement
Emission rates (g/s)
Velocity (km/h)
CO2
China IV with TWC replacement
Emission rates (g/s)
Velocity (km/h)
CO2
China V without TWC replacement
Emission rates (g/s)
Velocity (km/h)
CO2
China V with TWC replacement
Emission rates (g/s)
Velocity (km/h)
NOx
China IV without TWC replacement
Emission rates (g/s)
Velocity (km/h)
NOx
China IV with TWC replacement
Emission rates (g/s)
Velocity (km/h)
NOx
China V without TWC replacement
Emission rates (g/s)
Velocity (km/h)
NOx
China V with TWC replacement
Emission rates (g/s)
Velocity (km/h)

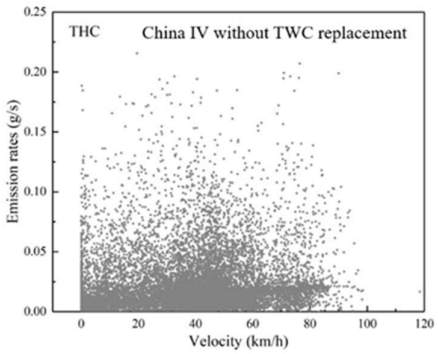

PN
China IV without TWC replacement
China IV with TWC replacement
China V without TWC replacement
China V with TWC replacement
Emission rates (#/s)
Velocity (km/h)

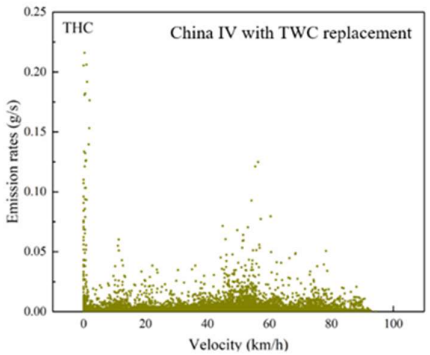

CO
China IV without TWC replacement
Emission rates (g/s)
Velocity (km/h)

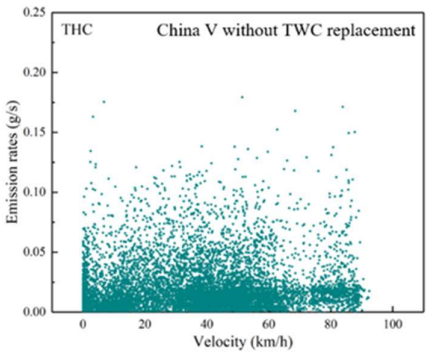

CO
China IV with TWC replacement
Emission rates (g/s)
Velocity (km/h)

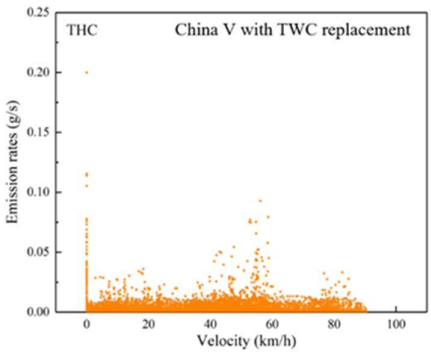

CO
China V without TWC replacement
Emission rates (g/s)
Velocity (km/h)


CO
China V with TWC replacement
Emission rates (g/s)
Velocity (km/h)


THC
China IV without TWC replacement
Emission rates (g/s)
Velocity (km/h)


THC
China IV with TWC replacement
Emission rates (g/s)
Velocity (km/h)


THC
China V without TWC replacement
Emission rates (g/s)
Velocity (km/h)


THC
China V with TWC replacement
Emission rates (g/s)
Velocity (km/h)

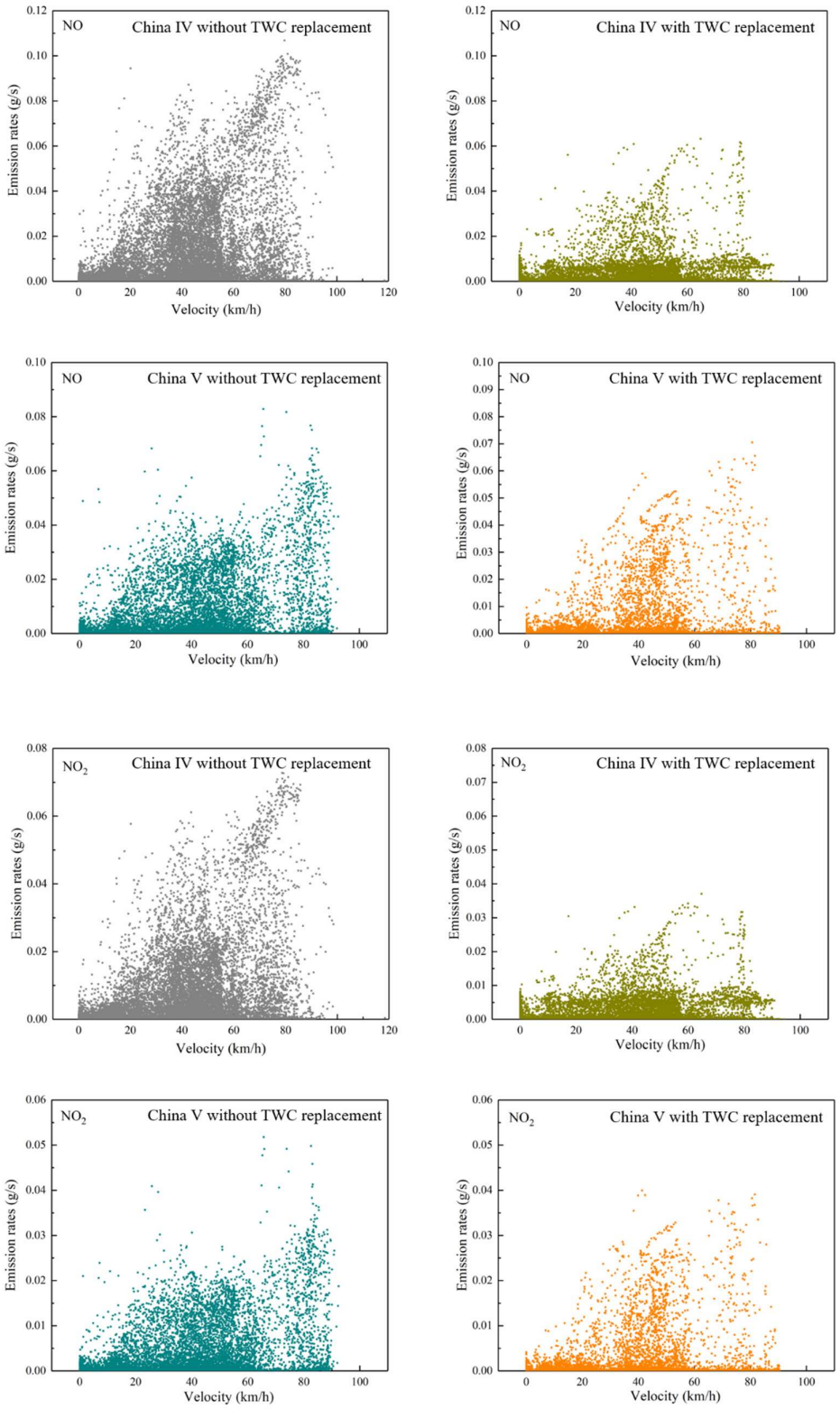


Figure S5. The emission rates of taxis according to different velocity.

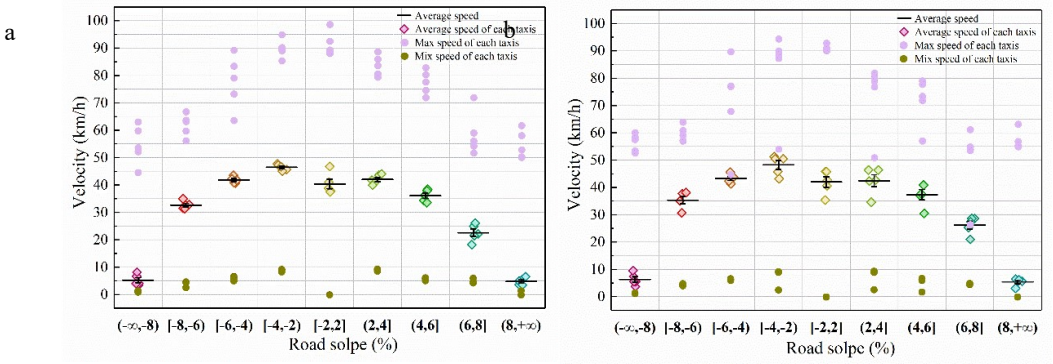


Figure S6. Distribution of velocity in different road grade bins: (a) CNG taxis without TWC replacement, (b) CNG taxis with TWC replacement.

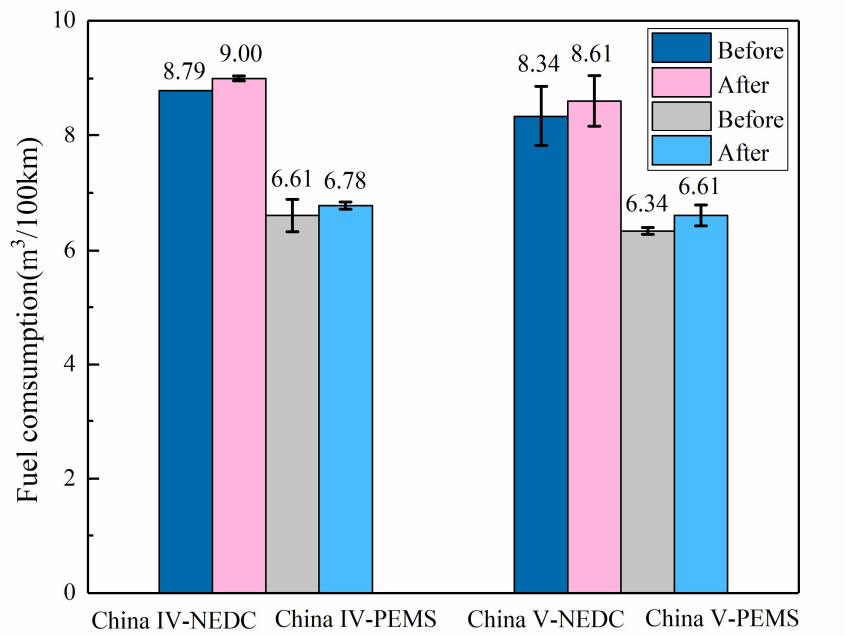


Figure S7. The natural gas consumption of CNG taxis before and after TWC replacement.

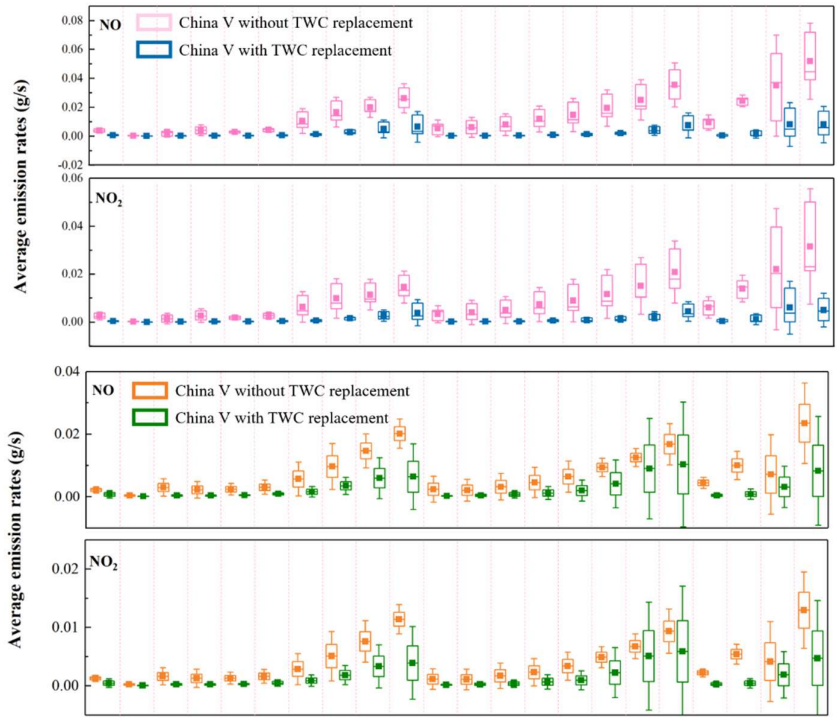


Figure S8. Average emission rates of NO and NO_2 from CNG taxis according to operating mode.