Supplementary Tables

Supplementary Table 1: Technical details of the two-stroke scooters used in this study.

Scooter	**E1**	**E2a**	**E2b**
Registration date	26/10/2007	05/03/2010	2010
km at start of testing	7716	20	1700
Displacement (cm^3)	50	50	50
After- treatment	Oxidation catalyst	Oxidation catalyst	Oxidation catalyst, Carburetor
EC Norm	97/24/CE Euro1	97/27/5/CE Euro 2	97/27/5/CE Euro 2
Fuel	Gasoline+2% lubricant	Gasoline+2% lubricant	Gasoline+2% lubricant

Supplementary Table 2: Emission limit values for Euro 1 and Euro 2 powered two wheelers. Euro 3 legislation is to be introduced by 2016 [ref 53].

Norm	Directive	Effective	CO	$HC+NO_x$
			mg km^{-1}	mg km^{-1}
EURO 1	97/24/EC	17.06.1999	6000	3000
EURO 2	97/24/EC	17.06.2002	1000	1200

Supplementary Table 3: List of smog chamber tests with driving conditions, smog chamber OA concentrations, initial NO concentrations and calculated primary and secondary organic aerosol in g carbon (C) kg^{-1} fuel for idling, simulated low power and ECE47 driving cycle (chassis dynamometer) 2S scooter experiments.

Vehicle	Date	Test	OA		Aged OA /POA	NO	Emission Factors	
			POA	Aged OA			POC	SOC(5h)
			µg m^{-3}	µg m^{-3}		ppb(v)	g C kg^{-1} Fuel	g C kg^{-1} Fuel
E1	17.11.10	Idle	11	121.8	11.1	41	1.02	6.45
	19.11.10	Idle	7.5	196.1	26.1	87	0.72	5.45
	22.11.10	Low Power	70.4	116.4	1.7	87	5.17	6.59
E2a	15.11.10	Low Power	38.8	114.9	5.0	52	5.17	6.59
	24.11.10	Low Power	8.3	23.3	3.0	64	9.18	15.37
	26.11.10	Idle	1.7	157.9	2.8	49	1.48	2.02
E2b	30.09.11	Full cycle	3.04	4.98	1.6	119	0.49	0.78
	03.10.11	Phase one only	30.56	71.23	2.3	60	2.08	3.25

Supplementary Table 4: Average primary organic aerosol (POA) emission factors and aged organic aerosol (POA+SOA, g C kg^{-1} fuel) from the literature.

Study	POA	Aged OA	Notes
European 2S Scooters			
Chirico et al., (in prep.)	15.8	-	2 scooters (includes Euro 1 of this study and one Euro 2), mix of hot and cold idle on line measurement
Chirico et al., (in Prep.)	15.5	16.2	Same vehicles as above, ECE47 driving cycle. Aged OA=POA+(0.084×Aromatic)
Adam et al. (2010)[7]	1.12	2.00	4 Euro 2 scooters. ECE47 driving cycle. Gravimetric measurement, assumes 100% POA. Aged OA=POA+(0.084×Aromatic)
Indian 2S Autorickshaws			
Apte et al. (2011)[8], Reynolds et al., (2011)[9]	10.7		In-use vehicles, Indian Driving Cycle. Mix of compressed natural gas and gasoline powered
Euro 5 light duty vehicles			
Platt et al. (2013)[1]	0.02	0.05	One gasoline vehicle, NEDC driving cycle
Platt et al. (in Prep.)	0.01	0.02	Two gasoline and two diesel vehicles, NEDC. Same methodology as for driving cycle scooters of this study.
Light duty vehicles not meeting Euro 5			
Nordin et al. (2013)[10]		0.10	Mix of gasoline vehicles, mostly <Euro 3.

			SOA only. Non standardised driving cycle
Chirico et al., (2010)[11]	0.11	0.26	One diesel vehicle with catalyst. Non standardised driving cycle
Gordon et al. (2013a)[12], Gordon et al., (2013b)[13]	0.05	0.08	Diesel and gasoline vehicles complying with US LEV1, LEV2, and LEV3. Standardised US driving cycles
Schauer et al. (2002)[14]	0.05		Mix of gasoline vehicles. Sampled during federal cold start test procedure
Chirico et al. (in Prep.)	0.07		NEDC driving cycle
Heavy duty vehicles			
Gordon et al. (2013)[12]	0.02		Standardised driving cycles
Chirico et al. (in Prep.)	0.03		ETC driving cycle
Zardini et al. (in Prep.)	0.007	0.009	Same methodology as for driving cycle scooters of this study.
Schauer et al. (1999)[15]	0.11		Medium duty diesel trucks. Federal hot start test procedure
Ambient roadside/ tunnel mainly light duty (>50%)			
Grieshop et al. (2006)[16]	0.08		US: Pittsburgh highway tunnel, average of high and low speed
Handler et al. (2008)[17]	0.09		EU: tunnel in Austria, measurements in 2005
Phuleria et al. (2007)[18]	0.12		US: California tunnel, measurements in 2005

Fraser et al. (1998)[19]	0.18		US: LA tunnel
Geller et al. (2005)[20]	0.03		US: Northern California tunnel, measurements in 2004
He at al. (2008)[21]	0.33		Asia: Zhujiang Tunnel, China, measurements in 2004
Gillies et al. (2001)[20]	0.27		US: Sepulveda tunnel, LA, measurements in 1998
Lough et al. (2005)[21]	0.14		US: average Kilburn and Howell tunnels, Milwaukee, in winter and summer, on weekends and weekdays
Cheng et al. (2010)[22]	0.14		Asia: Xueshan Tunnel, Taiwan
Dallmann et al. (2013)[23]	0.01		US: Caldecott tunnel, LA, measurements in 2010
Kirchstetter et al. (1999)[24]	0.05		US: California, measurements in summer 1997
Kam et al. (2012)[25]	0.05		US: California roadside, measurements in 2011
Hung-Lung et al. (2009)[26]	0.07		Asia: tunnel in Taiwan, measurements in 2005
EPA (2006)[29]	0.08		US: remote sensing at roadside in Kansas City. Average of winter/ summer
Ambient roadside/ tunnel mainly heavy duty (>50%)			
Geller et al. (2005)[30]	0.18		US: Northern California tunnel, measurements in 2004

Cheng et al. (2010)[24]	0.19		Asia: Xueshan Tunnel, Taiwan
Kirchstetter et al. (1999)[26]	0.5		US: California, measurements in summer 1997
EPA (2006)[29]	0.08		US: remote sensing at roadside in Kansas City. Average of winter/ summer

Supplementary Table 5: Roadside benzene, toluene, ethylbenzene and xylene (BTEX) concentrations in different cities (μg m^{-3}).

City	Time	Benzene	Toluene	Ethylbenzene	Xylene	Ref.
Guangzhou, China	Oct and Nov 1996	51.5	77.3	17.8	82.1	Wang et al. (2002)[30]
Guangzhou, China	Sep 2000	47.9	75.3	15.2	106.3	Chan et al. (2006)[31]
Guangzhou, China	Feb and Aug 2000	61.6	103.9	15.4	109.8	Tang et al. (2008)[32]
Guangzhou, China	Feb 2002	34.6	56.2	11.4	48.2	Zhao et al. (2004)[33]
Guangzhou, China	Sep 2005	6.6	15.1	4.0	11.1	Tang et al. (2007)[34]
Dongguan, China	Jan 2006	12.3	76.0	14.6	48.0	Tang et al. (2007)[34]
Macau	Nov 1995	34.9	85.9	24.1	95.6	Wang et al. (2002)[30]
Hong Kong	Jan and Feb 1998	24.9	68.9	2.5	14.5	Chan et al. (2002)[35]
Nanjing, China	April 2006 – Jan 2007	15.8	38.2	7.0	16.3	Wang et al. (2008)[36]
Nanjing, China	Aug 2011	5.6	10.6	4.0	7.8	Lan et al. (2012)[37]
Changchun, China	Sep 1997 – Jul 1998	38.5	80.2	18.8	23.4	Liu et al. (2000)[38]

Taipei, Taiwan	Spring 1992	371.0	849.0	189.0	606.0	Chan et al. (1994)[39]
Taichung, Taiwan	1998	145.0	442.0	74.0	198.0	Kuo et al. (2000)[40]
Kyoto, Japan	May 2011	2.3	12.2	2.8	3.7	Lan et al. (2012)[37]
Osaka, Japan	May 2011	2.1	11.8	2.1	5.9	Lan et al. (2012)[37]
Bangkok, Thailand	Sep 2003	/	246.7	/	106.3	Oanh et al. (2008)[41]
Kuala Lumpur, Malaysia	Aug 2011	48.0	105.6	15.8	82.6	Lan et al. (2012)[37]
HoChiMinh, Vietnam	Oct – Dec 2009	93.5	208.5	33.8	200.4	Lan et al. (2013)[42]
HoChiMinh, Vietnam	Oct 2011	87.0	200.1	39.2	150.9	Lan et al. (2012)[37]
Hanoi, Vietnam	Dec 2011	52.0	88.4	23.4	84.0	Lan et al. (2012)[37]
Singapore	May 2011	6.9	42.8	5.2	14.0	Lan et al. (2012)[37]
Delhi, India	Oct 2001 – Sep 2002	103.5	185.5	22.5	127.0	Hoque et al. (2008)[45]
Delhi, India	Jan – Dec 2001	358.5	74.8	31.3	37.6	Srivastava et al. (2005)[44]
Mumbai, India	May 2001 – April 2002	237.8	216.0	1.7	0.7	Srivastava et al. (2006)[45]
Karachi,	Dec 1998	93.9	246.9	/	249.0	Barletta et al.

Pakistan	– Jan 1999					(2002)[46]
Rome, Italy	Jan, May, July, Oct 2000	6.2	44.1	8.2	41.4	Fuselli et al. (2002)[47]
Izmir, Turkey	Aug – Sep 1998	46.3	102.8	29.3	177.1	Muezzinoglu et al. (2001)[48]
Zurich, Switzerland	Oct 1993	6.0	/	/	7.4	Monn et al. (1996)[49]
London, UK	July 1991 – June 1992	15.6	25.8	4.2	18.7	Derwent at al. (1995)[50]
London, UK	Jan – Dec 1996	6.0	13.6	3.2	12.8	Derwent et al. (2000)[51]
Birmingham, UK	2005 – 2006 (13 months)	2.0	9.5	1.7	5.4	Vardoulakis et al. (2011)[52]

Supplementary Note 1

Secondary organic aerosol yields

A secondary organic aerosol (SOA) yield y is defined as:

$$y = \frac{\Delta C_{OA}}{\Delta VOC}, \tag{1}$$

Where ΔC_{OA} is the organic aerosol production for a given change in volatile organic compound concentration ΔVOC. The SOA yields for an individual aromatic i as a function of aerosol loading may be estimated using two-product fits [4]:

$$y_i = \Delta C_{OA} \cdot \left[\frac{\alpha_1 k_{om,1}}{1 + k_{om,1} \cdot C_{OA}} + \frac{\alpha_2 k_{om,2}}{1 + k_{om,2} \cdot C_{OA}} \right], \tag{2}$$

Where C_{OA} is the organic aerosol loading, measured using a high resolution time of flight mass spectrometer, and α_j and $K_{om,j}$ are the mass fraction and partitioning coefficients of gas phase species i, respectively. Using literature values of α_i and $k_{om,i}$ for aromatic hydrocarbons[4] a concentration-weighted predicted yield $y_{predicted}$ is calculated for the oxidation of aromatics in 2S scooter exhaust using:

$$y_{predicted} = \frac{\sum_i (y_i \cdot \Delta i)}{\sum_i \Delta i} \tag{3}$$

SOA yields from the literature for high NO_X conditions were used to calculate a predicted yield $y_{predicted}$ from the decay of aromatic hydrocarbons, measured with the PTRMS from the smog chamber. $y_{predicted}$ is then compared with the apparent yield (Eq. 1, main text), which assumes that all observed SOA is from the oxidation of aromatics.

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