Supplemental Online Material (SOM)

Electric vehicles in China: emissions and health impacts

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There are two sections in this online Supporting Information document that parallel the main article:

Supporting Information – Methods

Supporting Information – Results

The results of the analyses are detailed for the 34 cities analyzed in this paper, including estimation of emission rates, intake fraction, excess mortality, and rural/urban distributional impacts. Table S1 provides regression coefficients for EGU iF estimation. Table S2 provides information about input variables and distributions for Monte Carlo simulation. Table S3 presents estimated average emission factors for EVs and CVs. Emission factors for non-$PM_{2.5}$ pollutants for EVs in 34 cities are in Table S4. Table S5 gives iF values for urban areas and EGUs. Table S6 illustrates excess mortality estimation based on assumed person-km traveled by vehicles and cities, based on the simulation. Table S7 illustrates the health analysis of $PM_{2.5}$ for Shanghai. Figure S1 presents a map of average emission factors of CO_2 and $PM_{2.5}$ for regional electricity grids. Figure S2 graphically illustrates different e-car CO_2 and $PM_{2.5}$ emission factors for electricity grids. The results of Monte Carlo simulation of $PM_{2.5}$ mortality risk per 10^{10} passenger-km for all 34 cities with the number of simulations per city proportional to population is shown in Figure S3. Figure S4 illustrates the Monte Carlo simulation of weighted average of 34 cities $PM_{2.5}$ mortality risk per 10^{10} passenger-km. Figure S5 is the scatter plot for $PM_{2.5}$ emission factors and proportion of risks to rural population from urban EV electricity use for each electricity grid.

Supporting Information - Methods

Emission Factors

To estimate EVs station-to-wheel emission factors, we identify two metrics. First, we use electricity generation and total emissions to estimate emission intensities of the power sector. These values are estimated by regional power sector, using the CARMA database[1] to track yearly electricity generation and CO_2 emissions. The NASA INTEX-B[2] dataset reports total emissions of conventional pollutants, including BC, CO, NO_X, $PM_{2.5}$, PM_{10}, SO_2, and VOC throughout China and is used in conjunction with the CARMA database to estimate emission intensity of electricity generation in grams per kilowatt hour (g kWh^{-1}). Second, the energy use of EVs (kWh km^{-1}), including transmission loss rates, is coupled with average emission intensity from the power sector (g kWh^{-1}). The product of electricity generation emission intensity and electricity use from vehicles results in station-to-wheel emission factors from EVs (g km^{-1}). In the process of estimating station-to-wheel emission factors, estimated energy requirements of EVs are obtained for several types of battery EVs such as existing Chinese e-bikes (average energy efficiency1.8 kWh $100km^{-1}$) and a compact e-car (average energy efficiency 18 kWh $100km^{-1}$).[3, 4] These energy requirements are reported as the energy required from station-to-wheel, namely the recharger or motor efficiency losses are included in the energy use rate. Moreover, we consider approximately 14% transmission and in-plant use loss in China.[5, 6] The average station-to-wheel emission factors of these pollutants are estimated for 16 relatively independent power grids in China.[7] For sake of this analysis, we assume that cities are served by power plants in the grid in which they are located. Data are unavailable for Tibet.

Intake Fraction (iF)

One-compartment model for urban iF. The one-compartment iF model estimates exposure of air pollution over a city that occupies a compartment bounded by the borders of the city and the atmospheric mixing height. This model is treated as an approximate method to estimate pollution exposure in urban areas. A one-compartment model may provide an acceptably accurate evaluation of spatially averaged concentrations in an urban area.[8,9] The compartment model used here is static and is suitable for estimating iF for non-reacting or slowly reacting pollutants. The expression is as follows:

$$iF_{compartment} = \frac{BP}{uH\sqrt{A}}$$

Where, B is the population average breathing rate (m^3 person-s^{-1}) 14.5 based on metabolic activity studies;[10] P is the urban population for the designated city; H is the atmospheric mixing height (m); u is wind speed averaged over the mixing height (m s^{-1}); A is urban land area (m^2).

Regression Model for EGUs iF. Intake fraction of EGU emissions can be calculated based on previous multivariate regression analyses of many EGUs in China.[11] The following relationships between iF and population in Table S1 is used to predict iF of EGUs emission in China. The population living in the radii of 100km, 500km, 1000km and farther than 1000km from more than 1000 fossil EGUs in China are estimated using GIS, based on the EGUs location presented in the CARMA database and county-level Chinese population data from the 2000 Census.[12] The coefficients in Table S1 and related population are applied to estimate iF from EGU emissions using the following relationships:

$$iF_j^k = \sum_{i=1}^{n} \alpha_i^k P_i$$

Here, iF_j^k is the iF of pollutant k from EGU j. P_i is the population in each i radius from the EGU; α_i^k is the parameter estimate for pollutant k on the pollution in each i radius of the EGU. The α_i^k parameters are given in Table S1. Intake fraction of pollutants from each EGUs is estimated and the capacity-weighted average iF of all EGUs in a grid is applied to develop an average iF parameter for each electricity grid. Zhou et al.[11] only predicted the coefficient for iF of PM_1 and PM_3 based on their atmospheric dispersion modeling results. We interpolate the iF calculated from PM_1 and PM_3 relationships to estimate $PM_{2.5}$ iF.

Table S1. Regression Coefficient for EGU iF Estimation[11]

	R^2	Pop. <=100 km	100km<Pop.<500km	500km<Pop.<1000km	Pop.>=1000 km
SO_2	0.95	9.5E-8**	1.2E-8**	2.5E-9	1.4E-9**
		(3.9E-8)	(4.6E-9)	(2.3E-9)	(7.0E-10)
PM_1	0.95	1.3E-7*	2.0E-8**	9.8E-9**	2.9E-9**
		(8.2E-8)	(9.8E-9)	(4.8E-9)	(1.5E-9)
PM_3	0.89	1.2E-7*	1.3E-8**	4.5E-9	1.5E-9**
		(7.9E-8)	(9.4E-9)	(4.6E-9)	(1.4E-9)
PM_7	0.88	9.1E-8**	7.1E-9*	2.1E-9	7.8E-10*
		(4.7E-8)	(5.7E-9)	(2.8E-9)	(8.5E-10)
PM_{13}	0.87	6.4E-8**	3.6E-9	5.6E-10	4.5E-10
		(2.6E-8)	(3.1E-9)	(1.5E-9)	(4.7E-10)
SO_4	0.93	1.5E-8	6.0E-9*	5.9E-9**	1.8E-9**
		(4.2E-8)	(5.1E-9)	(2.5E-9)	(7.6E-10)
NO_3	0.86	2.9E-8	9.6E-9**	2.0E-9	1.3E-9**
		(5.0E-8)	(6.0E-9)	(2.9E-9)	(9.1E-10)

1. ** Parameter estimate significant at 0.05 level.
2. * Parameter estimate significant at 0.10 level.
3. Numbers in parenthesis are the standard error of parameter estimates.
4. PMx= particulate matter with diameter precisely equal to x µm.
5. Population variable in millions of people.
6. No intercept term is used in the above regression models and R-square is not corrected for the mean.

Public Health Impacts

While there are many different types of pollution emitted from CVs and buses and EVs, this paper focuses on primary $PM_{2.5}$ because of its well-documented health effects. It is important to note however that omission of other pollutants does not minimize their impact.[13] The mortality risks due to $PM_{2.5}$ and chronic cancer risk owing to diesel particulate matter (DPM) present the largest concern associated with diesel vehicle emissions. Because most PM emissions from diesel engines are smaller than 1 μm in diameter, it is acceptable to consider all DPM as $PM_{2.5}$.[14] The value of the *unit dose*, or the total amount of $PM_{2.5}$ inhaled for each case of premature mortality, is estimated from the American Cancer Society (ACS) cohort.[15] Their research concludes that, with each 10 $\mu g\ m^{-3}$ increase in average $PM_{2.5}$ ambient concentrations, the risk of all-cause mortality will increase approximately 4%. Chinese death rate is approximately 7 deaths (1000 people)$^{-1}$ year^{-1} in 2009.[16] Therefore, in China, a 4% increase in the death rate is 0.28 deaths (1000 people)$^{-1}$ year^{-1}. Assuming a breathing rate is 14.5 m^3 person^{-1} day^{-1} - namely 5292.5 m^3 person^{-1} year^{-1}, exposure to 10 $\mu g\ m^{-3}$ $PM_{2.5}$ concentration elevation would lead to an inhalation intake rate of 52925 μg person^{-1} year^{-1}, or equivalently 5.3 deaths kg^{-1}, or 188 g death^{-1}. The mortality risk is calculated based on a 1-year exposure periods. We consider primary $PM_{2.5}$ station-to-wheel emission factors from gasoline cars, diesel cars, and diesel buses using on-road empirical estimates.

Sensitive Analysis

Monte Carlo simulation is employed to conduct sensitivity analysis. The distribution type and boundaries for each input variable depend on observations from peer-reviewed literature and authors' professional judgment. The details are shown in Table S2.

Table S2. Input Variables and Distributions for Monte Carlo Simulation

Variable	Mode	Base-case value	Distribution used in Monte Carlo simulations	Units
Energy Efficiency[1]	E-bike	1.8	Triangular (1.2, 2.1)	kWh $100km^{-1}$
	E-car	18	Triangular (11, 25)	
Station-to-wheel $PM_{2.5}$ Emission Factor[2]	Gasoline Car	5	Triangular (1, 10)	mg km^{-1}
	Diesel Car	50	Normal (50, 5.5)	
	Diesel Bus	600	Triangular (200, 1000)	
Intake Fraction	E-bike	iF*[3]	Normal (iF*, 2.3)[5]	ppm
	E-car	iF*	Normal (iF*, 2.3)	
	Gasoline Car	iF**[4]	Triangular (0.5iF**, 1.5iF**)	
	Diesel Car	iF**	Triangular (0.5iF**, 1.5iF**)	
	Diesel Bus	iF**	Triangular (0.5iF**, 1.5iF**)	
Load Factor[7]	E-bike	1	(Constant)	person $vehicle^{-1}$
	E-car	1.5	Uniform (1.3, 1.7)	
	Gasoline Car	1.5	Uniform (1.3, 1.7)	
	Diesel Car	1.5	Uniform (1.3, 1.7)	
	Diesel Bus	50	Uniform (25, 75)	
Dose Response[8]	Mortality	4%	Triangular (1%, 20%)	

Notes:

1. E-bike energy efficiency source: lower bound[17] and upper bound[3]; E-car energy efficiency source: lower bound[18] and upper bound[19].
2. Gasoline car $PM_{2.5}$ emission factor source: lower bound[20] and upper bound[21]; diesel car $PM_{2.5}$ emission factor source.[22]
3. iF* is the point estimate for the EGU iF for EVs in a specific city.
4. iF** is the point estimate for the tailpipe iF for a CV in a specific city.
5. Normal (iF*, 2.3) indicates a normal (Gaussian) distribution, with mean = iF* and standard deviation = 2.3 ppm. The value for the standard deviation (2.3 ppm) is the model residual standard deviation for EGU iF source.[11]
6. The distribution of intake fraction of CVs is based on: Zhou et al.[23].
7. Passenger car load factor source: lower bound[24] and upper bound [25].
8. Dose response source.[15, 23, 24, 26, 27] The value indicates the percentage increase in mortality rate per 10 $\mu g\ m^{-3}$ increase in $PM_{2.5}$.

Supporting Information – Results

Well-to-station emissions include fossil energy extraction, refining, storage, and transportation processes. We use previous energy life cycle analyses for CVs and EVs in China to estimate average well-to-station emissions (Table S3). Well-to-station emissions are lower for motorcycle, e-bike and diesel bus than for cars. Compared to a new (Euro IV) gasoline car, average e-car emissions are about 4× lower for CO, 2× lower for NOx, 4× lower for HC, 3× lower for SO_2, 15× lower for CO_2 and 2× greater for $PM_{2.5}$ and PM_{10}. This finding reflects, in part, that oil production and refining can generate greater HC, CO_2, NOx and SO_2 per kilometer driven (but lower PM) than electricity generation. In general, well-to-station fuel emissions constitute a small portion (<20%) of total well-to-wheel emissions for EVs and diesel cars. However, well-to-station emissions can constitute a large portion of total well-to-wheel emissions for several gasoline car pollutants.

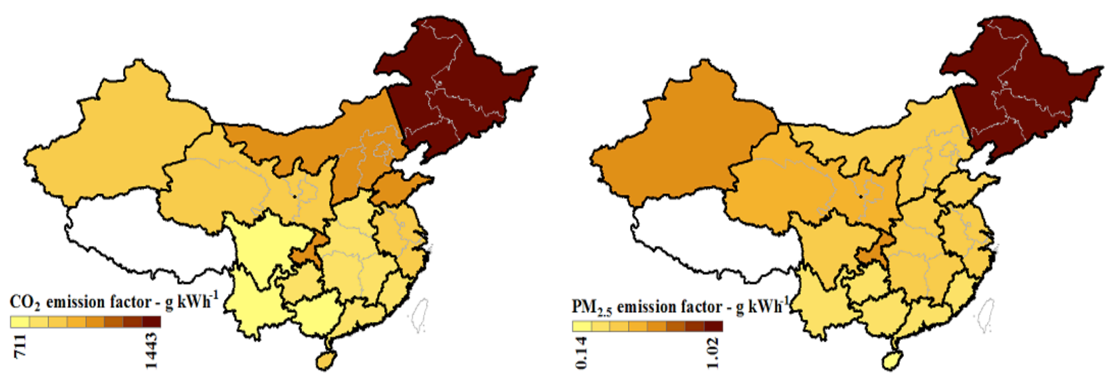

Figure S1. Average station-to-wheel emission factors for CO_2 (left plot) and $PM_{2.5}$ (right plot) for China's 15 electricity grids.

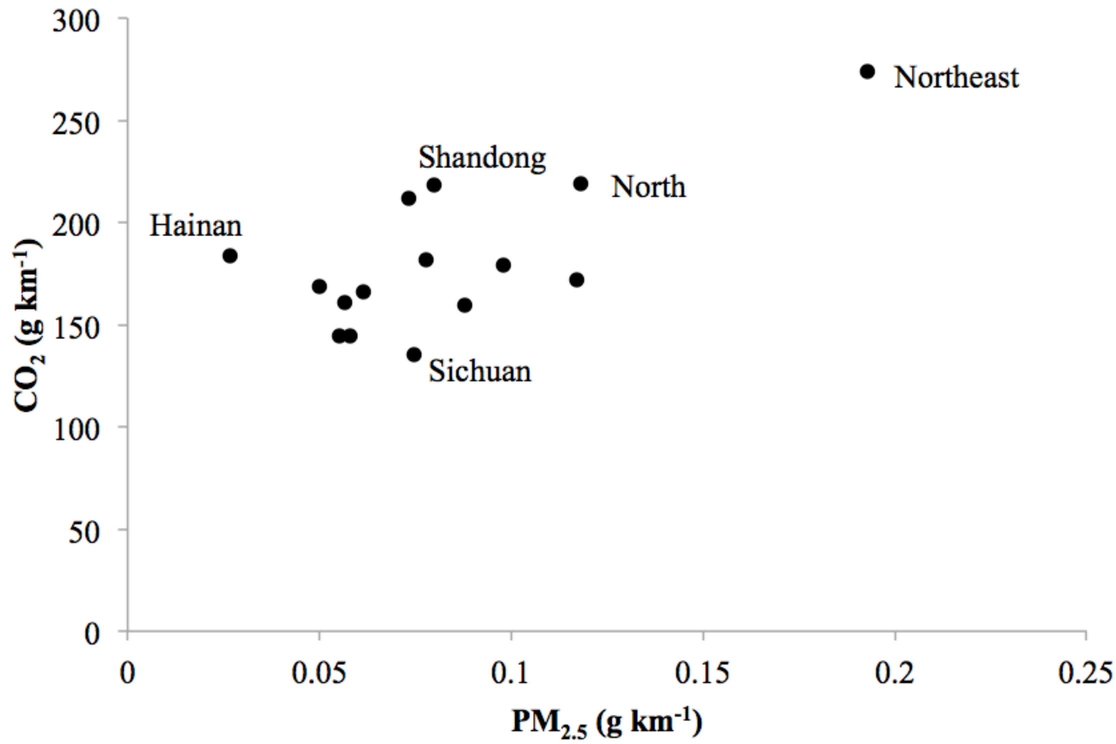

Figure S2. Average e-car station-to-wheel emission factors for CO_2 and $PM_{2.5}$ for China's 15 electricity grids. In general, points in the lower left represent grids in the southwest and points on the upper right represent grids in the northeast.

Table S3. Midpoint Emission Factors of EVs and CVs (g person-km^{-1})

	CO	NO_X	HC	SO_2	$PM_{2.5}$	PM_{10}[6]	CO_2
Euro III Diesel Car	0.43	0.33	0.04	-	0.03	-	104
(17 km l^{-1})	(0.19)	(0.05)	(0.001)	(N/A)		(0.004)	(22.6)
Euro III Gasoline Car	1.23	0.14	0.05	-	0.003	-	121
(12.8 km l^{-1})	(0.04)	(0.14)	(0.04)	(0.09)		(0.008)	(54.1)
Euro IV Gasoline Car	0.27	0.04	0.02	-	0.003	-	121
(12.8 km l^{-1})	(0.04)	(0.14)	(0.04)	(0.09)		(0.008)	(54.1)
Electric Car (E-car)	0.09	0.36	0.04	0.74	0.058	0.10	125
(18 kWh (100 km)$^{-1}$)	(0.01)	(0.06)	(0.01)	(0.03)		(0.015)	(3.7)
Motorcycle	1.25	0.15	12.55	-	0.1	-	55
(40 km l^{-1})	(0.12)	(0.03)	(0.001)	(N/A)		(0.003)	(14.4)
Electric Bike (E-Bike)	0.014	0.05	0.005	0.11	0.009	0.015	18.8
(1.8 kWh (100 km)$^{-1}$)	(0.001)	(0.01)	(0.001)	(0.01)		(0.002)	(0.6)
Bus	0.16	0.27	0.02	0.002	0.012	-	25.5
(2.2 km l^{-1})	(0.04)	(0.01)	(0.0002)	(0.001)		(0.001)	(5.2)

1. Values without parenthesis are station-to-wheel emission factors. Values in parenthesis are average well-to-station emission factors.
2. Midpoint Car (diesel, gasoline, e-cars) load factors assume 1.5 persons, bus load factor assumes 50 people and motorcycle and e-bike load factors assume 1 person. The vehicle emission factor is averaged over all passengers to estimate emissions per person kilometer.
3. Average station-to-wheel emission factors of various pollutants for EVs are weighted by electricity generation in each electricity network.
4. Motorcycle emission factors reported in Meszler[28]
5. Several studies measure bus emission factors with comparable fuel quality, engine technology and exhaust treatments as those in China. Emission factors of $PM_{2.5}$ range from 0.2-1.0 g km^{-1}with a mean of 0.6 g km^{-1} [3, 29, 30] or 0.012 g person-km^{-1}.
6. The well-to-station emission factors of PM_{10} include emissions of $PM_{2.5}$ and PM_{10}.
7. In the process of estimating well-to-station emissions for coal-based electricity generation, we employ 0.404 as energy conversion factor, meaning generation of 1 kWh electricity will require 0.404 kg standard coal.[31]

Table S4. Station-to-wheel Emission Factors of EVs with Representative Energy Efficiency (g $100km^{-1}$)

City	Vehicle	$PM_{2.5}$	PM_{10}	SO_2	NO_X	VOC	BC	CO	CO_2
Beijing	E-bike	0.80	1.34	11.46	5.38	0.56	0.02	1.38	2183
	E-car	7.97	13.36	114.57	53.84	5.58	0.21	13.80	21828
Changchun	E-bike	1.93	3.19	12.16	10.02	1.00	0.03	2.47	2741
	E-car	19.29	31.90	121.62	100.21	10.01	0.26	24.73	27414
Changsha	E-bike	0.88	1.46	11.40	5.68	0.59	0.03	1.45	1593
	E-car	8.79	14.60	114.00	56.80	5.86	0.31	14.50	15926
Changzhou	E-bike	0.78	1.32	8.89	5.36	0.58	0.02	1.44	1817
	E-car	7.77	13.20	88.90	53.60	5.84	0.16	14.40	18167
Chengdu	E-bike	0.75	1.27	16.60	4.59	0.45	0.03	1.11	1351
	E-car	7.48	12.70	166.00	45.90	4.50	0.31	11.10	13508
Chongqing	E-bike	1.18	1.99	22.30	7.03	0.68	0.05	1.69	2189
	E-car	11.80	19.90	223.00	70.30	6.82	0.49	16.90	21886
Dalian	E-bike	1.93	3.19	12.16	10.02	1.00	0.03	2.47	2741
	E-car	19.29	31.90	121.62	100.21	10.01	0.26	24.73	27414
Foshan	E-bike	0.57	0.95	5.62	3.34	0.38	0.01	0.93	1608
	E-car	5.67	9.54	56.20	33.40	3.76	0.06	9.28	16085
Guangzhou	E-bike	0.57	0.95	5.62	3.34	0.38	0.01	0.93	1608
	E-car	5.67	9.54	56.20	33.40	3.76	0.06	9.28	16085
Guiyang	E-bike	0.50	0.85	16.50	3.37	0.36	0.01	0.88	1687
	E-car	5.01	8.47	165.00	33.70	3.56	0.12	8.80	16868
Hangzhou	E-bike	0.78	1.32	8.89	5.36	0.58	0.02	1.44	1817
	E-car	7.77	13.20	88.90	53.60	5.84	0.16	14.40	18167
Harbin	E-bike	1.93	3.19	12.16	10.02	1.00	0.03	2.47	2741
	E-car	19.29	31.90	121.62	100.21	10.01	0.26	24.73	27414
Huai'an	E-bike	0.78	1.32	8.89	5.36	0.58	0.02	1.44	1817
	E-car	7.77	13.20	88.90	53.60	5.84	0.16	14.40	18167
Jinan	E-bike	0.73	1.24	14.20	5.44	0.56	0.03	1.39	2121
	E-car	7.34	12.40	142.00	54.40	5.62	0.31	13.90	21209
Kunming	E-bike	0.58	1.03	10.80	4.45	0.47	0.02	1.17	1444
	E-car	5.80	10.30	108.00	44.50	4.74	0.16	11.70	14437
Lanzhou	E-bike	0.98	1.69	11.60	4.97	0.55	0.01	1.35	1789
	E-car	9.80	16.90	116.00	49.70	5.46	0.12	13.50	17891
Nanjing	E-bike	0.78	1.32	8.89	5.36	0.58	0.02	1.44	1817
	E-car	7.77	13.20	88.90	53.60	5.84	0.16	14.40	18167

Ningbo	E-bike	0.78	1.32	8.89	5.36	0.58	0.02	1.44	1817
	E-car	7.77	13.20	88.90	53.60	5.84	0.16	14.40	18167
Putian	E-bike	0.62	1.03	4.24	3.15	0.38	0.01	0.94	1662
	E-car	6.15	10.30	42.40	31.50	3.79	0.08	9.36	16619
Qingdao	E-bike	0.73	1.24	14.20	5.44	0.56	0.03	1.39	2121
	E-car	7.34	12.40	142.00	54.40	5.62	0.31	13.90	21209
Shanghai	E-bike	0.78	1.32	8.89	5.36	0.58	0.02	1.44	1817
	E-car	7.77	13.20	88.90	53.60	5.84	0.16	14.40	18167
Shenyang	E-bike	1.93	3.19	12.16	10.02	1.00	0.03	2.47	2741
	E-car	19.29	31.90	121.62	100.21	10.01	0.26	24.73	27414
Shijiazhuang	E-bike	0.80	1.34	11.46	5.38	0.56	0.02	1.38	2183
	E-car	7.97	13.36	114.57	53.84	5.58	0.21	13.80	21828
Suzhou	E-bike	0.78	1.32	8.89	5.36	0.58	0.02	1.44	1817
	E-car	7.77	13.20	88.90	53.60	5.84	0.16	14.40	18167
Taiyuan	E-bike	0.80	1.34	11.46	5.38	0.56	0.02	1.38	2183
	E-car	7.97	13.36	114.57	53.84	5.58	0.21	13.80	21828
Tangshan	E-bike	0.80	1.34	11.46	5.38	0.56	0.02	1.38	2183
	E-car	7.97	13.36	114.57	53.84	5.58	0.21	13.80	21828
Tianjin	E-bike	0.80	1.34	11.46	5.38	0.56	0.02	1.38	2183
	E-car	7.97	13.36	114.57	53.84	5.58	0.21	13.80	21828
Wuhan	E-bike	0.88	1.46	11.40	5.68	0.59	0.03	1.45	1593
	E-car	8.79	14.60	114.00	56.80	5.86	0.31	14.50	15926
Wuxi	E-bike	0.78	1.32	8.89	5.36	0.58	0.02	1.44	1817
	E-car	7.77	13.20	88.90	53.60	5.84	0.16	14.40	18167
Xi'an	E-bike	0.98	1.69	11.60	4.97	0.55	0.01	1.35	1789
	E-car	9.80	16.90	116.00	49.70	5.46	0.12	13.50	17891
Xiangfan	E-bike	0.88	1.46	11.40	5.68	0.59	0.03	1.45	1593
	E-car	8.79	14.60	114.00	56.80	5.86	0.31	14.50	15926
Zaozhuang	E-bike	0.73	1.24	14.20	5.44	0.56	0.03	1.39	2121
	E-car	7.34	12.40	142.00	54.40	5.62	0.31	13.90	21209
Zhengzhou	E-bike	0.88	1.46	11.40	5.68	0.59	0.03	1.45	1593
	E-car	8.79	14.60	114.00	56.80	5.86	0.31	14.50	15926
Zibo	E-bike	0.73	1.24	14.20	5.44	0.56	0.03	1.39	2121
	E-car	7.34	12.40	142.00	54.40	5.62	0.31	13.90	21209

Table S5. Average iF Comparison – Urban vs. EGUs

City	iF-Urban (ppm) Non-reactive Station-to-wheel Emissions from CVs (including $PM_{2.5}$)	iF - EGUs (ppm) Station-to-wheel Emissions from EVs							
		$PM_{2.5}$ (Interpolated)	SO_2	PM_1	PM_3	PM_7	PM_{13}	SO_4	NO_3
Beijing	73.2	5.9	4.0	8.7	5.0	2.7	1.4	4.2	3.1
Changchun	12.9	4.1	2.9	6.1	3.4	1.9	1.0	3.1	2.3
Changsha	31.3	8.2	5.5	11.9	7.0	3.9	2.0	5.3	4.0
Changzhou	12.1	8.2	5.5	11.7	7.0	4.0	2.1	5.1	3.9
Chengdu	64.3	6.2	4.4	8.8	5.4	3.1	1.7	3.9	3.1
Chongqing	11.4	7.4	5.2	10.4	6.5	3.8	2.1	4.4	3.5
Dalian	12.7	4.1	2.9	6.1	3.4	1.9	1.0	3.1	2.3
Foshan	116.8	7.4	5.1	10.5	6.4	3.7	2.0	4.6	3.5
Guangzhou	31.7	7.4	5.1	10.5	6.4	3.7	2.0	4.6	3.5
Guiyang	8.7	6.2	4.3	9.1	5.2	2.9	1.5	4.2	3.3
Hangzhou	17.0	8.2	5.5	11.7	7.0	4.0	2.1	5.1	3.9
Harbin	15.0	4.1	2.9	6.1	3.4	1.9	1.0	3.1	2.3
Huai'an	6.5	8.2	5.5	11.7	7.0	4.0	2.1	5.1	3.9
Jinan	25.7	7.6	5.4	10.9	6.6	3.7	2.0	4.7	3.9
Kunming	21.9	4.5	3.1	6.8	3.8	2.1	1.1	3.5	2.5
Lanzhou	15.4	4.8	3.2	7.2	4.0	2.2	1.1	3.7	2.5
Nanjing	19.1	8.2	5.5	11.7	7.0	4.0	2.1	5.1	3.9
Ningbo	15.0	8.2	5.5	11.7	7.0	4.0	2.1	5.1	3.9
Putian	11.0	8.3	5.9	11.8	7.2	4.1	2.2	4.9	4.2
Qingdao	26.9	7.6	5.4	10.9	6.6	3.7	2.0	4.7	3.9
Shanghai	50.6	8.2	5.5	11.7	7.0	4.0	2.1	5.1	3.9
Shenyang	22.2	4.1	2.9	6.1	3.4	1.9	1.0	3.1	2.3
Shijiazhuang	52.0	5.9	4.0	8.7	5.0	2.7	1.4	4.2	3.1
Suzhou	15.1	8.2	5.5	11.7	7.0	4.0	2.1	5.1	3.9
Taiyuan	49.9	5.9	4.0	8.7	5.0	2.7	1.4	4.2	3.1
Tangshan	11.1	5.9	4.0	8.7	5.0	2.7	1.4	4.2	3.1
Tianjin	25.6	5.9	4.0	8.7	5.0	2.7	1.4	4.2	3.1
Wuhan	38.2	8.2	5.5	11.9	7.0	3.9	2.0	5.3	4.0

Wuxi	16.0	8.2	5.5	11.7	7.0	4.0	2.1	5.1	3.9
Xi'an	38.3	4.8	3.2	7.2	4.0	2.2	1.1	3.7	2.5
Xiangfan	10.7	8.2	5.5	11.9	7.0	3.9	2.0	5.3	4.0
Zaozhuang	6.3	7.6	5.4	10.9	6.6	3.7	2.0	4.7	3.9
Zhengzhou	31.1	8.2	5.5	11.9	7.0	3.9	2.0	5.3	4.0
Zibo	9.6	7.6	5.4	10.9	6.6	3.7	2.0	4.7	3.9
Average	**27.2**	**6.8**	**4.7**	**9.8**	**5.8**	**3.3**	**1.7**	**4.5**	**3.4**

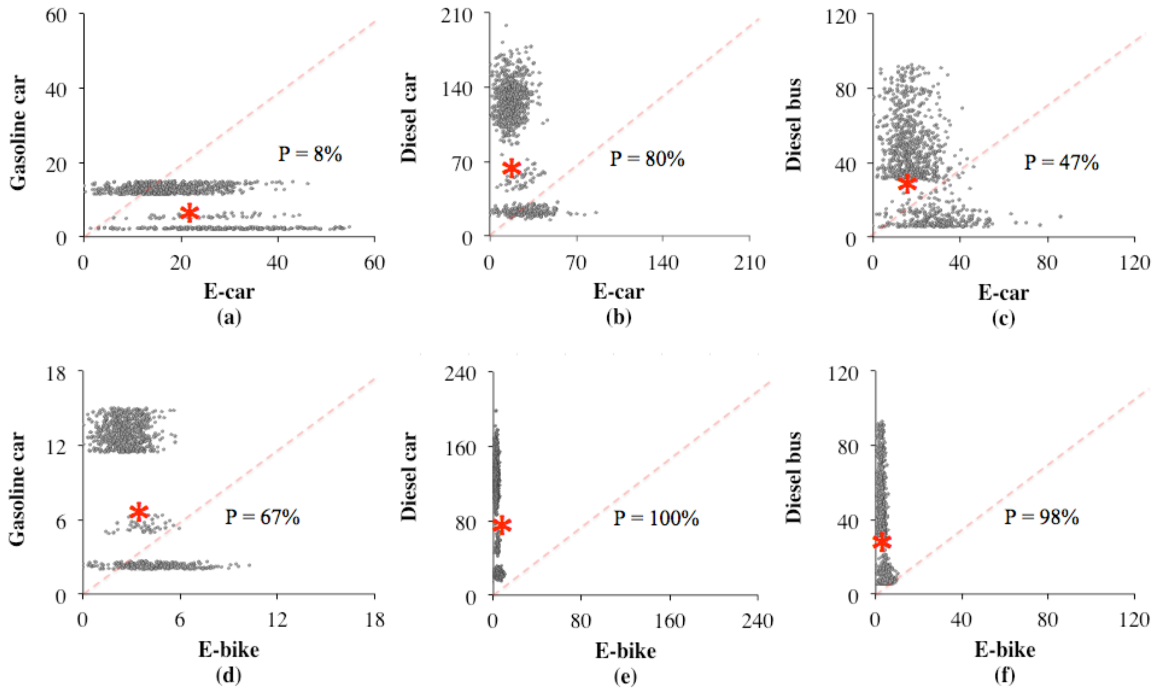

Figure S3. Monte Carlo simulation of $PM_{2.5}$ mortality risk per 10^{10} passenger-km for all 34 cities considered. A total of n=10,000 Monte Carlo simulations was carried out, with the number of simulations per city proportional to population. In each plot, "P" is the proportion of the simulation outcomes for which the mortality risk is lower for EVs that for CVs. The dashed lines on each plot are 1:1 lines. The population-weighted average value is indicated with an asterisk.

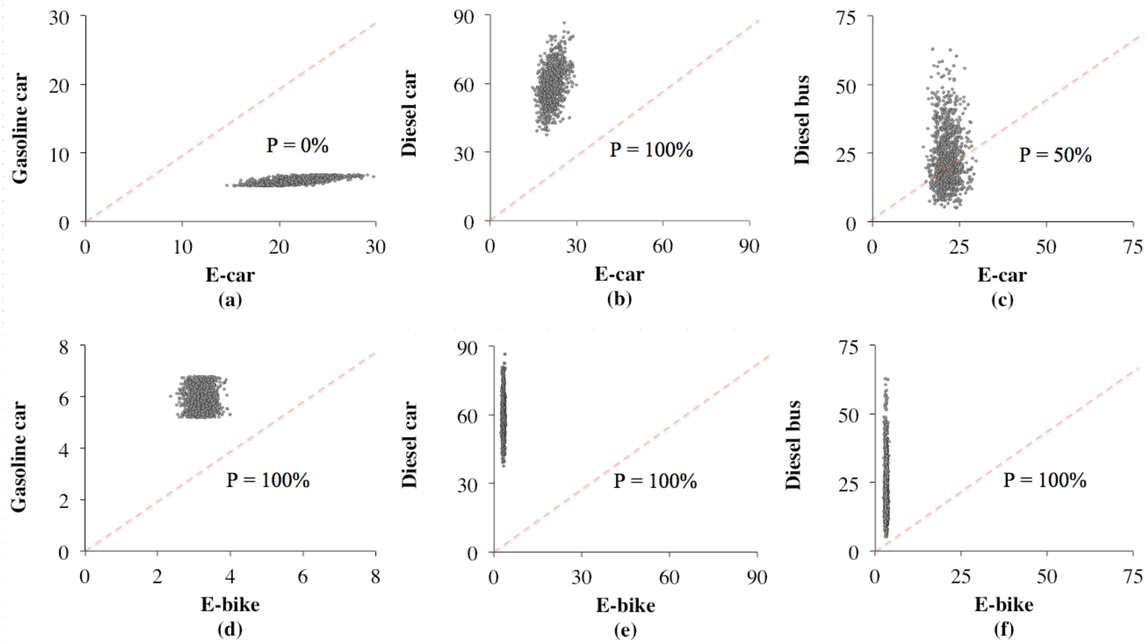

Figure S4. Monte Carlo simulation of weighted average of 34 city $PM_{2.5}$ mortality risk per 10^{10} passenger-km. Population-weighted average mortality risk is calculated from simulation of 34 cities (asterisk in Figure 6). Simulation totaled 1,000 runs per city. This graph illustrates a random sample of calculated points. In each plot, "P" is the proportion of the simulation outcomes for which the mortality risk is lower for EVs that for CVs. The dashed lines on each plot are 1:1 lines.

Table S6. Excess Mortality per 10^{10} Person-km Traveled by Vehicle and City based on Monte Carlo Simulation

City	E-bike	E-Car	Diesel Car (Euro III)	Gasoline Car (Euro III)	Bus
Beijing	2.5 (1.0)	16.9 (7.3)	130.7 (17.5)	13.1 (1.0)	51.5 (23.3)
Changchun	4.1 (2.4)	27.1 (17.1)	23.0 (3.1)	2.3 (0.2)	9.1 (4.1)
Changsha	3.9 (1.1)	26.3 (8.8)	55.9 (7.5)	5.6 (0.4)	22.0 (10.0)
Changzhou	3.4 (1.0)	22.7 (7.7)	21.6 (2.9)	2.2 (0.2)	8.5 (3.8)
Chengdu	2.5 (0.9)	16.5 (6.8)	114.8 (15.4)	11.5 (0.9)	45.3 (20.5)
Chongqing	4.7 (1.4)	31.8 (11.2)	20.4 (2.7)	2.0 (0.2)	8.0 (3.6)
Dalian	4.1 (2.5)	27.6 (17.6)	22.7 (3.0)	2.3 (0.2)	8.9 (4.0)
Foshan	2.2 (0.7)	14.6 (5.7)	208.9 (28.0)	20.9 (1.6)	82.3 (37.2)
Guangzhou	2.2 (0.7)	15.0 (5.5)	56.6 (7.6)	5.7 (0.4)	22.3 (10.1)
Guiyang	1.6 (0.6)	11.1 (4.6)	15.5 (2.1)	1.5 (0.1)	6.1 (2.8)
Hangzhou	3.4 (0.9)	22.6 (7.5)	30.4 (4.1)	3.0 (0.2)	12.0 (5.4)
Harbin	4.2 (2.4)	28.8 (17.5)	26.8 (3.6)	2.7 (0.2)	10.6 (4.8)
Huai’an	3.4 (0.9)	22.5 (7.7)	11.5 (1.5)	1.2 (0.1)	4.5 (2.1)
Jinan	2.9 (0.9)	19.6 (6.9)	45.9 (6.1)	4.6 (0.4)	18.1 (8.2)
Kunming	1.4 (0.7)	9.2 (5.3)	39.1 (5.2)	3.9 (0.3)	15.4 (7.0)
Lanzhou	2.5 (1.2)	16.7 (8.9)	27.5 (3.7)	2.7 (0.2)	10.8 (4.9)
Nanjing	3.4 (0.9)	23.1 (7.6)	34.1 (4.6)	3.4 (0.3)	13.4 (6.1)
Ningbo	3.4 (0.9)	22.7 (7.8)	26.8 (3.6)	2.7 (0.2)	10.6 (4.8)
Putian	2.7 (0.7)	18.3 (5.9)	19.6 (2.6)	2.0 (0.2)	7.7 (3.5)
Qingdao	3.0 (0.9)	20.5 (7.2)	48.0 (6.4)	4.8 (0.4)	18.9 (8.6)
Shanghai	3.4 (1.0)	22.8 (7.9)	90.4 (12.1)	9.0 (0.7)	35.6 (16.1)
Shenyang	4.1 (2.4)	28.0 (17.5)	39.6 (5.3)	4.0 (0.3)	15.6 (7.1)

Shijiazhuang	2.5 (1.0)	16.7 (7.3)	92.9 (12.4)	9.3 (0.7)	36.6 (16.5)
Suzhou	3.4 (1.0)	22.7 (7.9)	27.0 (3.6)	2.7 (0.2)	10.6 (4.8)
Taiyuan	2.5 (1.0)	16.9 (7.3)	89.1 (11.9)	8.9 (0.7)	35.1 (15.9)
Tangshan	2.5 (1.0)	16.4 (7.4)	19.8 (2.7)	2.0 (0.2)	7.8 (3.5)
Tianjin	2.5 (1.0)	17.0 (7.5)	45.7 (6.1)	4.6 (0.3)	18.0 (8.1)
Wuhan	3.8 (1.1)	25.6 (8.7)	68.2 (9.1)	6.8 (0.5)	26.9 (12.2)
Wuxi	3.4 (0.9)	22.7 (7.5)	28.6 (3.8)	2.9 (0.2)	11.3 (5.1)
Xi'an	2.5 (1.2)	17.1 (8.8)	68.4 (9.2)	6.8 (0.5)	27.0 (12.2)
Xiangfan	3.8 (1.1)	25.4 (8.7)	19.1 (2.6)	1.9 (0.1)	7.5 (3.4)
Zaozhuang	3.0 (0.9)	19.9 (7.4)	11.2 (1.5)	1.1 (0.1)	4.4 (2.0)
Zhengzhou	3.8 (1.1)	25.6 (8.8)	55.5 (7.4)	5.6 (0.4)	21.9 (9.9)
Zibo	3.1 (0.9)	20.6 (7.1)	17.2 (2.3)	1.7 (0.1)	6.8 (3.1)

1. Numbers in parenthesis are the standard deviation of results

Table S7. Public Health Analysis of $PM_{2.5}$ in Shanghai

	Station-to-wheel Emission Factor (g person-km^{-1})	Station-to-wheel Emission Factor Ratio (CV/EV)	iF (ppm)	iF Ratio	Mortality Risk (per 10^{10} person-km)	Mortality Ratio
Diesel Bus (50 Person)	0.012	1.5	50.6	6.2	32.2	9.6
E-bike	0.008		8.2		3.4	
Diesel Car	0.033	0.6	50.6	6.2	89.5	4.0
Gasoline Car (Euro IV)	0.003	0.06	50.6	6.2	9.0	0.4
E-Car	0.058		8.2		22.5	

1. Car (diesel, gasoline, e-cars) load factors assume 1.5 persons, bus load factor assumes 50 people and motorcycle and e-bike load factors assume 1 person. The vehicle emission factor is averaged over all passengers to estimate emissions per person kilometer.

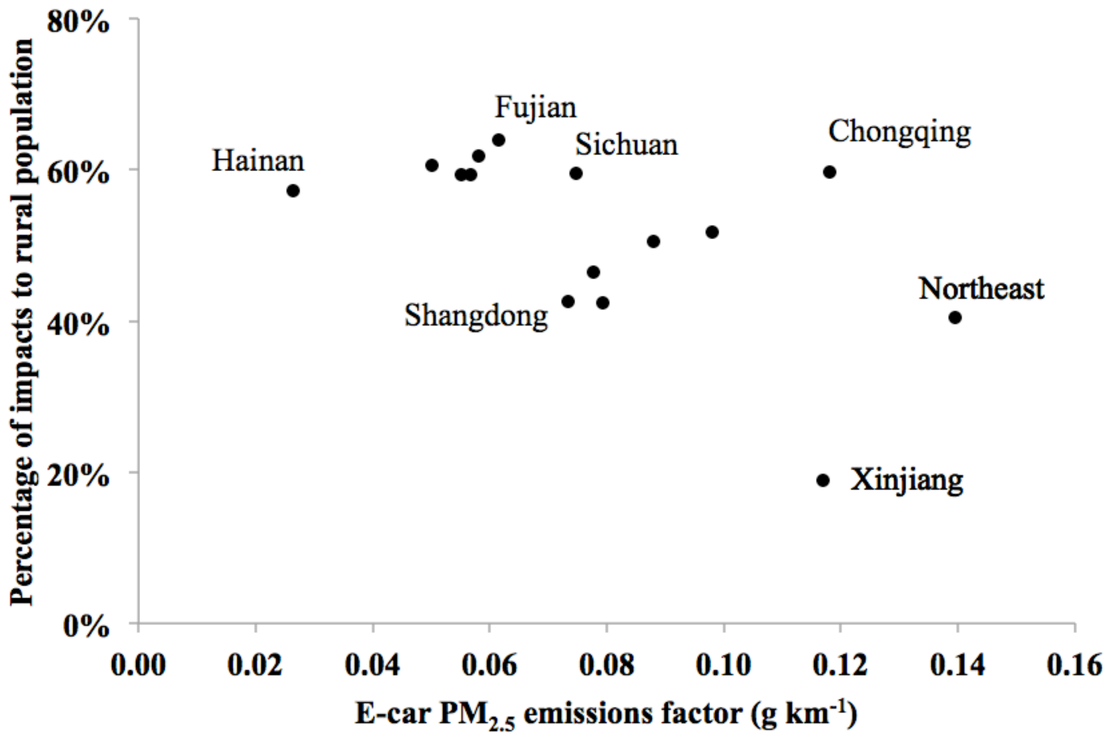

Figure S5. E-car $PM_{2.5}$ station-to-wheel emission factors and proportion of impacts of urban EV use to non-urban populations. In general, urban use of EVs rather than CVs moves emissions and health impacts to rural locations. The data exhibit a weak negative relationship between emission factors and proportion of health impacts born by rural populations, implying that grids with higher emission factors are more urbanized.

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