Supporting Information

Are E-Scooters Polluters? The Environmental Impacts of Shared Dockless Electric Scooters

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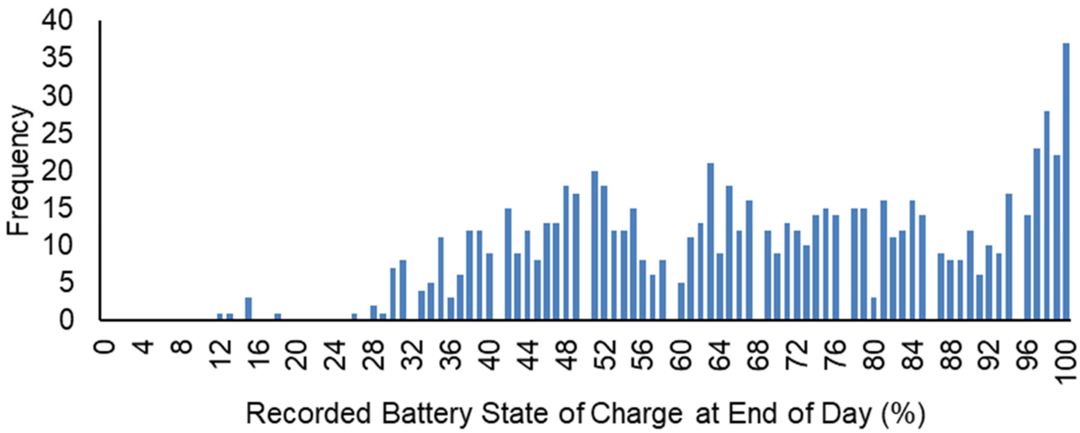

Figure S1: Recorded battery state of charge at the end of the day with 800 data points. Records were taken from 8-10pm from March 29th – April 28th, 2019. These data are fit to a lognormal distribution in the manuscript as shown in Table 1.

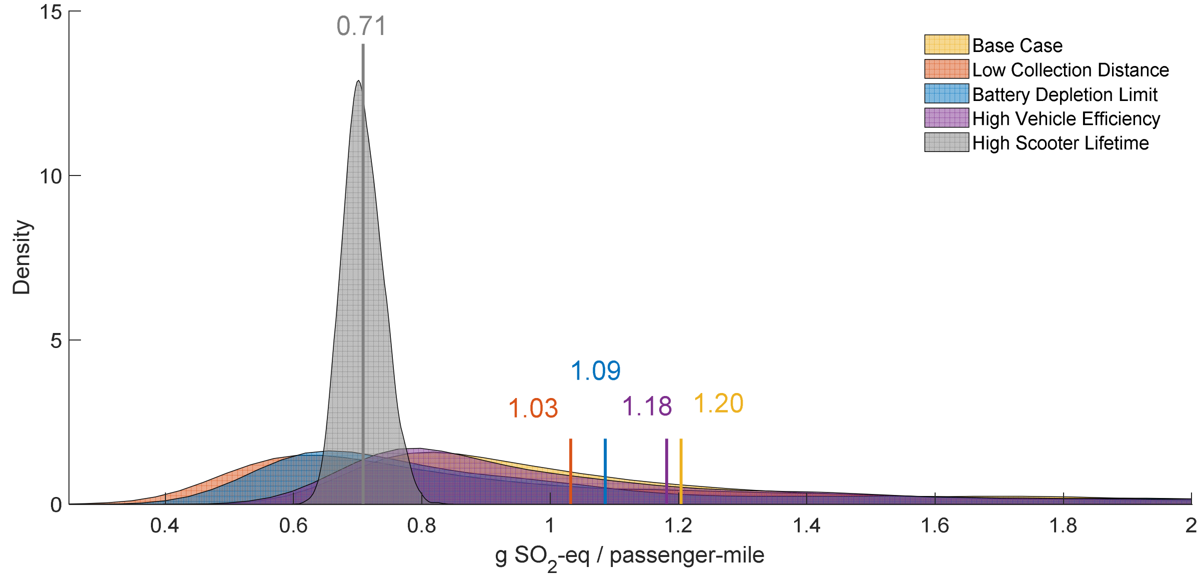

Figure S2: Shared e-scooter Monte Carlo analysis of acidification impact. Similar to Figure 3 in the manuscript, kernal density functions show the Base Case and four alternative collection and distribution scenarios: Low Collection Distance, Battery Depletion Limit, High Vehicle Efficiency, and High Scooter Lifetime. Colored vertical lines indicate the mean value for each scenario.

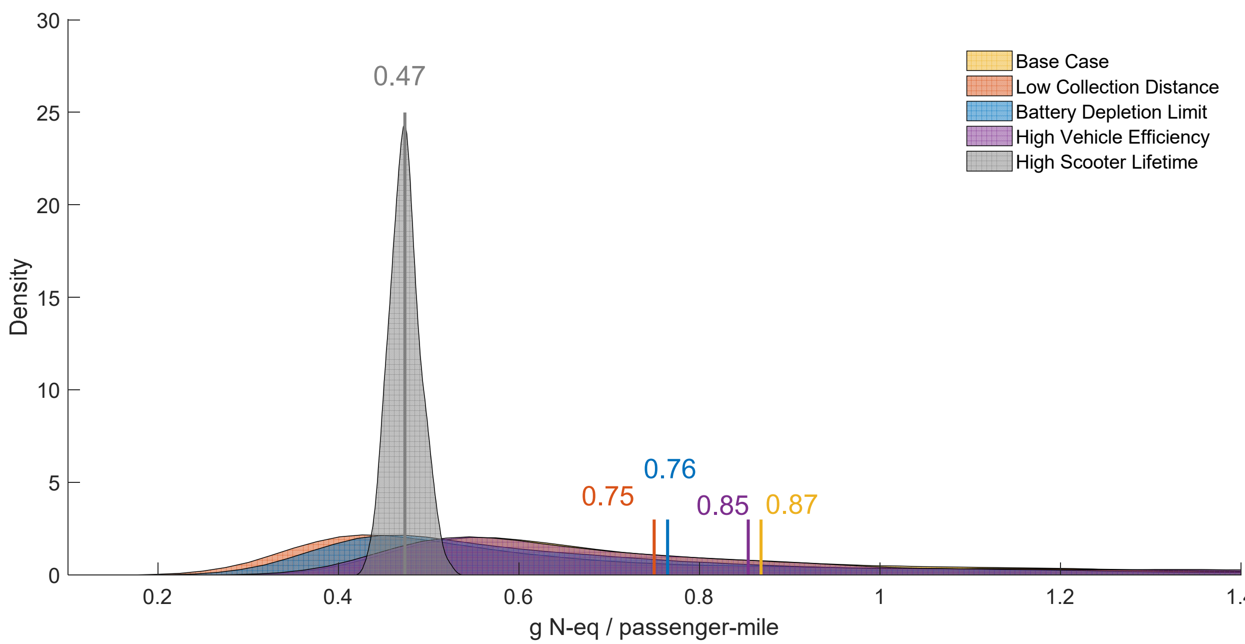

Figure S3: Shared e-scooter Monte Carlo analysis of eutrophication impact. Similar to Figure 3 in the manuscript, kernal density functions show the Base Case and four alternative collection and distribution scenarios: Low Collection Distance, Battery Depletion Limit, High Vehicle Efficiency, and High Scooter Lifetime. Colored vertical lines indicate the mean value for each scenario.

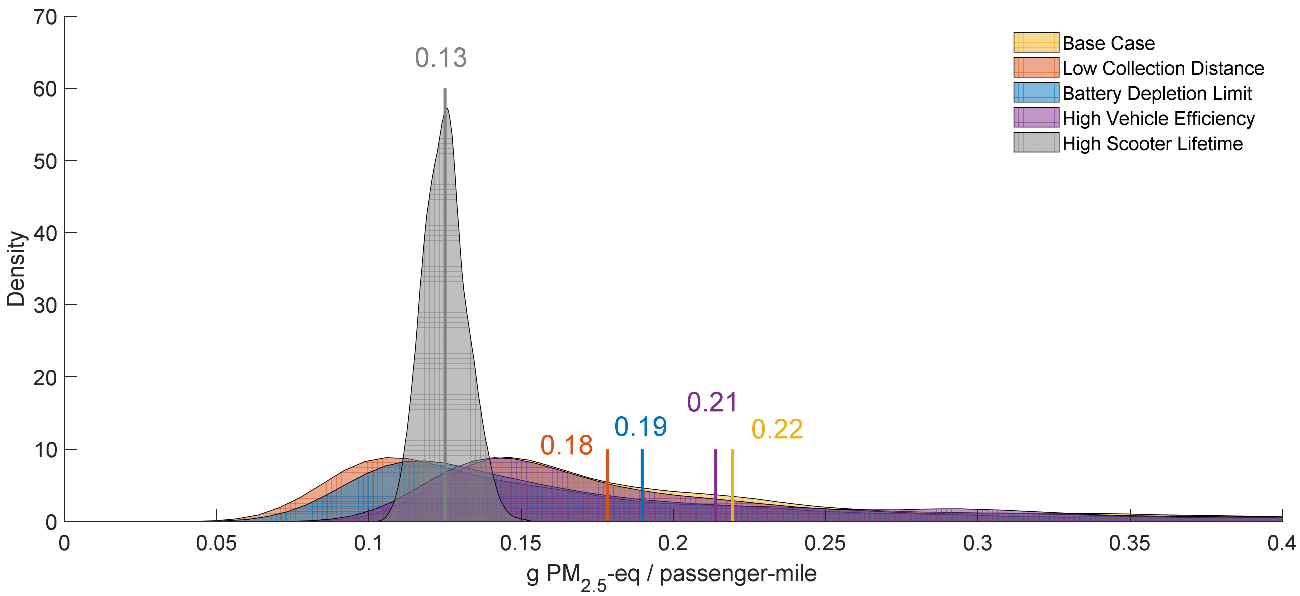

Figure S4: Shared e-scooter Monte Carlo analysis of respiratory effects impact. Similar to Figure 3 in the manuscript, kernal density functions show the Base Case and four alternative collection and distribution scenarios: Low Collection Distance, Battery Depletion Limit, High Vehicle Efficiency, and High Scooter Lifetime. Colored vertical lines indicate the mean value for each scenario.

Table S1 - E-scooter life cycle inventory for materials and manufacturing

Flows into Scooter Production	Flow property	Unit	Amount	Description	Measured/Proxy, Data Source
Aluminum alloy, $AlMg_3$[2]	Mass	kg	5.731	Frame and wheels	Measured, ecoinvent
Aluminum, cast alloy[2]	Mass	kg	0.256	Brakes, bell, circuit board cover, misc	Measured, ecoinvent
Battery cell, produced	Mass	kg	1.159	Li-ion NMC 111 Cathode	Measured, Ellingsen et al.
Used Li-ion battery	Mass	kg	1.169	Includes mass of anode, cathode, separator, electrolyte, and cell container	ecoinvent
Charger, for electric scooter	Mass	kg	0.385	Charging cord	Measured, ecoinvent
Electric motor, for electric scooter	Mass	kg	1.187	Motor with magnets	Measured, ecoinvent
Electricity, medium voltage, at grid	Energy	kWh	6.89	Manufacturing requirements	Proxy[1], ecoinvent
Heat, district or industrial, natural gas	Energy	MJ	13.6	Manufacturing requirements	Proxy[1], ecoinvent
Heat, district or industrial, other than natural gas	Energy	MJ	0.193	Manufacturing requirements	Proxy[1], ecoinvent
Light emitting diode	Mass	kg	0.016	LED brake and headlights	Measured, ecoinvent
Polycarbonate	Mass	kg	0.266	Splash guard, wheel cover, hub caps cover, base trim, accelerator, frame cover	Measured, ecoinvent
Polycarbonate	Mass	kg	0.008	Misc plastic	Measured, ecoinvent
Powder coat, aluminum sheet	Area	m^2	0.35	Manufacturing requirements	Proxy[1], ecoinvent
Printed wiring board, mixed mounted, unspec., solder mix, at plant	Mass	kg	0.059	Circuit boards for battery and to power on	Measured, ecoinvent
Steel, low-alloyed	Mass	kg	1.349	Screws, washers, frame items, brake disc, misc hardware	Measured, ecoinvent
Synthetic rubber	Mass	kg	1.185	Wheels, handle grips, standing mat, frame wire plugs	Measured, ecoinvent
Tap water	Mass	kg	0.744	Manufacturing requirements	Proxy[1], ecoinvent
Transistor, wired, small size, through-hole mounting	Mass	kg	0.062	Wiring	Measured, ecoinvent
Welding, arc, aluminum	Length	m	0.75	Manufacturing requirements	Proxy[1], ecoinvent
End of Life Flows					
Electric scooter - produced	Number of items	Item(s)	1		
Municipal solid waste	Mass	kg	4.5	Disposal requirements	Proxy[1], ecoinvent
Wastewater, average	Volume	m^3	0.0007	Disposal requirements	Proxy[1], ecoinvent
Water	Mass	kg	0.0001	Disposal requirements	Proxy[1], ecoinvent
Used Li-ion battery	Mass	kg	0.8487	Disposal requirements	ecoinvent

[1]Proxy values for manufacturing requirements are drawn from the ecoinvent process for electric bicycle production.

[2]Used lognormal distributions for inputs as seen in ecoinvent 3.3 in Monte Carlo analysis

Table S2 - Battery inputs for 1 kg of battery cell, produced

Flows into Battery Production	Flow property	Unit	Amount	Description	Measured/Proxy, Data Source
Anode	Mass	kg	0.39		Ellingsen et al.
Cathode	Mass	kg	0.43	NMC 111	Ellingsen et al.
Cell Container	Mass	kg	0.0067		Ellingsen et al.
Electricity mix - CN	Energy	kWh	28		ecoinvent, Ellingsen et al.
Electrolyte	Mass	kg	0.16		Ellingsen et al.
Facilities precious metal refinery - SE	No. Items	Item(s)	2E-08		ecoinvent, Ellingsen et al.
Separator	Mass	kg	0.022		ellingsen et al.
Transport, freight, rail - RER	Transport	t*km	0.26		ecoinvent, Ellingsen et al.
Transport, lorry >32t, EURO3 - RER	Transport	t*km	0.1		ecoinvent, Ellingsen et al.
Water, decarbonized, at plant - RER	Mass	kg	380		ecoinvent, Ellingsen et al.

Table S3 - Scooter impacts for 1 Xiaomi m365 e-scooter

Materials	Acidification (kg SO_2-eq)	Respiratory Effects (PM $_{2.5}$-eq)	Eutrophication (kg N-eq)	GWP (kg CO_2-eq)	Human Health - Carcin (CTUh)
Aluminum Frame (76/24: P/R)	4.4E-01	1.2E-01	2.3E-01	7.4E+01	1.5E-05
Aluminum (Other)	2.9E-02	7.1E-03	1.4E-02	4.8E+00	1.0E-06
Battery	7.4E-01	7.1E-02	4.4E-01	4.5E+01	4.3E-06
Battery Recycled Content	-9.2E-03	-1.5E-03	-4.3E-03	-9.2E-01	-5.8E-08
Motor	1.2E-01	2.3E-02	1.7E-01	1.1E+01	3.1E-06
Disposal	1.1E-02	3.5E-03	1.7E-02	5.8E+00	1.5E-07
Plastics	1.4E-02	1.8E-03	1.5E-03	4.4E+00	1.4E-07
Charger	5.8E-02	9.8E-03	8.7E-02	4.8E+00	1.3E-06
Circuit Board	6.3E-02	5.8E-03	2.4E-01	9.3E+00	2.3E-06
Steel	5.9E-03	2.2E-03	4.4E-03	1.1E+00	3.7E-06
Rubber	1.7E-02	3.9E-03	9.0E-03	3.6E+00	1.5E-07
Water	1.3E-06	5.2E-07	9.5E-07	2.5E-04	1.3E-11
Manufacturing	7.9E-02	8.8E-03	1.0E-02	8.8E+00	2.9E-07
Other	4.0E-02	1.0E-02	4.4E-02	6.4E+00	1.0E-06

Materials	Human Health-Non-Carcin (CTU_h)	Ozone Depletion (kg CFC11-eq)	O_3 Formation (kg O_3-eq)	Ecotoxicity (CTU_e)	RD (MJ Surplus)
Aluminum Frame (76/24: P/R)	1.6E-05	3.0E-06	4.0E+00	3.7E+02	3.1E+01
Aluminum (Other)	8.5E-07	2.0E-07	2.6E-01	1.9E+01	2.0E+00
Battery	7.7E-05	1.1E-06	4.7E+00	1.5E+03	1.8E+01
Battery Recycled Content	-3.5E-07	-7.7E-08	-4.3E-02	-7.4E+00	-7.1E-01
Motor	3.0E-05	1.1E-06	7.2E-01	6.1E+02	9.9E+00
Disposal	8.4E-06	4.3E-07	1.3E-01	2.5E+02	1.5E+00
Plastics	5.2E-08	2.0E-09	1.7E-01	2.5E+00	6.9E+00
Charger	1.7E-05	2.5E-07	3.3E-01	3.5E+02	4.5E+00
Circuit Board	4.1E-05	1.1E-06	6.2E-01	8.2E+02	8.6E+00
Steel	4.8E-07	9.0E-08	6.7E-02	4.4E+01	1.1E+00
Rubber	5.8E-07	9.7E-07	1.7E-01	1.3E+01	1.2E+01
Water	3.8E-11	1.5E-11	1.3E-05	8.2E-04	1.6E-04
Manufacturing	9.5E-07	1.1E-07	6.7E-01	1.1E+01	2.6E+00
Other	5.6E-06	4.6E-07	3.9E-01	1.2E+02	5.3E+00

Table S4 - MCS scenarios associated with Figure 2 in manuscript

Scenario	Static Value
1. Low collection & distribution miles (miles/scooter)[1]	0.6
2. High scooter lifetime (years)[1]	2
3. Efficient vehicles for collection/distribution (g CO_2-eq/mile)[2]	235
4. Battery depletion limit to charge (%)[3]	50%

[*]This table displays the scenario with a new static value which was previously a range in the MCS base case

[1]Represents the low end of the uniform range used in the MCS

[2]Represent the 5th percentile value from the lognormal distribution fit

[3]Represents a minimum battery state of charge that must be reached for employees to be sent to pick up.

Table S5 - Median values results from Monte Carlo analysis for each scenario and impact category

Scenario	Global Warming Potential (kg CO_2-eq)	Acidification (kg SO_2-eq)	Eutrophication (kg N-eq)	Respiratory Effects ($PM_{2.5}$-eq)
Base Case	178	0.989	0.697	0.179
Low Collection Distance	123	0.814	0.567	0.142
Battery Depletion Limit	134	0.841	0.601	0.149
High Vehicle Efficiency	150	0.961	0.690	0.174
High Scooter Lifetime	152	0.707	0.473	0.125

Table S6 - Survey results for riders reason to ride

1.) Why did you try e-scooters for the first time?

	Answer	%	Count
1	To save money on transport	0.00%	0
2	To get around quickly or more conveniently	46.67%	28
3	To help the environment	1.67%	1
4	For recreation / Curious to try it out.	48.33%	29
5	Other	3.33%	2
	Total	100%	60

2.) Thinking of your most recent e-scooter trip, why did you choose to take an e-scooter?

	Answer	%	Count
1	It was the fastest and most reliable.	49.18%	30
2	It was the least expensive	0.00%	0
3	Parking would be too difficult	9.84%	6
4	No other more of transport was available	1.64%	1
5	Don't own a car	4.92%	3
6	Didn't want to get sweaty	8.20%	5
7	For fun / recreation	26.23%	16
8	Other	0.00%	0
	Total	100%	61

Table S7 - Survey results for riders use and alternatives

Q3 - 3.) When riding e-scooters, what percentage of the time do you use them for getting to a destination or for recreation? (Note your answers should add up to 100%)

	Field	Minimum	Maximum	Mean	Std Deviation	Count
1	Travel to a destination	0	100	67.72	33.64	61
2	Recreation	0	100	32.28	33.64	61

Q4 - 4.) If e-scooters were not available, what percentage of the time would you use these alternatives? (Note the total value should add up to 100%)

	Field	Minimum	Maximum	Mean	Std Deviation	Count
1	Walk	0	100	41.18	30.34	61
2	Drive	0	100	23.8	29.4	61
3	Bicycle	0	80	7.39	15.65	61
4	Bus	0	100	10.51	18.69	61
5	Taxi / Uber / Lyft	0	100	9.98	18.6	61
6	Would not have gone	0	100	7.13	19.11	61