DOCKLESS E-SCOOTER CO2 EMISSIONS: AN EARLY ANALYSIS FOR SALT LAKE CITY

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Abstract. Carbon dioxide emissions associated with dockless e-scooters are estimated using simple modeling. There are two components to dockless electric scooter network emissions: First, 5.7 CO2 grams-mile are emitted when recharging the scooter. Second, gasoline powered vans are used each day to transport the scooters to a recharging station and to reposition them to balance the pickup network of the next day's demand. This can allocate an additional 300 to 600 CO2 grams per scooter-day to each device. Even so, e-scooters are estimated to be 1 in 5 to 1 in 6 times more CO2 efficient than automobiles on a comparable 7.5 mile trip (642 CO2 grams-7.5 miles vs. 3,427 CO2 grams-7.5 miles for the Salt Lake City electrical grid). The consumer substitution rate of e-scooters to automobile trips (18%) must exceed this ratio for e-scooters to reduce CO2 pollution. The most likely initial market impact of e-scooters is to slightly increase air pollution as scooters displace the local human-powered bike sharing market. Eventually, after e-scooters replace human-powered bike sharing, they can make a significant long-term environmental contribution to improving air-quality. It is suggested that to improve e-scooter CO2 efficiency, municipal governments should consider installing remote charging stations to reduce CO2 emitting transport by van to recharge and reposition dockless e-scooters.

1. Introduction

It is important when new technology is introduced to view potential greenwashing claims by profit driven companies who seek to have their market share rapidly increase and to bypass municipal regulators. E-scooter claims that scooters many times more emissions efficient than cars. The Lime app claims that riders save 350 grams of CO2 per mile driven and the company asserts in the their first three months of operation, their riders avoided injecting 500,000 pounds (250 short-tons) of CO2 in the atmosphere (Lime, April 2018).

These are examples of advertising claims that the need to be looked critically for greenwashing. Using guesstimation computations (Weinstein and Adam 2009), e-scooters may theoretically be 70 times more efficient in terms of CO2 emissions than the average U.S. auto (400 grams per mile/6 grams per mile). But when including recharge and redistribution travel CO2 emissions, dockless e-scooters may be only 5 to 6 times less polluting than the same travel by automobile - not 70 times more efficient. This means that to reduce total CO2 emissions, in the higher efficiency scenario, at least 1 in 6 e-scooter trips (18%) must substitute for a car trip in order

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to reduce air pollution. In a lower efficiency scenario, about 1 in 5 e-scooter trips (21%) must substitute for a car trip in order to reduce air pollution.

In summary, dockless e-scooters as part of a transportation network, although efficient, are not as pollution efficient as advertising by their proponents may claim. There is not enough publicly available research to conclude that as presently marketed, how much the dockless e-scooters transportation network reduces air-pollution. Analysis of this question also gathered background information on the Utah CO2 efficiency of related products like electric and hybrid cars.

This analysis suggests that the CO2 efficiency of Salt Lake dockless e-scooter industry could best be improved by the City entering the scooter recharge market. The City could explore modifying its digital parking meter stations to also be recharging stations. By requiring e-scooter companies to achieve recharging a percentage of its fleet at City stations for a fee, the main CO2 emissions of e-scooters - their delivery van pickup, recharge and redistribution - could be reduced. Then e-scooters might reach their theoretical 70 times improvement of CO2 emissions over automobiles.

There appears to be no published journal literature evaluating this question, although journalistic articles have questioned their true "green" efficiency (Pricop Oct. 2018; Joselow August 2018; Buchele May 2018). In the absence of scientific journal articles, we have to fall back on to simple modeling and critical reasoning. The art of guesstimation can be used to guide our intuitions (Weinstein and Adam 2009, Harte 1988).

The total CO2 emissions of e-scooters are part of a transportation system: the emissions include the trucks that gather the scooters, take them to a centralized location, recharge them, and then redistribute the scooters back to pickup points that balance with the next morning's user demands. The CO2 emissions of dockless e-scooters depend on(1) the per mile emissions of the heavy trucks that pickup and recharge the e-scooters each day, (2) the distance those trucks transport the e-scooters each day, (3) and the extent to which e-scooters substitute for automobile trips. The CO2 emissions for picking up, recharging and re-delivering the e-scooter is termed here their "recharge-redistribution CO2 emissions. Additionally, if e-scooters simply create a new market that displaces walking, then e-scooters add CO2 to the atmosphere. E-scooters only reduce emissions when they substitute for automobile trips.

The redistribution CO2 emissions affects even human powered bike share programs. In 2016, Salt Lake City's successful GreenbikeSLC organization recorded 140,865 human-powered bicycle checkouts. But of those trips, 26,153 bikes (19%) had to picked up by a van and redistributed (GreenBike 2016). The bike program also made 8,459 bike and station inspections and 6,263 bike and station repairs. These were done using gasoline powered vans (personal observation). The key issue is that even human powered bicycle networks are not "carbon free". Redistribution and maintenance require CO2 emitting auto travel. E-scooters are no different.

The automobile trip substitution rate for e-scooters is largely unknown. How far contractors who pickup, recharge and redistribute the scooters each day is unknown. How many trips and how far consumers travel each day are trade secrets not publicly disclosed and are also uncertain. All the foregoing introduces further uncertainty into the question of whether e-scooters are as efficient as their marketers' claim.

Nonetheless, some rough estimates can be made in the absence of published studies. (I am not physics or transportation expert.) Here, I follow a blog example in Chester Energy 2018, but the numbers are updated to be Utah-Salt Lake City specific, and I address an upstream component omitted by Chester Energy - CO2 emitted by refining a gallon of gasoline.

2. How much CO2 dockless e-scooters emit?

Utah E-scooters emit about 70 times less pollution than an average U.S. car per mile during travel (5.7 grams per mile vs. 459 grams per mile, see computations below). But the recharge CO2 emissions for the dockless e-scooter network are significant - perhaps between 300 to 600 grams per scooter per day - again, by rough calculations below.

When individual e-scooters driven from home to work, driven back again and recharged at home, unquestionably they emit far fewer grams of CO2 than driving a car, but commercial dockless e-scooters are different. E-scooters emit about 70 times less pollution than an average U.S. car. That an individual e-scooter generates far less CO2 pollution than an individual car is self-evident from the physics of the matter. If as a self-absorbed yuppie, if you wrap yourself in a 6,000 pound Ford Expedition to go to work on the theory that you and not the smaller car will do better in an I-15 car crash, then you will emit more CO2 than your neighbor who drives a 2,500 lb Prius. If you go the grocery store using a 30 lb e-scooter instead of wrapping yourself in the 2,500 lb Prius of your environmentally conscious neighbor, then you will generate less CO2. It's just a matter of physics. Accelerating 6,000 lbs to 30 miles per hour takes more energy than accelerating 2,500 lbs to 25 miles per hour and more than accelerating 30 lbs to 15 miles per hour.

A useful analogy for e-scooters is our local bus and train system. I have no doubt that a 25,000 lb UTA bus fully loaded with passengers emits less grams of CO2 per passenger per mile than the Prius that I used to drive. The same goes for rush hour loaded light rail trains. But in both transportation systems, the net CO2 per miles traveled includes the many times that you have seen a bus or light rail train during off hours inefficiently going down the street with one, two or no passengers. Factoring in these higher polluting times have to be included in society's estimation of the total CO2 burden of those transportation systems.

2.1. **How much electric energy does one e-scooter use?**

What are the CO2 emissions of e-scooters - dockless or not? Let's first look at the simple case of riding an e-scooter or driving a car for 1 mile to the grocery store and back. The data for the Segway ES4 e-scooter will be used as proxy for the Lime and Bird e-scooters. Its characteristics are:

Top Speed: 19 mph (crippled to 15 mph for Lime and Bird scooters)
Range: 28 miles
Battery capacity: 374 watt-hours

How much CO2 does the e-scooter emit per mile traveled? That will equal the amount of CO2 that it took to charge the e-scooter from the electricity grid divided by 28. The overall formula is: Segway ES4 E-scooter CO2 grams/miles = Average CO2 grams per watt-hour from electric grid times 374 watt hours divided 28 miles.

2.2. **How much CO2 is emitted by recharging one e-scooter from the electric grid?** To find the average CO2 grams per watt-hour from the electric grid, various data on the CO2 emissions by state and for the state of Utah were gathered. The amount of CO2 emitted by state per kilowatt hour generated varies widely. Utah is coal energy state and we generate a higher percentage of domestic-home electricity from dirty coal as compared to other states. (An alternative argument could be made that in Salt Lake City, our electricity comes primarily from cleaner natural gas, but since the electric grid is connected, the state-wide average is used here. In some areas (Washington, D.C.), the grams of CO2 emitted per watt-hour of home electricity is approximately 0.622 grams (Chester Energy 2018)).

In 2016, the total electricity generated in Utah was 31,133,928 megawatts hours, or 31,133,928 x 1,000,000 watt hours (U.S. EIA 2018). In 2016, Utah electricity generators emitted 28,244,970 metric tons of CO2, or 28,244,970 x 1,000,000 grams of CO2. Finally, Utah electric grids lose about 4.3 percent in line transmissions between the power plant and your home outlet (Wirfs-Brock 2015). The foregoing suggests that the average CO2 grams per watt-hour from Utah's electric grid is,

31,133,928 x 1,000,000 metric tons of CO2
divided by 28,244,970 x 1,000,000 watt hours
divided by 0.957 transmission loss
==================
equal 1.15 grams of CO2 per watt hour
or 1.15 kilograms of CO2 per kilo watt hour

The corresponding 2016 computation limited to the portion of Utah's electricity grid generated from less polluting natural gas is:

3,740,766 metric tons of CO2
divided by 8,691,720 megawatt hours
divided by 0.957 transmission loss
==================
equal 0.430 grams of CO2 per watt hour
or 0.430 kilogram of CO2 per kilo watt hour

One way to think about the CO2 is in terms of bread loafs. A loaf of white bread weighs about 28 ounces or about 800 grams. Home use of about a kilowatt-hour of electricity generated with natural gas generates CO2 gases that weigh about 1/2 of a loaf of bread. With Utah's mixed fuel electric grid, a kilowatt of electricity use generates CO2 gases that weigh about 1 and 1/4 a loaf of Wonder bread.

For the Segway ES4 e-scooter, the estimated grams of CO2 per mile are under two scenarios:
For Utah average CO2 electric generation emissions:
1.15 grams of CO2 per watt hour
times 374 watt-hours of battery capacity.
divided by 28 mile range
==================
15.4 grams of CO2 per mile

For Utah natural Gas CO2 electric generation emissions only:
0.430 grams of CO2 per watt hour
times 374 watt-hours of battery capacity.
divided by 28 mile range
==================
5.74 grams of CO2 per mile

(As an aside, others have requested similar information on E-bikes and E-Vespa-like scooters. The following data for proxy devices GenZe 2.0 E-vespa like scooter and the GenZe 200 Series, apparently used by Salt Lake City's Department of Waste Management. The Ford GoBike is a variant of the GenZe 200 series.)

GenZe 200 Series E-bike
Range: 15-18 miles
Speed: 20 mph
Battery Capacity: 36 volt, 9.6 amp hours = 345 watt hours

For Utah average CO2 electric generation emissions:
1.15 grams of CO2 per watt hour
times 345 watt-hours of battery capacity.
divided by 18 mile range
==================
22 grams of CO2 per mile

GenZe 2.0 Vespa-like scooter:
Range: 35 miles
Speed: 30 mph
Battery Capacity: 2000 Watt-hours

For Utah average CO2 electric generation emissions:
1.15 grams of CO2 per watt hour
times 2000 watt-hours of battery capacity.
divided by 35 mile range
==================
65 grams of CO2 per mile

In the scenario where you charge your e-scooter at home and take the scooter to the grocery store instead of your car, you emit about 70 times less pollution than the average car. Again, this is simple physics of accelerating 30 lbs of the scooter to 15 miles per hour instead of 5,000 lbs of the car to 30 miles per hour. The lower weight and speed of the e-scooter take less energy to move and, thus, it and emits less pollution. The e-scooter is the clear emissions winner.

2.3. **How much CO2 is emitted by the dockless e-scooter industry when recharging and re-balancing the distribution of its e-scooter fleet?** But that is not the transportation system service that dockless e-scooters provide. Dockless e-scooters have to be picked up by CO2 emitting trucks every day, driven to a centralized station, repaired, recharged, and then driven back to deployment points that will meet tomorrow morning's consumer demand.

Here again, we have a lack of published studies. And again, we have to rely on some simple modeling and guesstimation. My own observation of Salt Lake City downtown area during the night is that there are two types of trucks picking up and recharging Lime and Bird scooters:

1) Ford 150 trucks pulling a trailer and carrying about 10 Bird scooters. The Ford 150 is rated at about 19 per gallon in the city. Given the nature of e-scooter picks, I assume that they get on average 14.6 miles per gallon in the city.

2) Ford Transit cargo vans picking up about 10 Lime scooters that get about 21 miles per gallon in the city. I assume that they get on average 14.6 miles per gallon in the city.

For both vehicles scenarios, this equates to an assumed 600 grams of CO2 emissions per mile.

I personally know of one recharge location, and my anecdotal estimate of the total round trip miles driven to collect e-scooters and return them to the CBD is about 5 miles for 10 e-scooters. This excludes the higher emissions that come from the truck driving around the Avenues and Central City to pick up e-scooters dispersed outside the Central Business District.

How do we allocate the emissions from the recharging trucks to each dockless e-scooter? First, look at the fixed base load of CO2 from recharging each scooter:

300 grams of CO2 per scooter per day = 5 miles x 600 grams CO2 per mile /10 scooters
600 grams of CO2 per scooter per day = 10 miles x 600 grams CO2 per mile /10 scooters

2.4. **How far and how many times are dockless e-scooters driven each day?** Next, how far are dockless e-scooters driven each day? Here again, there is a lack of data. Lime and Bird do not share their wealth of GPS gathered data with public; they do with municipalities. Bird reported an average trip length of 1.5 miles per day and 5 rides per day, for an average scooter use of 7.5 miles per day (Chester 2018). During the first 2 1/2 weeks of operation in Salt Lake City, Lime anecdotally reported about 30,000 trips total about 40,000 miles (Raymond 2018). That is an average of 1.3 miles per scooter trip.

Ford's GoBike human-powered bike share program may provide a useful analogy. GoBike is spread between 5 densely population cities surrounding San San Francisco Bay. Bikes are checked out of and returned to specific stations. The organization releases anonymous ride data to the public. (Companies like Lyft, Uber, Bird and Lime will release anonymous data to municipalities on request.) I analyzed the 519,700 trips in GoBike's 2017 data file (Ford GoBike 2017). The mean checkouts per day per human powered bike was 2.5; the mean distance ridden was 2.1 miles. SLC's Greenbike human powered bike share program does not release data similar to GoBike. Its annual report contains no information analyzing the average number of checkouts per day per bike or the distance that their user's ride (GreenbikeSLC 2016).

The Ford human-powered GoBike program suggests the number of rides per day and distance traveled might be higher if applied to e-scooters. But for Salt Lake City, the Bird estimate of 5 rides at 1.5 miles per ride assumption seemed more appropriate. The Bird estimate for e-scooters is used for modeling here.

2.5. **What is the total allocation of CO2 emissions for 7.5 miles of e-scooter travel?** In total, dockless e-scooters emit under the two efficiency scenarios (Utah average coal powered electricity grid and a hypothetical Utah natural gas electricity grid) the following amounts of CO2 during a 7.5 mile trip:

Utah Average Electricity Grid:
715 grams CO2 to travel 7.5 miles = 600 grams of CO2 for daily recharge and redistribution + 15.4 grams per mile CO2 during 7.5 miles of travel.

Utah Natural Gas Only Electricity Grid:
642 grams CO2 to travel 7.5 miles = 600 grams of CO2 for daily recharge and redistribution + 5.7 grams per mile CO2 during 7.5 miles of travel.

These e-scooter estimates do not account for seasonal variations. Recharge and redistribution CO2 emissions would be expected to increase during the winter. Fewer rides per day are expected in winter.

3. How much CO2 do gasoline, hybrid electric and fully electric cars emit?

3.1. **How much CO2 do automobiles emit when burning gasoline?** How much does a car emit? The EPA estimates the average U.S. automobile emits 404 grams of CO2 per mile (US EPA March 2018). If the upstream electricity generation CO2 emissions are included, a 2018 Chevrolet Bolt All-electric vehicle emits 90 grams per mile when driven in the Salt Lake area and 170 grams per mile on average in the United States (US EPA 2018). A 2015 Prius emits 133 grams of CO2 per mile. A 2016 Ford 150 truck about 409 grams per mile (US EPA 2018).

3.2. **How much CO2 is emitted to refine the gasoline that goes into an automobile and to transport that gasoline to a local station?** Upstream of the gas station is the oil refinery. According to the EPA in 2017, the five Utah refineries reported that they emitted 2.1 million metric tons of CO2 gases (EPA 2018c). The U.S. EIA reported that Utah residential and industrial needs consumed 53,601,000 barrels of petroleum products, or at 31 gallons per U.S. barrel, 1,661,631,000 gallons. This comports with the Utah Petroleum Association's report that the five Woods Cross refineries can process about 168,000 barrels of oil per day, or about 61,320,000 barrels of oil per year (Utah Petroleum Assoc.). Thus, refining a gallon of gasoline emits:

2,100,000 metric tons of CO2
x 1,000,000 grams per metric ton
divided by 1,745,331,000 gallons
=================
1,263 grams of CO2 emitted to refine one gallon of gasoline.

This estimate comports with another non-authoritative estimate that refining a gallon of gasoline generates 2.4581 lbs or 1,114 grams of CO2 emissions (Serpa 2008).

At 22 miles per gallon, your auto also has caused to be generated another 57 grams of CO2 to refine the gasoline burned by the car (1,263 grams per gallon divided by 22 miles per gallon).

Next the refined gasoline is transported to your local gas station. A typical tanker holds 9,000 gallons of gas that weighs about 25.5 metric tons. The Environmental Defense Fund, based on EPA data, did a study on how to green the heavy duty truck industry. A tanker truck emits 1,700 grams of CO2 per mile driven (EDF 2015). On average, heavy-duty trucks emit 168.1 grams of CO2 U.S. short-ton mile (id., 11-12). A Salt Lake gasoline tanker that does a 20 mile round trip from a Wood Cross refinery roughly emits about 4 grams of CO2 per gallon of gasoline delivered. At a personal automobile efficiency of 22 miles per gallon, the CO2 costs of delivering the gas from the refinery are about 0.2 grams per mile. It can be safely ignored from the accounting of automobile CO2 emissions per mile. But, the analysis was done anyway to assure that we are comparing the delivered CO2 grams of energy on the same basis for cars and e-scooters. This estimate ignores the carbon footprint of the gasoline station itself.

3.3. **What is the total CO2 emitted for automobiles per mile for a 7.5 mile trip?** An average Utah automobile emits an estimated 457 grams of CO2 per mile, including the upstream refining process and tanker delivery. What do automobiles emit for a 7.5 mile trip?

3,427 CO2 grams for 7.5 miles = 457 CO2 grams per mile x 7.5 miles.

4. What are unknown factors in CO2 emissions used in these estimates for e-scooters and cars?

The above modeling ignores three important aspects of the dockless e-scooter industry. First, Lime has a program for users to self-recharge at home. The participation rate in this program is unknown.

Second, the life-cycle of e-scooters when used in the dockless industry is unknown. One analyst suggests that the e-scooters may have a useful life of only 300 to 500 rides - our about four month's equivalent trips in an personal automobile at 3 trips per day (Kamps 2018). Some have suggested that an industrial dockless e-scooter will last 2 years. To achieve the same number of rides over the 7 year life-span of a vehicle at 3 trips a day - 7,665, one would need 16 e-scooters. How the e-scooters will be recycled is unclear.

Third, and most importantly, these estimates do not include the upstream CO2 emissions above the largely Utah coal fired generating plant or above the Woods Cross oil refineries. I was unable to any data on the CO2 emissions from mining and transporting one ton of coal to a power plant. Similarly, CO2 emissions of transporting large volumes of natural gas around the country were unclear. The CO2 emissions of oil extraction for any refinery hub are also unclear. Some fields flare off huge volumes of CO2 in the form of unrecoverable methane and natural gas. Although Utah industry prides itself on selling relatively "clean" low-sulfur coal, Utah Woods Cross oil refineries obtain much their crude oil via a 2,000 mile long pipeline system that reaches to the Canadian Tar oil sands. Tar sands oil emits 17% more CO2 during extraction than non-tar sand oil (Cusham 2014).

The picture for power plants becomes even more muddled, since in Utah they run on coal or natural gas. Some Utah electricity generation comes from using oil as a fuel.

Fourth, the carbon footprint of storing and retrieving automobiles verses e-scooters in an urban setting is not considered.

All of this lack of data introduces a large uncertainty into upstream allocations of CO2 emissions between fossil fuel resources and the power plants that fuel automobiles, electric vehicles and e-scooters. But personal decisions and social policy can only be made based on what is known and not on what is not known.

The purpose of these extended computations is to place e-scooters and automobiles on the same basis for comparison. The comparison includes "upstream" carbon generated at the point of the gasoline refinery and at the electric power plant.

5. What is ratio of total CO2 emissions for dockless e-scooters and automobiles?

How do e-scooters compare to the automobile CO2 estimate? What is the relative CO2 efficiency of dockless e-scooters and automobiles in Utah? The CO2 total emissions for a 7.5 mile trip are used:

Utah Average Electricity Grid:
715 grams CO2 per 7.5 miles per scooter / 3427 grams CO2 per 7.5 miles per automobile = 0.21 (1 in 5)
Utah Natural Gas Only Electricity Grid:
642 grams CO2 per 7.5 miles per scooter /3427 grams CO2 per 7.5 miles per automobile = 0.19 (1 in 6)

Two worksheets have been prepared, attached, that aid in performing most of the above computations:

1) Formula Worksheet - Estimating Driving CO2 Emissions Grams Per Mile Driven for Electric Vehicles, e.g. E-scooters, E-bikes and Electric Cars.

2) Formula Worksheet - Allocating Oil Refinery CO2 Emissions to a Gasoline Powered Automobile in Grams Per Mile Driven.

6. How do trip substitution rates affect the CO2 efficiency of e-scooters as relates to cars?

6.1. **What percent of dockless e-scooter trips have to substitute automobile trips for e-scooters to be more CO2 efficient than cars?** The last question is what is how many e-scooter trips substitute for automobile trips. To reduce emissions, e-scooter rides have to replace automobile trips in 21% (1 in 5) of scooter rentals. Again, there is little actual data and much uncertainty in the above rough estimates.

6.2. **What are the reported substitution rates for e-scooters replacing car trips?** What are the reported substitution rates for e-scooters replacing auto trips? Again, there is little in actual data. In July 2018, Lime reported that in San Francisco, Lime scooter riders self-reported that they choose an e-scooter over a car in 53% of their trips - implying a 53% substitution rate (Lime July 2018). Uber, in analyzing its GPS data for its JUMP e-scooter program, found that in

San Francisco, its e-scooter rides went up 15% during the same period that Uber taxi-rides declined 10%. The company attributed those changes to a direct 1 to 1 substitution of scooter rides for taxi cab rides - or a 10% substitution rate (Walker July 2018).

In Salt Lake City, only about 10% of riders that I anecdotally see daily seem to be taking trips that are long enough to qualify as replacing an e-scooter trip. Of the 500 or so e-scooters deployed downtown, I might see 10 e-scooters at dusk placed outside the Central Business District. This suggests that unknown substitution rate is closer to 10% (1 in 10), not 53% (1 in 2).

In Salt Lake City, another unknown factor is whether e-scooters are and will displace the more CO2 efficient GreenBike program. Of GreenbikeSLC riders, 14% report that they use the program every day. This suggests that group are daily commutes for whose trips, their automobiles are replaced. The program is cost effective for consumers because 60% of the program's cost is provided by corporate donations, principally from the travel industry (GreenBike 2016). Greenbike reports and surveys do not indicate what portion of their riders disembark from light-rail or bus transit, and then precede over the last mile by Greenbike. Will Greenbike users substitute with e-scooters, and thus, increase their CO2 travel emissions?

7. Discussion

E-scooters are another important element in evolving United States cities like Salt Lake towards a future, idealized all-electric city. The Salt Lake City of today is perhaps the City's 5th or 6th incarnation - it has been effectively rebuilt that many times since 1850. Salt Lake, like other major American cities, evolved into an inverted pattern after the arrival of the street car in the 1880s and automobile of the 1910s: the poor lived in the central core and the wealthy on the periphery. In European cities, the wealthy live at the city's core and the poor on the outskirts. That is consistent with the centuries of European economic evolution from feudal keeps to industrial societies.

The American city suburbanized development pattern is changing. In the past, development of Salt Lake City has been limited by energy technology. The Salt Lake Valley of 200,000 in the 1920s was pollution limited by the use of coal for home heating. The arrival of natural gas beginning in the late 1920s and lower emission automobiles have allowed the valley to grow to 1.3 million persons, but again, it has reached an air pollution limit. As the valley has approached its suburban development limits, the pattern of class residency is again changing. The wealthy are returning downtown, and the poor will be displaced to the periphery.

Conversion of home heating and transportation to electricity is the next great step that will needed to be taken for Salt Lake City to again expand and transform. E-scooters are one small component in various possible City transformations to an electric future.

In making that change, it is important that residents not uncritically accept every market scheme put forth by private industry and every request for monetary or regulatory relief to aid in their market penetration. Thinking through the consequences of new technology first can lead to better decisions. For example, this analysis suggests converting City parking meters to include recharge stations in order to reduce the main component of e-scooter CO2 emissions: recharging and redistribution by delivery vans. Careful consideration also lets us examine alternatives. For example, far more reduction in City CO2 emissions and improvement in air quality might be had by reversing the state legislature's decision to double registration fees for electric vehicles.

8. Conclusion

The Bay Area Ford GoBike data, analyzed above, suggests that human-powered bike sharing may be the first wave of substitutions for e-scooter trips - not automobiles. In the Bay Area, the average trip distance by human-powered shared-bikes is 2.1 miles - an ideal distance that e-scooters can compete against. E-scooter market entry will most likely first increase air pollution as the technology captures the core of the human powered bike riders who use Salt Lake City's Greenbike program. Of Greenbike's 29,000 users in 2016, 9,000 annual pass holders formed the core of its business. There is some precedent for this view. Although already failing, Austin, Texas's private green bike program closed in July, 2018, two months after the arrival of e-scooters (Allbright May 2018; Salazar July 2018).

But the e-scooter appeals to a broader range of consumers who have lower physical fitness, and at some future point, e-scooters will begin to reduce total pollution from substituting for automobile trips as these lower fitness adults change their travel preferences. E-scooter low CO2 emissions, which is due primarily to their low vehicle weight, will make substantial contributions to improving the Salt Lake Valley's air quality.

About: I am a mathematics student and not an expert on energy or transportation policy. I am supportive of e-scooter technology except that dockless sharing escooters do not carry liability insurance.

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Formula Worksheet - Estimating Driving CO2 Emissions Grams Per Mile Driven for Electric Vehicles, e.g. E-scooters, E-bikes and Electric Cars

Note: For most consumer electric cars, the Environmental Protection Agency has already done these computations and the result can be looked up using:

U.S. Environmental Protection Agency. 2018a. Find and Compare Cars (Fuel economy andenvironmental impacts by year, make and model, database).

https://www.fueleconomy.gov/

$$EV_e \frac{CO_2\,grams}{mile} = \frac{\dfrac{\alpha\, CO_{2e}\, metric\ ton \times \dfrac{1000000\ grams}{metric\ ton}}{\beta\ mega\ watt\ hour \times \dfrac{1000000\ watt\ hour}{1\ mega\ watt\ hour}}}{1 - \gamma\ transmission\ loss\ \%} \times \frac{\delta\ watt\ hour\ EV\ battery\ capacity}{\varepsilon\ miles\ EV\ range} = \frac{\alpha \times \delta}{\beta \times (1-\gamma) \times \varepsilon}\ \frac{CO_2\,grams}{mile}$$

where:

EV_e = electric vehicle emissions.

CO_{2e} = CO2 emissions.

α = metric tons of CO2 emitted by all electric power plant types in your state.

Data source: U.S. Energy Information Administration. 2018a. FAQ: How much carbon dioxide is produced per kilowatt hour of U.S. electricity generation? U.S. Electric Power Industry Estimated Emissions by State. File: emission annual.xls. Accessed November 26, 2018. https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

β = metric tons of CO2 emitted by all electric power plant types in your state.

Data source: U.S. Energy Information Administration. 2018b. FAQ: How much carbon dioxide is produced per kilowatt hour of U.S. electricity generation? Net Generation by State by Type of Producer by Energy Source. File: annual_generation.xls. Accessed November 26, 2018. https://www.eia.gov/tools/faqs/faq.php?id=74&t=11

γ = average percent transmission line power loss for your state.

Data source: Wirfs-Brock, J. Nov. 6, 2015. Lost In Transmission: How Much Electricity Disappears Between A Power Plant And Your Plug? Inside Energy Blog.

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δ = watt hour storage capacity of your electric vehicle. Data source: Your manufacturer's specification sheet.

ε = the range of your electric vehicle. Data source: Your manufacturer's specification sheet.

Example computation for a Segway ES4 escooter used in Salt Lake City, Utah (*See* main paper):

$$\frac{31133928 \cdot 374}{28244970 \cdot (1 - 0.043) \cdot 28} \frac{CO_2\,grams}{mile}$$

$$\frac{15.38489129\ CO_2\,grams}{mile} \tag{1}$$

Kurt A. Fisher November 28, 2018 "Dockless E-scooter CO2 Emissions: An Early Analysis for Salt Lake City"

Formula Worksheet - Allocating Oil Refinery CO2 Emissions to a Gasoline Powered Automobile in Grams Per Mile Driven

$$GV_{er}\frac{CO_2\,grams}{mile}=\frac{\alpha\,CO_{2e}\,metric\ ton\times\frac{1000000\ grams}{metric\ ton}}{\beta\,gallons}\times\gamma\frac{gallon}{mile}=\frac{\alpha}{\beta\times\gamma}\,\frac{CO_2\,grams}{mile}$$

$$GV_{et}\frac{CO_2\,grams}{mile}=GV_{er}\frac{CO_2\,grams}{mile}+GV_{ed}\frac{CO_2\,grams}{mile}$$

where:

GV_{er} = a gasoline powered vehicle's emissions allocated from oil refining.

$GV_{ed}\frac{CO_2\,grams}{mile}$ = a gasoline powered vehicle's emissions burning gasoline while driving. The U.S. average is 404 $\frac{CO_2\,grams}{mile}$.

Data source: For most consumer electric cars, the Environmental Protection Agency has already done these computations and the result can be looked up using:

U.S. Environmental Protection Agency. 2018a. Find and Compare Cars (Fuel economy andenvironmental impacts by year, make and model, database).

https://www.fueleconomy.gov/

For e-scooters and e-bikes, use the worksheet: "Estimating Driving CO2 Emissions Grams Per Mile Driven for Electric Vehicles".

GV_{et} = a gasoline powered vehicle's total emissions

CO_{2e} = CO2 emissions.

α = metric tons of CO2 emitted by all oil refineries in your state.

Data source: U.S. Environmental Protection Agency. 2018b. EPA Facility Level Infomration on Greenhouse Gases Tool (Flight). Internet database.

https://ghgdata.epa.gov/ghgp/main.do#/facility/

β = gallons of gasoline refined by all the oil companies in your state.

Data source: Your state petroluem association or state energy office.

Example For Utah: Utah Petroluem Association. http://www.utahpetroleum.org/

γ= gallons per mile rating for your car. U.S. average for all automobiles is 22 miles per gallon highway in 2018.

Data source: U.S. Environmental Protection Agency. 2018a. Find and Compare Cars (Fuel economy andenvironmental impacts by year, make and model, database).

https://www.fueleconomy.gov/

Example computation for Utah's five oil refineries the produce gasoline used in Salt Lake City, Utah (*See* main paper):

$$evalf\left(\frac{2100000 \times 1000000}{1745331000 \times 22}\right)\frac{CO_2\,grams}{mile}$$

$$\frac{54.69137112\;CO_2\,grams}{mile} \tag{1}$$

$$54.7\,\frac{CO_2\,grams}{mile} + 404\,\frac{CO_2\,grams}{mile}$$

$$\frac{458.7\;CO_2\,grams}{mile} \tag{2}$$

Kurt A. Fisher November 28, 2018 "Dockless E-scooter CO2 Emissions: An Early Analysis for Salt Lake City"