Reducing Transportation Emissions in Charlottesville

Prepared for The Local Energy Alliance Program - VA

MAY 2020 // JAMES BARBER

UNIVERSITY *of* VIRGINIA
FRANK BATTEN SCHOOL *of* LEADERSHIP *and* PUBLIC POLICY

Table of Contents

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Disclaimer

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Honor Statement

On my honor as a student, I have neither given nor received aid on this assignment.

James Barber

James Barber

Basic Definitions and Acronyms

ICEV: Internal Combustion Engine Vehicle
EV: Electric Vehicle. In this document, EV exclusively refers to Battery Electric Vehicles.
EPA: Environmental Protection Agency
$MTCO_2e$: Metric Tons of CO_2 Equivalent. $MTCO_2e$ is a uniform measure of the greenhouse warming potential of a substance.
MPG: Miles per Gallon
TNC: Transportation Network Company, like Uber or Lyft.
GHG: Greenhouse Gas
SOV: Single-Occupancy Vehicle. An SOV is a privately operated vehicle whose only occupant is the driver.
LDV: Light Duty Vehicle. An LDV is any vehicle with a gross vehicle weight rating of less than 8,500 lbs (passenger cars, pickup trucks, etc).
FPL: Federal Poverty Line
CVRP: Clean Vehicle Rebate Program. An EV subsidy program in California.
AGI: Adjusted Gross Income. An individual's total gross income minus specific tax deductions.
CARS: U.S. Consumer Assistance to Recycle and Save Act of 2009. Better known as Cash for Clunkers.
Embodied Carbon: The GHGs emitted in the production of a good. For cars, this would be the GHGs emitted in building the car and shipping the car to the point of sale.

Executive Summary

In 2019, the City of Charlottesville has committed to the goal of reducing emissions by 45 percent by 2030 (relative to 2011 levels) and becoming carbon neutral by 2020. Since community transportation emissions account for 26.6 percent of emissions in Charlottesville, they provide a natural target for any program aiming to meet the City's emissions goals. Most of these vehicles are caused by single occupancy internal combustion engine vehicles.

In addition to allowing present trends to continue, this paper posits three methods to reduce community transportation emissions in Charlottesville:

1) Implementing an electric vehicle subsidy for residents of Charlottesville
2) Creating a subsidy program to encourage rideshare drivers in Charlottesville to switch to electric vehicles
3) Launching an accelerated vehicle retirement program to replace old, fuel-inefficient vehicles

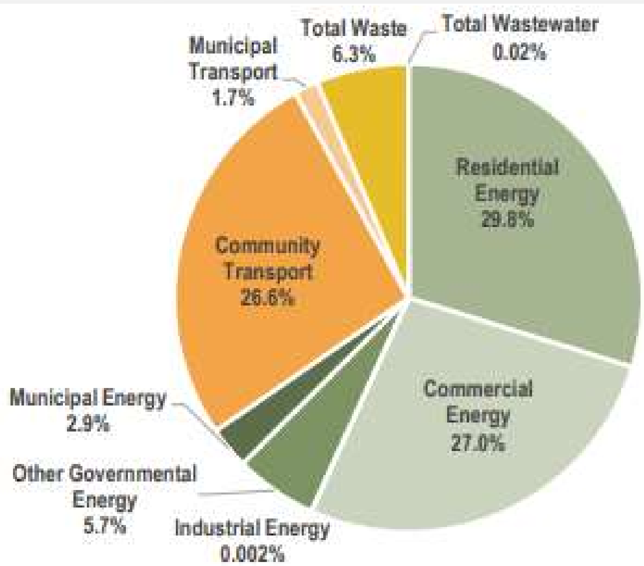
Each option is evaluated based on its cost effectiveness, its equity implications, and its net emissions abatement potential.

The final recommendation of this paper is to allow present trends to continue. This paper's analysis demonstrates that each of the proposed alternatives costs significantly more than the social cost of carbon while causing little reduction in the City's community transportation emissions. These results may change in the future as electric vehicles become less expensive and as the social cost of carbon increases. However, in the short term, Charlottesville's emissions reduction efforts will likely be more effective elsewhere.

Background

The City of Charlottesville's 2016 emissions inventory reported that community transportation[1] is responsible for 26.6 percent of annual GHG emissions (City of Charlottesville, 2019). When combined with the 1.7 percent of annual GHG emissions originating from municipal transport, the City's annual transportation emissions are slightly lower than the 29 percent of national GHG emissions stemming from transportation (Environmental Protection Agency, n.d.). Though the share of transportation emissions relative to total annual emissions decreased slightly since the first emissions inventory in 2000 (from 30 percent to 26.6 percent), the absolute value has declined much more rapidly, with community transportation emissions decreasing roughly 31 percent, or from about 140,000 MTCO2e to about 96,000 MTCO2e (City of Charlottesville, 2019). This reduction accounted for roughly 40 percent of the City's total emissions abatement over the same period.

Figure 1: Charlottesville's Emissions Profile



2016 Total Emissions	$MTCO_2e$
Total Stationary Energy	236,855.30
Residential	107,857.26
Commercial	97,907.25
Industrial	6.50
Other Governmental	20,641.58
Municipal	10,442.72
Total Transportation	102,274.33
Community	96,238.02
Municipal	6,036.31
Total Waste	22,997.92
Total Wastewater	64.75
TOTAL	**362,192**

Source: City of Charlottesville, 2019.

Electric Vehicles

Electric vehicles (EVs) provide a promising avenue through which to reduce community transportation emissions in the Greater Charlottesville Area. Since EVs move the power generation of the vehicle from the engine block to the traditional electric grid, EVs are able to take advantage of the greater efficiency of traditional power generation to reduce overall transportation emissions. EVs still generate what are called *well-to-wheel* emissions, which are the emissions associated with the total production chain of the electricity used to power the EV (Woo, Choi, & Ahn, 2017). The amount of well-to-wheel emissions generated by an EV is

[1] Community transportation includes all personal transportation emissions but does not include municipal transportation emissions (all vehicles owned by the City).

largely dependent on the mix of electricity generation used to power the grid where the EV charges Woo, Choi, & Ahn, 2017). As energy efficiency has improved throughout the grid and renewable power generation continues to proliferate, the grid has become progressively more decarbonized, reducing well-to-wheel emissions (Woo, Choi, & Ahn, 2017). On average in the U.S., an ICEV would have to reach 68 miles per gallon in order to emit less than an EV (Nealer, Reichmuth, & Anair, 2015). This means that, on average, EVs are over three times more efficient than the average ICEV (the average MPG of the U.S. light duty vehicle fleet was about 22 MPG in 2016) (Bureau of Transportation Statistics, n.d.). However, well-to-wheel emissions are still highly variable throughout the country, with EVs demonstrating higher emissions than high fuel efficiency ICEVs in several states throughout the Midwest (Nealer, Reichmuth, & Anair, 2015).

Virginia's electricity is primarily generated by natural gas and nuclear power, which generate about 53 percent and 31 percent of the state's electricity, respectively (U.S. Energy Information Administration, n.d.). These relatively low emissions fuels mean that the state is well-suited for electric vehicles, with most of the state sitting right around the national average, requiring a gasoline vehicle to reach 68 MPG to be emissions equivalent (U.S. Department of Energy, n.d.) In absolute terms, an average ICEV will generate 11,435 lbsCO_2e per year, while an average EV will generate 3,423 lbsCO_2e per year, making EVs about 70 percent more emissions efficient than ICEVs in Virginia (Alternative Fuels Data Center, n.d.).

As it stands, EVs are an extremely small share of total vehicles throughout the United States. At the end of 2018, there were about 1,125,000 EVs registered in the United States—or about 0.45 percent of the total 276 million registered vehicles (Hedges & Company, n.d.; Kane, 2019). The majority of American EVs are in California, where over 500,000 EVs are registered (Richardson, 2018). In comparison, the roughly 10,000 EVs in Virginia comprise only about .12 percent of the state's LDVs (Solar United Neighbors, n.d.; Virginia Department of Motor Vehicles, 2019a).

There are several factors delaying the mass adoption of EVs in the United States. First, it takes time for the existing vehicle fleet to "age out." Over time, the U.S. vehicle fleet has gotten older: in 1995, the average age of light duty vehicles in the U.S. was 8.4 years, but in 2016, it was 11.6 (Schwartz, 2018). This is in large part due to the used vehicle market in the U.S., which accounted for 40 million sales in 2018 (compared to 17.4 million new car sales in the same year) (James, 2019; Krisher, 2019) Price plays a major role in this: in 2016, the average used car cost about $15,000—or about 56 percent—less than the average new car (Carrns, 2016; Edmunds, 2017). EVs have limited penetration into the used vehicle market both due to the young age of the technology (meaning there are fewer EVs to be sold on used markets) and the rapid depreciation of value compared to gasoline vehicles (which incentivizes EV owners to keep their vehicles rather than selling them) (Montoya, 2018).

Price is also a major mitigating factor in EV adoption: in 2019, the average EV cost $55,600, or about $20,000 more than new gasoline vehicles (Coren, 2019). Several states and the federal government provide tax incentives to help offset this price difference and encourage EV adoption. California, for example, scales their tax rebates based off of gross annual income (California Air Resources Board, n.d.). Meanwhile, the federal government provides a $2,500-7,500 tax credit for the purchase of qualifying vehicles under the Qualified Plug-in Electric Drive Motor Vehicle Tax Credit (Internal Revenue Service, 2019). Virginia offers no such incentives (EnergySage, 2019).

Electric Vehicle Subsidies

Subsidies, usually in the form of a tax credit, are the most common EV adoption incentive in the United States. These subsidies exist on the state and federal levels, though the primary federal subsidy, the Qualified Plug-In Electric Vehicle Credit, is beginning to expire for the largest EV producers in the U.S. (Shepardson, 2019). California, which accounts for 40 percent of U.S. and 10 percent of global EV sales, maintains the largest suite of EV subsidies in the U.S. (Muehlegger & Rapson, 2018).

The literature on the efficacy of EV subsidy programs is mixed. Earlier research into subsidies for hybrid vehicles estimated that a $1000 federal tax incentive was associated with a 31 to 38 percent increase in hybrid vehicle purchases (Chandra, Gulati, & Kandlikar, 2010; Gallagher & Muehlegger, 2011). Newer research claims these numbers represent the purchasing behaviors of high-income households, who were more likely to be early adopters of the technology (Muehlegger & Rapson, 2018). More recent research into Californian subsidies suggests that while subsidies still increase EV adoption in low- and middle-income households, the effects are far less pronounced; for low- and middle-income households, a one percent reduction in EV purchase price results in a 3.9 percent increase in demand for EVs (Muehlegger & Rapson, 2018).

Some research has been more bearish on subsidies. In 2012, the Congressional Budget Office estimated that 70 percent of EV purchases would have occurred even if federal subsidies had not been implemented, while later research in 2017 estimated that, at most, 40 percent of EV purchases between 2011 and 2013 could be attributed to subsidies (Congressional Budget Office, 2012; Li, Tong, Xing, & Zhou, 2017). This same CBO study suggests that the cost of abating one ton of CO_2 emissions through EV subsidies is far greater than the social costs associated with that same ton of carbon (Congressional Budget Office, 2012). Other research has indicated that the people most likely to purchase EVs are more likely to be using low-carbon transport methods already, reducing the emissions abatement potential of EV subsidies (Rudolph, 2016).

EV subsidies also generates equity concerns. Research from 2015 suggests that almost 90 percent of federal EV tax credits are claimed by households with an AGI of $75,000 or more

(Borenstein & Davis, 2015). However, future subsidy programs could be means-tested like in California, thereby alleviating some of these equity concerns.

Critics also point to the massive price tag associated with EV subsidies. Current subsidy programs in California are expected to cost $2.2-2.9 billion by 2025 (Williams, 2018). Reaching the state's goal of 1.5 million EVs in California would require somewhere between $9-14 billion (Muehlegger & Rapson, 2018).

Insufficient charging infrastructure represents one of the largest stumbling blocks in EV adoption. A 2019 analysis of the largest 100 cities in the U.S. found that only 88 had installed more than 50 percent of the charging infrastructure that would be required by 2025 (Nicholas, Hall, & Lutsey, 2019). Recent research into the cost effectiveness of charging infrastructure subsidies is in short supply. While one study in 2013 determined that investing in plug-in hybrid electric vehicle batteries was more cost-effective for reducing gasoline consumption than charging infrastructure investment, it does not sufficiently address fully battery powered EVs, and predates major developments in the EV market (Peterson & Michalek, 2013). Further research into the efficiency of ongoing infrastructure subsidies in California is necessary.

EVs for Rideshares

Some researchers believe that the United States and other developed countries are at or approaching peak car usage, after which the number of miles traveled by automobile per person per year will decline (Goodman & Van Dender, 2013; Millard-Ball & Schipper, 2011; Newman & Kenworthy, 2011). It is unclear what is causing this effect, but possible explanations include urbanist revival, decaying road infrastructure, expanding public transportation, increased fuel coasts, and changing demographics (Newman & Kenworthy, 2011). Other research casts doubt on the existence of a peak car phenomenon, suggesting that the downturn in private automobile usage can be explained by traditional factors such as variations in GDP and fuel price rather than a larger cultural change (Bastian, Börjesson, & Eliasson, 2015).

If the peak car hypothesis holds true, there will be large implications for urban transportation policy. While generalized EV adoption may reduce emissions, it still maintains the other negative social costs associated with car ownership. Single occupancy vehicles (SOVs) are parked 95 percent of the time, meaning an outsized amount of downtown space is used for parking garages and other car-centric infrastructure (Klock-McCook & McIntosh, 2017). Building cities around personal vehicle-centric infrastructure, and the resulting traffic, stress, and inefficiencies, is estimated to cost American cities over $2 trillion (Klock-McCook & McIntosh, 2017). Some cities and companies have piloted subsidies aimed at Transportation Network Companies (TNC) such as Uber and Lyft in order to reduce SOV use in urban centers.

In 2016, Boulder, Colorado piloted a subsidy program in which participants received $5 off five rides into the downtown area (Klock-McCook & McIntosh, 2017). Of those individuals who participated in the program, 42 percent would have otherwise used a single occupancy vehicle (SOV) to do so (Klock-McCook & McIntosh, 2017). Estimates suggest that expanding this policy would cost 2/3rds as much as expanding parking in downtown Boulder over five years (Klock-McCook & McIntosh, 2017).

While the Boulder programs did not provide specific subsidies for rideshares using EVs, its data can be used to extrapolate the emissions abatement potential of electrifying TNC vehicle fleets. The Rocky Mountain Institute estimates that, had the subsidy program solely used EVs, 0.5 $MTCO_2e$ would have been abated (Klock-McCook & McIntosh, 2017). While this number is dwarfed by the emissions abatement potential of electrifying 20 percent of participants' annual SOV travel (which would abate 230 $MTCO_2e$), it comes at a lower cost than traditional subsidy programs—the Boulder program cost only $30,000 dollars, including marketing, and generated roughly $8000 to $15,000 dollar in sales tax revenue (by increasing the amount of trips people took to downtown) (Klock-McCook & McIntosh, 2017).

TNC fleets have characteristics that make them uniquely suited for EV usage. Maintenance costs for vehicles scale with the number of miles driven by that vehicles (ICCT, 2019). Since TNC drivers travel three to five times more miles per year than private vehicles, maintenance costs present a large portion of operating expenses, especially for older vehicles (ICCT, 2019; Li & Garrett, 2018). EVs, with their lower maintenance costs, can help to significantly reduce this expense; research suggests that fulltime TNC drivers can save $2700 per year in maintenance if they switch to an EV—enough to offset the cost premium of purchasing an EV after five years (Li & Garrett, 2018). These savings are even greater for drivers of older vehicles (model year 2007 or earlier) (Li & Garrett, 2018). Lyft and Uber have both recognized the benefits of EVs in recent years, with both companies providing premiums to drivers of EVs (Field, 2018; Lyft, 2019). If targeted properly, TNC-targeted EV adoption alleviates some equity concerns, as TNC drivers are overwhelmingly low- or middle-income (ICCT, 2019). Anecdotal evidence suggests EVs in TNC fleets could help increase EV adoption in the general public, as it exposes more consumers to EVs and overcomes some of the mental barriers preventing purchases, but further research is required to determine the validity of such claims (ICCT, 2019).

While TNCs are attractive targets for electrification, there are still significant barrier to overcome. First, TNCs like Lyft and Uber have been unprofitable since their inception, with analysts suggesting that the companies will have to increase ride prices (thereby decreasing ridership) or decrease operating costs (by cutting labor costs, such as through automation) (Business Insider Intelligence, 2016). If the latter occurs, drivers who have purchased EVs may be fired, thereby reducing the value of any EV subsidy program targeting these individuals as their driving patterns return to those of the normal consumer. Second, long charging times, especially in cities with insufficient public DC charging infrastructure, present large opportunity costs (time spent charging is time not spent driving customers), though these are expected to decrease as batteries and charging infrastructure improve (ICCT, 2019).

Accelerated Vehicle Retirement Programs

Accelerated Vehicle Retirement Programs, also called scrappage programs, are a form of subsidy in which vehicle owners are provided a rebate on the purchase of a newer vehicle when they trade in their older vehicle. The most famous of these in the U.S. is the 2009 CARS program, more commonly known as Cash for Clunkers, which dedicated $3 billion to replacing old, fuel inefficient vehicles with newer, more fuel-efficient vehicles. In total, almost 680,000 vehicles were taken off the road.

While CARS was primarily intended as a stimulus for the American auto industry in the wake of the 2008/2009 financial crisis, it also had an impact on American transportation emissions. On average, the traded-in vehicles had a fuel economy of 15.8 MPG, while the new vehicles had a fuel economy of 25 MPG (Herman, 2009).

Exact estimates of the emissions abatement potential of the federal CARS program vary greatly due to disagreements on methodology, though all put the cost of abatement at higher than the social cost of carbon (Gayer & Parker, 2013; Lenski, Keoleian, & Bolon, 2010; Li, Linn, & Spiller, 2013; Sachs, 2009).

More recently, Accelerated Vehicle Retirement Programs have been trialed as a method to increase EV and hybrid adoption in parts of California under the Clean Cars 4 All program. Research into this program is still limited, but one study into the Los Angeles area's Replace Your Ride program (a part of the larger Clean Cars 4 All program) suggests that Replace Your Ride has increased sales of electric vehicles by 44 percent, and is 1.5 times more cost effective than California's CVRP (Sheldon & Dua, 2019).

Accelerated Vehicle Retirement Programs are theoretically more equitable than EV subsidies, as low- and middle- income households are more likely to own older, fuel inefficient vehicles than high-income households (U.S. Energy Information Administration, 2018). In practice, how much more equitable they are is up for debate: analysis of the 2009 CARS program shows that participants had higher incomes than the average American (Gayer & Parker, 2013).

Alternatives

Alternative 1: Let Present Trends Continue

Alternative 1 involves allowing present trends at the local level to continue, meaning neither the City nor the County would adopt policies meant to increase EV usage.

While the share of Charlottesville's total emissions made up by transportation emissions remained more or less stagnant between the 2011 and 2016 emissions inventories (28 percent in 2011 vs 28.3 percent in 2016), emissions declined across the board (City of Charlottesville, 2019). Transportation emissions decreased 20.6 percent between 2011 and 2016, accounting for about 27 percent of the total emissions reduction over that period (City of Charlottesville, 2019). Comparatively, U.S. transportation emissions increased 4.2 percent over the same period, despite a net decrease in total emissions of 4.3 percent (Environmental Protection Agency, n.d.).[2] This suggests that the existing policy suite in Charlottesville is already making headway in reducing total emissions at well above the national rate.

Alternative 2: Electric Vehicles Subsidies

Alternative 2 would see a local subsidy program enacted to encourage the sale of EVs to residents of Charlottesville and Albemarle County, with the possibility of expansion to the Greater Charlottesville Area (including Buckingham, Fluvanna, Greene, and Nelson Counties). EV subsidies have been successful at increasing EV sales in the past, though there is disagreement on how successful they have been, as previous research may have overestimated the efficiency of subsidies on the purchasing patterns of low- and middle-income households (Muehlegger & Rapson, 2018). As the Charlottesville market is so small, changes in national or state policy could dramatically affect the outcomes of the City's policy.

Alternative 3: Rideshare Electric Vehicle Subsidies

Alternative 3 involves a targeted subsidy program enacted to encourage the adoption of EVs by transportation network companies (TNCs) such as Uber and Lyft and their drivers.

One concern with the traditional EV subsidy model is that they do not optimize emissions abatement potential per dollar spent. EV subsidies are most effective when they are used to replace the most emissions-intensive cars and/or the cars that drive the most miles (Li & Fitzgerald, 2018). Research suggests that the people most likely to purchase EVs are more likely to already be using low-carbon transport methods already, meaning that the emissions abatement potential of subsidies are reduced (Rudolph, 2016).

TNCs provide an opportunity to target vehicles with some of the highest annual mileages (Klock-McCook & McIntosh, 2017). TNC vehicles travel three to five times more miles per year than private vehicles, meaning that each TNC vehicle electrified is roughly equivalent to between three and five private vehicles electrified (ICCT, 2019). If these vehicles are owned by the operator (as opposed to the TNC), there are added equity benefits: due to the lower maintenance costs of EVs, full time TNC drivers can save approximately $2700 per year in

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[2] Due to the lack of a comprehensive emissions inventory for Virginia, it is difficult to compare Charlottesville to the rest of the state. The last emissions inventory was completed in 2007.

maintenance, which is enough to offset the cost premium of an EV after five years (Li & Fitzgerald, 2018).

Over time, TNCs have been altering their business model in certain areas, switching from individually owned and operated vehicles to more traditional fleet operations, in which the vehicles are owned by the TNC or a partner and rented out to multiple operators (Borches, 2019). Implementation is largely contingent on which model is more prevalent in the Charlottesville area. In the event that vehicles are predominantly owned by their operators, new subsidy infrastructure will have to be created as in Alternative 1. If the fleet model is more prevalent, the City will likely have to provide subsidies directly to TNCs or their partners to incentivize them to maintain larger EV fleets. Regardless, this model is likely to reduce transportation emissions faster and at a lower cost than Alternatives 1 and 2, since each vehicle converted will abate a greater amount of emissions, but the maximum reduction will be capped, as there are only so many TNC vehicles to convert.

Alternative 4: Accelerated Vehicle Retirement Program

Alternative 4 involves the implementation of a subsidy program like the federal Cash for Clunkers program, in which individuals are provided a cash rebate when trading in old, high-emitting vehicles in favor of newer, lower-emitting vehicles.

Due to fuel efficiency standards set by the federal government, the fuel efficiency of new vehicles has increased steadily since 1978 (U.S. Department of Transportation, 2014). As such, newer cars emit less CO_2 than older cars of the same type. This means that emissions abatement policies are made more efficient by targeting older vehicles rather than newer vehicles, assuming other factors like vehicle usage and vehicle type are held constant.

This alternative takes advantage of this fact by targeting the subsidy towards the City's oldest vehicles. Following the Cash for Clunkers model, dealerships in the Greater Charlottesville Area would be able to apply to participate in the program and would submit a claim for reimbursement to the City and/or operating agency after a sale is made. This alternative can provide rebates for the purchase or lease of EVs, for more fuel-efficient vehicles (excluding EVs), or for both, with EVs receiving a larger rebate.

Criteria

The four alternatives will be assessed on the following criteria: **equity, cost effectiveness,** and **net emissions reduction.**

Cost Effectiveness

This criterion will assess the emissions abatement potential of an alternative in terms of the cost per unit of CO_2 abated. The goal of any emissions-reduction alternative is to achieve the greatest reduction in emissions at the lowest possible cost. This criterion will allow a comparison of the emissions abatement potential of alternatives that may differ in scope. For example, one alternative may abate a larger amount of emissions than another, but at a higher cost per unit. This criterion will help to ensure that the city government, which has limited resources, exerts its authority in the most efficient manner possible.

This criterion will be measured in metric tons of CO_2 equivalent ($MTCO_2e$) abated per 2020 dollar spent. An important threshold in assessing this criterion is the EPA's various estimates of the social cost of carbon (which, in 2020 dollars, ranges from $14.94 to $77.18 (Environmental Protection Agency, 2016). Alternatives that abate emissions at a cost that falls below the upper end of this range will be viewed favorably.

Equity

Clean energy subsidies have traditionally been distributed very unequally throughout the population. For example, 90 percent of households claiming the federal electric vehicle tax credit have an adjusted gross income of $75,000 or more (Borenstein & Davis, 2015). It is imperative that the proposed alternative not serve to further existing distributional divides by favoring higher-income households at the expense of lower-income households.

This criterion will be measured on a scale of High, Medium, and Low, wherein "High" represents an alternative that primarily targets low- and middle income households, "Low" represents an alternative that primarily targets higher-income households, and "Medium" represents an alternative that falls somewhere in between.

Net Emissions Reduction

This criterion will assess the total emissions abatement potential of an alternative. Some of the alternatives proposed differ greatly in scale, with some having a natural limit on the amount of emissions they can abate. For example, Alternative 3, which would provide EV subsidies to rideshare drivers, has a smaller target population than Alternative 2, which would provide EV subsidies to everyone who wants them. Alternatives with a greater net emissions reduction will be preferred to those with a lower net emissions reduction. Net emissions reduction will be measured in $MTCO_2e$ abated.

In order to ensure that the emissions reductions of the different alternatives are directly comparable, this paper will provide the *total* emissions reduction of any policy. This is in contrast to the methodology used in Charlottesville's 2016 GHG inventory, which only captures transportation emissions that occur within Charlottesville (City of Charlottesville, 2019). To put this into an example, if a vehicle registered in Charlottesville were to drive to Washington, D.C., this analysis would capture all of the emissions of the journey, while the Charlottesville GHG inventory would only capture the emissions occurring from the portion of the trip taken within the City of Charlottesville. Furthermore, the emissions that are not abated will be shifted from the "community transport" category into one of the electricity generation categories.

Findings

Alternative 1: Let Present Trends Continue

Cost Effectiveness

The status quo is used as the baseline for the cost-effectiveness analysis, meaning it cannot be judged by this criterion.

Equity

The status quo is used as the baseline for equity considerations, and as such, cannot be judged by this criterion.

Net Emissions Reduction

The status quo would see no change in emissions reduction, as it is simply a continuation of existing emissions reduction policies and trends.

Alternative 2: Electric Vehicle Subsidies

Cost Effectiveness

Research suggests that EV subsidies are cost inefficient for reducing emissions. Estimates vary greatly due to differing methodology, ranging between $338 and $1352.01 (Gillingham & Stock, 2018; Congressional Budget Office, 2012). The lower end of this range is greater than the upper end of the range of the social cost of carbon, meaning this policy alternative is likely to be cost inefficient.

Using the estimate calculated in the net emissions reduction section below (which is likely to be highly inaccurate), applying a $5000 EV subsidy in Charlottesville would cost $1363.64 per MT$CO_2$e abated.

Equity

Electric vehicle subsidies are highly inequitable. Research from 2015 suggests that 90 percent of Qualified Plug-in Electric Drive Motor Vehicle Credits (QPEDMV credits) have gone to households with adjusted gross incomes of $75,000 or more (Borenstein & Davis, 2015). California is currently attempting to improve this rate in their Clean Vehicle Rebate Project (CVRP), which provides larger rebates to low- and middle-income households. Between 1 November 2016 (when the means testing regime entered its current form) and 3 February 2020, 8.9 percent of CVRP spending on individuals[3] has gone to households making below 300 percent of the federal poverty line (FPL) (Center for Sustainable Energy, 2020). This is not perfectly

[3] The CVRP also provides rebates to businesses, government entities, and nonprofits, among a few other entities.

analogous to the QPEDMV credit, as the CVRP has a maximum income restriction[4] while the QPEDMV credit does not, and the FPL shifts based on household size. Assuming that the average household size in California is three persons,[5] this means 8.9 percent of CVRP spending on individuals has gone to households with an AGI of $65,500 or less. When limited to plug-in battery electric vehicles (the type of vehicle covered under the QPEDMV), this share drops to 7.5 percent (Center for Sustainable Energy, 2020).

Net Emissions Reduction

One issue in measuring the net emissions reduction of EV subsidies is that people who purchase an EV, regardless of whether there are subsidies, are likely to already be taking measures to reduce their transportation emissions. EV buyers are more likely to use non-auto modes (biking, walking, mass transit) or own fuel efficient or hybrid vehicles (Rudolph, 2016). Many would also purchase an EV without the introduction of subsidies, with estimates ranging from 40 percent to 70 percent (Congressional Budget Office, 2012; Li, Tong, Xing, & Zhou, 2017).

Research suggests that in California (the largest EV market in the U.S.) for every 1 percent reduction in EV price, demand for EVs increases by 3.9 percent (Muehlegger & Rapson, 2018). Assuming this elasticity holds true for Charlottesville and that the demand curve for EVs is linear, we would expect a $5000 subsidy to achieve an additional 21 EVs in Charlottesville. Assuming these EVs are replacing average fuel efficiency vehicles that travel an average number of miles per year, **electrifying these 21 vehicles would abate 77 MTCO$_2$e per year** (Federal Highway Administration, 2018; U.S. Energy Information Administration, 2014). This estimate likely overstates the emissions abatement potential per vehicle replaced due to the research discussed above. Furthermore, this estimate assumes that statistics from the EV market in California—a developed EV market with hundreds of thousands of EVs on the road—can be directly compared to the EV market in Virginia (which has roughly 10,000 EVs on the road) and Charlottesville (which had 46 EVs registered in the city in 2018) (Solar United Neighbors, n.d.; Virginia Department of Motor Vehicles, 2019).

Alternative 3: Rideshare Electric Vehicle Subsidies

Cost Effectiveness

The cost effectiveness of Alternative 3 is difficult to assess. To my knowledge, Charlottesville would be the first locality in the country to attempt a program like this, meaning that there are no programs to use as a comparison. As such, there is simply no data to pull from to estimate the cost effectiveness of this program.

[4] The maximum income restriction is based off tax filing status. For more information, please refer to the CVRP website.

[5] According to the 2010 census, the average Californian household size was 2.9 persons, but FPL can only account for whole persons.

TNC drivers drive three times more miles per year than the average individual, meaning that electrifying a TNC vehicle electrifies three times miles than electrifying a non-TNC vehicle (Federal Highway Administration, 2018; Li & Fitzgerald, 2018). Assuming a $5000 subsidy specifically for TNC drivers has the same effects as the generalized subsidy (which is a large assumption, as TNC drivers tend to have significantly lower incomes than traditional EV buyers), we would expect to see this alternative be three times more cost efficient than Alternative 1, or $454.55 per $MTCO_2e$ abated. However, this number is extremely fuzzy. If the City decides to pursue this alternative, it is highly recommended that they launch a pilot program first in order to obtain a better cost effectiveness estimate.

Equity

This alternative would have positive equity ramifications, as the subsidy targets a predominantly low- to middle-income group. According to revealed driver salaries on Indeed.com, the average Uber driver makes roughly $30,000 per year, placing them below the national median personal income ($33,706 in 2018), and well below the $75,000 AGI threshold that has traditionally received the bulk of federal EV subsidies (Federal Reserve Bank of St. Louis, n.d.; "Uber Driver Yearly…"). Electrifying TNC vehicles is also expected to lower operating costs for drivers, thereby increasing their take home pay (Federal Highway Administration, 2018; Li & Fitzgerald, 2018).

Net Emissions Reduction

This is the most difficult alternative to provide an accurate estimate of emissions reduction for, as the net emissions reduction is heavily dependent on the number of rideshare drivers in Charlottesville (which is not publicly available information) and the uptake of the subsidy program among these drivers (which will be less than perfect, as some drivers will choose not to purchase an EV even with a subsidy being made available). In lieu of providing an emissions abatement estimate for the alternative as a whole, I have instead elected to provide a breakdown of the potential emissions abatement per TNC vehicle converted.

The average TNC driver drives three times more miles per year than the average American, or 40,428 miles per year (Federal Highway Administration, 2018; Li & Fitzgerald, 2018). Assuming that TNC vehicles have average fuel efficiency (22.3 MPG in 2017) and that these vehicles are being replaced with EVs with an average fuel efficiency of 65 MPG (the national average), this would mean that every TNC vehicle electrified would abate roughly 10.25 $MTCO_2e$.

Alternative 4: Accelerated Vehicle Retirement Program

Cost Effectiveness

Research from the 2009 CARS program suggests that vehicle scrappage programs are less cost efficient than programs like carbon taxes and cap-and-trade but are on par or more cost efficient than programs like EV tax subsidies. Estimates of the precise cost per $MTCO_2e$ abated vary greatly due to differing estimates of the total emissions abatement of scrappage policies (see below for a more in-depth discussion of net emissions reduction estimates).[6] Cost effectiveness estimates for the 2009 policy range from $127.81 to $822.10 per MTCO$_2$e abated (Gayer & Parker, 2013; Lenski, Keoleian, & Bolon, 2010; Li, Linn, & Spiller, 2013; Sachs, 2009). All estimates of the cost effectiveness of the 2009 CARS program indicate that the program was **not** cost effective. There is no reason to suspect that a similar program implemented in Charlottesville would experience different outcomes.

Using the estimate below, this program would cost between $1599.52 and $9602.88 per MTCO$_2$e abated. Both the upper and lower bounds are outside of the upper range of the social cost of carbon, making them cost inefficient.

Equity

This alternative has an equity rating of "medium." Low income households account for a disproportionate share of the older, fuel inefficient vehicle fleet in the United States, meaning that low income households are more likely to qualify for a rebate program than middle- or high-income households (U.S. Energy Information Administration, 2018). However, data from the federal CARS program in 2009 suggests that this increased eligibility does not necessarily translate to increased uptake. On average, participants in the 2009 CARS program had higher incomes than the average American and non-participant Americans purchasing new or used vehicles but had lower incomes than non-participant Americans purchasing new vehicles (Gayer & Parker, 2013). There is no reason to suspect that this pattern would be different in Charlottesville.

Net Emissions Reduction

There is significant debate over the net emissions reduction of the 2009 CARS program, owing to different approaches to estimating the quantity of emissions abated by the program. Estimates on the upper end of the spectrum tend to account only for the direct emissions abatement of the program—that is, the gasoline that was not used as a result of increased fleet efficiency. Studies that fall on the lower end of the spectrum criticize this method, as it ignores the indirect emissions generated through the program through the premature production and disposal of vehicles (Lenski et al., 2010). Estimates of the program's emissions reductions range from 4.4 million to 28.2 million MTCO$_2$e, or about 0.4 percent to 2.4 percent of light duty vehicle emissions in 2010 (Lenski et al., 2010; Li et al., 2013; U.S. Environmental Protection Agency, 2015).

Extrapolating these trends to Charlottesville, we would expect to see an emissions reduction of about **55.4 to 332.6 MTCO$_2$e**—roughly a 0.06 to 0.3 percent reduction in community transportation emissions per $532,000 spent.

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[6] The 2009 CARS program cost $3 billion 2009 dollars (~$3.62 billion in 2020 dollars), so any variance in cost effectiveness comes from differing estimates in emissions reduction, not from differing estimates in cost.

Recommendation

At this point in time, the status quo is the most sensible option. None of the proposed alternatives significantly impact transportation emissions in Charlottesville, and the cost of any of the proposed interventions is significantly higher than the social cost of carbon ($14.94 to $77.18). Charlottesville's efforts would be better spent working to convince the state or federal government to implement larger-scale policies to reduce transportation emissions, or in targeting other sources of emissions in the City such as electricity generation.

Decision Matrix

Criterion	Status Quo	EV Subsidies	Rideshare EVs	Cash 4 Clunkers
Cost Effectiveness	N/a	$1363.64 per $MTCO_2e$ abated	???	$1599.52 to $9602.88 per $MTCO_2e$
Equity	N/a	Low	High	Medium
Net Emissions Reduction	N/a	21 to 77 $MTCO_2e$	10.25 $MTCO_2e$ per vehicle	55.4 to 332.6 $MTCO_2e$

Implementation

Stakeholders

Fortunately, Charlottesville does not need to engage any stakeholders in order to maintain the status quo, and no additional actions are strictly necessary to proceed with this policy alternative. However, there are significant stakeholders in the Charlottesville community that will likely take issue with the city government's inaction on reducing transportation emissions, including nonprofit groups like the Community Climate Collaborative. Other stakeholders, such as dealerships in the area and EV manufacturers, will also be impacted by the City's decision not to provide consumers rebates as proposed in Alternatives 2 (EV subsidies) and 4 (Cash for Clunkers). For both of these groups, it is unlikely that these stakeholders will resist the continuation of the status quo, as they are not necessarily *losing* anything. EV manufacturers in particular are unlikely to take any sort of action, as Charlottesville is simply too small of a market for this decision to meaningfully impact their sales.

It will be important for the City to publicize their continued commitment to the city's climate goals (45 percent reduction in 2011 emissions by 2030, net zero emissions by 2050). Inaction on this issue at the city level does not preclude action on other issues, such as Charlottesville's power supply, energy efficiency, and municipal transportation emissions. Similarly, it does not preclude action at the state or federal level (which would likely be more cost efficient), which Charlottesville can advocate for.

Worst Case Scenario

In the event that the City is unable to maintain the trust of environmental nonprofits within the city, these nonprofits and other affiliated groups may take steps to back candidates that are perceived as more environmentally forward-thinking during the 2021 and 2023 City Council elections. There is some chance that the owners of EV dealerships in the area may join in this effort as well. Both scenarios are unlikely due to the limited resources of both groups and the ongoing commitment to reducing city emissions in other sectors and through other programs.

It is also possible that any one of these policies may be the difference between meeting the City's emissions reduction goals and missing them. There is no monetary or legal cost associated with missing these goals—the City set them itself, and there is no enforcement mechanism associated with them—but it would cause some damage to the City's reputation, and call into doubt the City's ability to meet other commitments. This scenario is highly unlikely due to the very small emissions reduction that was predicted for any of the policy alternatives (0.3 percent reduction in personal transportation emissions in the best-case scenario—or about 0.0009 percent of the City's total emissions in 2016).

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