A Road Forward for Electric Vehicles in the Public Sphere

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Introduction and Methods

To meet the challenge of global climate change and stave off catastrophic warming, the United States will have to reduce and eventually eliminate emissions of greenhouse gasses. The United States is the world's top consumer of fossil fuels per capita, and has one of the largest populations of any country, but lags behind other states in doing its share to prevent the climate crisis. This is only possible through a massive rewriring of several sectors of the economy. The scope of this challenge has not been lost on the science and environmental policy spheres, where pathways to eliminating emissions have become a much discussed topic. This area of study is often termed “deep decarbonization:” a reduction in emissions across sectors of the economy, with an emphasis on their interconnection.

By and large, however, pathways to deep decarbonization have remained elusive for policymakers concerned about climate change, due to technological limitations. Lawmaker attention has focused primarily on decarbonization of the electrical sector through investment in clean energy and policies such as renewable energy portfolio standards. The business sector has focused on energy efficiency, with major innovations in more efficient appliances and building methods. Both of these are important in developing deep decarbonization pathways, but leave substantial portions of the economy untouched. Only forty percent of United States carbon emissions come from the electrical grid; the majority come from various sources of direct fossil fuel combustion, such as cars. (Williams et al. 2014). Emissions from the transportation sector have outpaced those from the energy sector (Energy Information Administration 2017), making transportation the biggest national contributor to climate change.

Meanwhile, many nonprofits and grassroots groups have found success in supply-side atacks on carbon emissions, by blocking new carbon-based energy infrastructure through a combination of direct action and legal intervention. While this strategy has had some notable successes, it has been vulnerable to criticism that its proponents lack a plan to fully transition away from fossil fuels. This, too, requires a greater complement in advancing more sustainable industrial models.

One major method proposed to fill this gap is the electrification of the transportation sector. Transportation combustion generates 35% of carbon emissions, but few clear alternatives are available (Williams et al. 2014). Advances in vehicle efficiency and numerous pushes for urban density and multimodal transit have not prevented the sector's emissions from rising by about 10% in the past five years (Energy Information Administration 2017). The most feasible solution to the transportation problem– and the only truly complete one– is a gradual shift from internal gasoline combustion to battery-powered vehicles charging on an increasingly clean grid.

Electrification for climate purposes also has significant co-benefits to society. Full electrification could insulate the economy from price shocks due to oil and reduce transportation noise. But more important are the human health benefits of reducing criteria pollutants. In densely populated areas, pollutants such as nitrogen oxides, sulfur dioxide, and particulate matter contribute to increased mortality and rates of respiratory disorders and heart disease. This has attracted the attention of health advocates, such as the American Lung Association, whose financial cost-benefit calculations (Holmes-Gen and Barrett 2016) suggest that the the health benefits of pollutant reductions could have a social value almost twice as large as the climate benefits.

The case for vehicle electrification is particularly strong in Minnesota. Policymakers have worked to reduce the state's contribution to climate change, but it has not advanced as planned. The state fell short of its 2015 greenhouse gas reduction goal (15% reduction from 2005 levels) by approximately twenty million tonnes, and a path to the 2025 goal, a 30% reduction in greenhouse gases, is even further out of sight (Minnesota Pollution Control Agency, 2014). However, the state's electricity mix is clean in comparison to many other states, and becoming still cleaner, thanks to robust renewable energy portfolio standards. Electrification of transportation would compound the carbon reductions from these standards while substantially reducing other forms of pollution.

While electrification is by far the least intrusive method for decarbonizing transportation, it still poses an enormous challenge. Like such a change in any sector, transportation electrification requires substantial change in both consumer technologies and infrastructure. Engines must be replaced with batteries, and refueling stations with charging stations, without either becoming an enormous cost burden, especially to private actors. Such a change also has to happen in a coordinated and decisive way across levels of government, ideally incorporating private actors. Looking at the scale of such a challenge and the variety of policy options available, it is easy to embark on an unproductive course of action, or become intimidated and avoid taking action whatsoever.

This paper will provide two forms of assistance for policymakers considering whether and how to move forward with transportation electrification. After a section providing the technical background, the first part of the paper will summarize the literature on the benefits of electrification and turn them into a model that can determine the overall social benefits of pro-electrification policies under various assumptions. The second part summarizes the policies currently being explored and implemented and makes recommendations for advancing socially just electrification policies at different levels of Minnesota government.

Background

An electric car (EV) is a vehicle powered by battery-stored electricity, in contrast to the typical internal-combustion vehicle (ICV), which runs on gasoline energy produced inside the car. Technically, the term “electric car” can refer to vehicles which are powered in part by electricity, such as hybrid vehicles, which store wasted energy from braking in a battery to substitute for some of the car's gas consumption. However, for the purposes of this paper, an electric vehicle should be defined as one which gets most or all of its energy from electricity, usually delivered through a plug.

This includes battery electric vehicles (BEVs), which run entirely on electrical charge, and plug-in hybrid electric vehicles (PHEVs), which have a gasoline motor, but only as a backup, for inclement weather and other extreme cases. Some policies use the broader term “zero-emission vehicles” (ZEVs), referring to any vehicles which produce no tailpipe emissions. This includes BEVs as well as potential alternatives to gasoline or electric vehicle development, which are largely undeveloped, but could in the future fall into the same regulatory framework.

For decades, the principle of an electric car was well out of reach, due to the high cost of batteries and, later, the opposition of industries. General Motors' first attempt at a mass-produced electric car, the 1996 EV1, was a clear failure, leading to skepticism about the industry and blame-laying from advocates. (See the 2006 documentary, *Who Killed the Electric Car?,* for an in-depth example.) But over the past decade, developments in battery technology have drastically lowered the cost of electric vehicles. Their existence and potential for mass adoption is seen as a way to combat climate change and pollution while insulating consumers from gasoline price shocks and generating energy independence.

The biggest changes have come in the cost of batteries, which used to impose an enormous cost per kWh on electric vehicles. This cost has fallen by four-fifths this decade alone – from about $1,000/kWh in 2010 to just over $200 in 2017. EVs are already lower in lifetime cost than some variants of diesel vehicles, because of the lower fuel and maintenance costs. The upfront costs are currently higher, sometimes by as much as $10,000, but experts predict parity in this respect as well, as soon as 2025 (Bloomberg New Energy Finance, 2018).

Governments see the possibility for reductions in carbon and other pollutants without direct challenge to entrenched transportation patterns and industries, and have seized upon the change. The United States has offered generous subsidies to the sale of new ZEVs, and many states have added subsidies of their own. California's Air Resources Board has adopted a policy known as the ZEV mandate, an addendum to the state's vehicle mileage standards which requires the production of a certain number of zero-emission vehicles. nine other states have signed on to the standards as well, becoming "ZEV States." But all of this is minor relative to changes happening overseas: Europe's stringent carbon standards have driven a rapid shift towards electrification (Vaughan 2017), and China's investments in electric public transit have already reduced gasoline demand by as much as the entire nation of Greece (Hodges 2018).

Industry has responded accordingly to the technological and policy shifts with bold goals to advance electric vehicles. General Motors has spoken about a "zero-emission future" and plans to introduce twenty electric models over the next five years. Not to be outdone, VW has promised thirty electric models, and Ford forty. Volvo has gone the furthest, pledging in 2017 that all of its new cars would be electric in only two years (Griffith 2018). These developments, if followed through, can make electric vehicles as accessible as internal-combustion vehicles, and shift individual and corporate vehicle use away from fossil fuels.

However, there are substantial challenges in achieving these full benefits. There is considerable debate over whether and when American electrical grids are actually lower-carbon than gasoline. While some of this debate is based on questionable interpretations of data, there are enormous differences in the carbon intensity of electricity in various parts of the country, meaning that electrification has varying benefits – which, on some grids, may not outweigh costs. For example, charging an EV in coal-dependent Kentucky will not provide the carbon savings that one could find in pro-renewables California.

Beyond this, there are substantial infrastructural hurdles to mass adoption. The high upfront cost of the vehicles must be managed to allow customers to reap the benefits of the vehicles. Electric vehicles need adequate charging station availability in order to match the wide availability of gasoline fueling stations for internal-combustion vehicles.

Businesses are moving rapidly towards electrification, but business can only go so far in creating industry-wide change. The public sector must be engaged in making electrification possible quickly and on a mass scale; maximizing its climate benefits; and ensuring social and economic justice in the process and outcomes. To this end, there has been an explosion in literature and policy discussion about how the public sector can fulfill this role. The next section will explore and discuss the literature indicating electrification's social value.

Literature Review

The Great Plains Institute, an environmental think-tank, has taken an interest in electrification, due to the potential for progress on decarbonization of the transportation sector. Their Minnesota partnership table, Drive Electric Minnesota, has conducted state-specific research on the potential impacts of EVs. Drive Electric has computed that, given Minnesota's electrical and gasoline input mix, EVs produce about 70% less carbon emissions per mile driven, and that this number will rise as the state's clean energy standards increase (McFarlane 2017). The exact number varies based on what utility the car is being charged on, with slightly better outcomes in Xcel Energy's territory, given their investment in clean energy, and slightly weaker outcomes in the greater MISO region. As described in the introduction, this positions electrification as a key component of a deep decarbonization plan that prevents or limits the catastrophe of global climate change.

The American Lung Association has also taken a keen interest in EVs, although they typically use the broader category of ZEVs in their research. The ALA's report indicates that the health impacts of gasoline are substantially larger than the climate impacts: a sixteen-gallon tank of gas generates $11.82 in health costs and $6.55 in climate costs (Holmes-Gen and Barret 2016). Health benefits come from reductions in morbidity, hospitalizations, heart attacks, lost work days, and asthma attacks. All of these are traced back to contaminants from air pollution, namely those designated “criteria pollutants” under the National Ambient Air Quality Standards.

Other research on the social cost of atmospheric carbon indicates that the ALA may be understating the climate cost of gasoline use. Pollution costs are never particularly easy to model. Local pollutants change in social cost based on the location of release and the health of those around them. Climate change costs can vary drastically with different discounting rates, and some of the costs imposed by climate change are triggered at a certain threshold of pollution, not gradually as pollution is released. However, Shindell (2015) provides a well-thought-through model that does passably well at managing pollution.

While the ALA puts the emissions from one gallon of gasoline at $1.15, most of which is health cost, Shindell pegs the social costs as $3.80 per gallon of gasoline and $4.80 per gallon of diesel, using a 3% discount rate. Even this is a conservative approach: when considering the catastrophic scope of climate change, a low discount rate, perhaps only matching inflation/economic growth, would be more conducive to intergenerational equity.

A white paper from Energy Innovation, using data from the Union of Concerned Scientists, finds that the average electric vehicle on today's road has per-mile greenhouse gas emissions comparable to a gasoline car getting 80 miles per gallon (Maracci 2018). This varies widely between grids: an EV ar in New York state is comparable to a 191-mpg car, while an EV in eastern Wisconsin could be replaced by a 38 mpg vehicle. Minnesota's grid (MRO-West) has one of the lower comparison levels, at only 51 mpg, due likely to the high rates of fossil fuel use in the Dakotas, Iowa, and Nebraska.

While the benefits of electric vehicles come primarily from pollution reductions, some have suggested other co-benefits. For example, electric vehicles have the potential to generate improvements in livability through the reduction of traffic noise. While no good data exists on the per-car health externalities of noise, the issue of noise pollution more broadly has been found to have substantial impacts on human well-being. A report by the World Health Organization, commissioned by the European Union, found that traffic noise "should be considered not only as a cause of nuisance but also a concern for public health and environmental health," blaming it for cardiovascular disease, sleep disturbance, childhood cognitive impairment, tinnitus, and general annoyance (Fritschi et al 2011).

Because of the lack of an engine, an electric vehicle will naturally produce no noise. However, a 2016 decision by the US Department of Transportation required that EVs produce some noise at low speeds, to alert pedestrians and others to their presence on the road. It is therefore not known to what degree electric vehicles could reduce traffic noise. A projection of the benefits of this reduction would also have to account for existing noise reduction projects and programs, the extent of which are not known.

Not all research has been as glowing about the benefits of electrification. A recent report from the Manhattan Institute made headlines with its declaration that electric vehicles are worse for the environment than conventional combustion vehicles. The study itself (Lesser 2018) calculated that the carbon savings from vehicle electrification are minimal, while the pollution from the electricity emitted would actually be substantially greater than the pollution from internal-combustion.

Interestingly, Lesser's computed ratio of carbon emissions from EV to ICV is similar to that used in the GPI study, at approximately 1:3. Therefore, the potential savings, and potential “wedge” progress towards solving climate change, are the same as in reports by EV optimists. Where their analyses differ is in the assumptions about the use of the wedge. Lesser uses projections of EV adoption by the Energy Information Administration (EIA), which see them becoming only about 5% of the market, making a miniscule impact on climate change.

The EIA's sales projection does not anticipate the considerable possibilities for greater adoption should governments decide to act in favor of EVs. It therefore tells us very little about the potential for the use of EVs as a wedge, and should be seen more as a business-as-usual (BAU) scenario against which we can measure policies to encourage or require greater EV adoption. Secondly, even among business-as-usual projections of EV adoption, the EIA is well on the conservative end. The Energy Policy Simulator's BAU projection predicts that EVs will make up over 60% of light-duty vehicles before 2040; projections by Bloomberg New Energy Finance (BNEF) concur (Maracci 2018).

As for the pollution statistic, it is certainly true that the “zero” in “zero-emission vehicle” refers only to tailpipe pollution, and that electricity generated to power an electric vehicle generates pollution of its own. But Lesser's research only gives the quantity of major air pollutants (NOx and SO2) without calculating the social cost. Most power plants, especially emissions-heavy coal plants, are located outside of population centers, and do not accumulate in the same way. Cars, on the other hand, are by their nature near people, creating greater buildups of pollution in population centers. Thus, the actual health cost of the energy emitted may be lower.

The National Bureau of Economic Research authored another piece critical of ZEV benefits which modeled the impacts of emissions from electric and conventional vehicles based on the expected location of release (Holland et al. 2015). Their model shows that the benefits of electric vehicles range, county-by-county, from modest to negative. This paper also received considerable media attention for its findings about the environmental consequences of electric vehicles.

However, this paper also has some questionable methodological choices. The model for damages from pollution does not consider climate damages whatsoever, only local damages to air quality. For the things they do calculate, it is not clear where the values placed on damages come from, and their measures of health are much lower than those from the lung health experts at the American Lung Association. The decision to model electricity use based on the efficiency of entire regional grids is also questionable, as electricity cleanliness standards vary from state to state. But even then, other research using regional grids to determine carbon intensity find consistent pollution benefits from electrification (Maracci 2018). The general consensus among the scientific community is that electric vehicles provide a range of positive pollution benefits, depending on location.

Benefits of Electrification Projects

The benefits of electrification can be modeled with relative ease using assumptions about a pro-electrification policy and the social cost of atmospheric release. To assist policymakers towards this end, we created a modeling spreadsheet that includes the necessary costs and assumptions.

This model exists in two forms. The first allows a complete cost-benefit analysis, which quantifies the social and private costs and benefits in financial terms in order to determine whether a policy or outcome is a net social benefit or cost. This requires the inputting of a greater number of parameters or assumptions.

The second is a common technique in climate policy known as wedge analysis. Developed by Pacala & Socolow (2004), wedge analysis explores how different policies or technologies reduce the percentage of greenhouse gases used in order to reach certain reduction targets. The resulting data allows us to visualize mitigation tactics as removing a certain percentage, or "wedge," of progress. While this provides a less complete picture of impact than a full cost-benefit analysis, it has the benefit of providing a clear focus, which in this case is the eventual necessity of industrial decarbonization. This is useful in complying with governmental or private greenhouse gas (GHG) reduction goals, and allows for cost-effectiveness analysis when compared with other "wedges."

Cost-Benefit Analysis

A cost-benefit analysis requires that we place dollar values on all costs and benefits, both public and private, for the policy in question. Social costs and benefits come primarily from the atmospheric releases from fuel sources. One useful way to quantify these is the social cost of atmospheric release, or SCAR, a measure developed by Duke economist Drew Shindell. This model calculates the social costs of different fuels based on the health and climate impacts of their emissions.

The social benefits of EVs come from avoided combustion emissions: on average, \$3.80 per gallon of gasoline, and \$4.80 per gallon of diesel (Shindell 2015). Social costs come from the electricity production required in its place: about \$0.30 for coal energy and \$0.15 for natural gas energy (ibid.). It is assumed here, that there is no major social cost associated with renewable energy. No infrastructure is truly without social cost, as it by its nature disrupts natural and wildlife patterns and causes some distress for nearby residents. But the intrusiveness of renewable energy infrastructure is minimal compared to that of fossil fuel extraction and refinement, and there is no marginal social cost to the production of renewable energy.

To determine the net social benefit of the shift in energy sources, a policymaker must know: the quantity of gasoline and diesel that will shift their energy source relative to the business-as-usual scenario (without a program's adoption), the miles per gallon each vehicle gets, and the average mileage per vehicle replaced. The same statistics are required for the new vehicles being purchased.

Policymakers must also know the electrical mix being used to charge electric vehicles. The coal-intensity of said electrical mix can dampen or even erase the benefits of electrification. In the Twin Cities-area territory of Xcel Energy, the projected mix in the middle of the next decade will be 28% nuclear, 26% wind, 24% coal, 11% gas, and small amounts of solar, hydro, and biomass (McFarlane 2017). This trends towards compliance with Minnesota's renewable portfolio standard of 30% clean energy by 2030, and serves as a good average for electrical policies moving forward in the coming decade. The broader Midcontinent Independent System Operator (MISO) North Region, which powers many smaller providers in Greater Minnesota, projects a dirtier mix – 48% coal, 28% wind, 14% nuclear, 8% natural gas, and 2% solar (ibid.). Electric vehicles operating in this service area will be considerably more carbon intensive.

Electrification policies may produce private costs, coming from the cost premium of purchasing and maintaining electric vehicles over internal-combustion vehicles. Even if the upfront cost of vehicles can be paid for with savings from vehicles down the line, the cost of and interest rate on the capital required for this mandates consideration. A purchasing policy will have to determine the premium of zero-emission over internal combustion vehicles and the quantity being replaced. A public subsidy or mandate would have to calculate the number of vehicles subsidized, and the cost thereof. Note that with a public subsidy or mandate, the quantity of vehicles subsidized is not the same as the quantity of EVs purchased due to the policy; some EVs would have been purchased without the subsidy as well.

Large-scale changes in vehicle fuel sources will require transitions in charger availability, which must be accounted for as well. The cost of charging infrastructure can be substantial enough that many policies which rapidly increase electrification may produce no net social benefit for several years, until the appropriate infrastructure has been scaled up. Policymakers should determine the cost of electric chargers and quantity thereof.

A typical Level 2 (240V) charging station costs a homeowner about $1,200 to own and install, with nearly half of the cost coming from installation labor. That number rises to $5,500 for a semi-public station (i.e. in a parking garage) or over $9,000 for a public curbside station (Agenbroad 2014). And level 2 chargers only provide around 10-20 miles of range per hour of charge for a typical passenger vehicle. To achieve charging speeds comparable to internal-combustion vehicles, one would need to use direct-current "fast chargers," which can cost nearly $60,000 to install (ibid.). These costs can all fall substantially if installed in groups, but the orders of magnitude remain the same.

All of these numbers, in tandem, allow for a strong estimate of the social and private costs and benefits incurred from a transition to electric vehicles. Certain benefits, such as noise reductions, are not certain enough to be quantifiable, and are thus not part of a cost-benefit analysis. A CBA also fails to account for the distribution of these costs and benefits throughout society, and thus, the equity implications of electrification policies. These both deserve consideration from policymakers alongside simple net benefit numbers.

In this model, the social costs of atmospheric release comes with a built-in discount rate, and no discount rate should be applied to electrical charging equipment, assuming those costs are paid upfront. The only discount rate in consideration should be when determining the cost premium for electric vehicles (C), as this requires balancing short-term costs over long-term benefits. If the money could otherwise be invested at a substantial premium, or a high interest rate would be applied to the money invested in vehicles, then this should be considered when deciding on the premium applied to electric vehicle purchases.

A cost-benefit figure is simple to calculate once the assumptions are determined. For example, imagine that a transit operator with a fleet of 500 diesel buses was considering electrification plans. The current buses get 3mpg and run 250,000 lifetime miles; the replacements run the same lifetime distance at 0.5 kWh. The electricity used is 24% coal-based and 11% gas based. In addition, each of the five hundred buses costs $10,000 in lifetime interest, and requires the installation of two high-voltage chargers, each costing $50,000. Under these parameters, and using the assumptions given, the net social benefit of electrifying this bus fleet is about $123 million: $200 million in social benefit, minus $22 million in social cost and $55 million in implementation cost of the alternative. Furthermore, this is only the benefit of the transition, over one cycle of vehicle turnover; future cycles would have even greater benefit, as the grid will likely become cleaner, and the charging infrastructure will already be installed.

Wedge Model

To determine progress, policymakers may adapt a formula developed by Ramaswami et al (2012). Their basic method for GHG mitigation impact is:

GHG Reduction % = (% Effectiveness/Unit) * (Participation Rate)

Effectiveness per unit depends on the service territory and dates in question. For agencies operating in Xcel Energy's core territory in the Twin Cities, the calculations are relatively simple. According to research by the Great Plains Institute, over the next decade, electric vehicle charging in Xcel's service territory will emit 133 gallons of CO_2 equivalent per mile, compared to 465 gallons for a gasoline vehicle (McFarlane 2017). This is only 28.6% of the emissions that would be emitted by a gasoline vehicle, meaning a 71.4% reduction in emissions. However, within the broader MISO-North territory, the carbon comparison is much worse – 218 gallons CO_2 equivalent, meaning a reduction only 54% (ibid), with no certainty of a cleaner portfolio anytime in the near future.

Beyond 2030, the carbon emissions from Minnesota's electrical providers are yet to be the determined. An increased renewable portfolio standard, which gives the state an eventual goal of 80% or 100% renewable energy, would provide more ability to forecast. For the time being, different models could use different assumptions for clean energy use, or simply calculate the potential for decarbonization if vehicles were entirely powered by clean energy.

The participation rate depends on the vehicle turnover for the fleet in question, with respect to time. For commercially or publicly managed fleets, this is relatively easy. For example, Metro Transit's bus fleet turns over almost completely over a twelve-year period. Mass consumer behavior requires more consideration. For light duty vehicles, most recent statistics, from 2014, show that new vehicles make up about 7% of the national fleet, with an average vehicle age of 11.4 years (USDOT). As the average vehicle age has been increasing by about 1.5 years per decade, even a 50% fleet overhaul, beginning today, would take at least 13 years (R.L. Polk & Co, 2015). Therefore, for wide-scale changes to the entire light-duty fleet market, the recommended participation rate should be multiplied by the share of cars being added to the market annually - 0.5 per 13 years – times the number of years.

There are several modifications we should make to improve the specificity of this model. First, the GHG impact should be represented as overall progress towards the climate goals, of which transportation is only a portion. For this reason, I've added in the variable of driving emissions over overall emissions. The most recent data from the Minnesota Pollution Control Agency indicates that transportation is responsible for 39 million tons of carbon, out of 158 million tons across uses – about one fourth of the total. Light-duty vehicles make up 60% of transportation emisssions, and trucks make up 23% percent (EPA 2017); therefore, driving emissions are 21% of overall emissions, and light-duty vehicles specifically make up 15%.

Second, with any efficiency calculation, we need to determine what the rebound effect is of cost savings. The "rebound effect" refers to the reality that more efficient technologies or forms of energy can lower the cost per use, leading to higher levels of use and reducing the overall effectiveness of promoting efficiency. In this case, it refers to the use of a more efficient or lower cost fuel, which makes car use marginally cheaper and increases the vehicle miles travelled. For this reason, we have added in a rebound effect multiplier. Research of vehicle efficiency standards indicates that the rebound effect for vehicle miles traveled is around 22% in the long run (Small & Van Dender 2007;

Linn 2013). In the short term, the increase is smaller, and tends to be lower for higher-income groups, due to the time cost of increased travel (Small & Van Dender 2007). However, for electric cars, the rebound effect is less certain. A wide range of estimates exist, some of which are negative, others of which are large due to the subsidies for electric vehicles. However, a meta-study by Vivanco et al (2016) showed that most estimates without special circumstances are in the high single digits. Therefore, we will use an 8% estimate of rebound assuming no large increases in subsidies.

Compiling these assumptions, we can find the wedge size using the formula:

GHG Reduction % = (Effectiveness/Unit) * (Driving Emissions/Overall Emissions)

* (1-Rebound) * (Participation * Turnover * Time)

For this second version of the model, it is necessary to determine the total greenhouse gas emissions in the area being surveyed. The survey area is the area of operations in which a decision-maker is attempting to reduce greenhouse gas emissions. This could be statewide, regional, local, or internally, for an organization reducing its operational carbon footprint.

To give a second example, let us suggest that a policy change will make 50% of new cars purchased electric, and that electric cars are 70% lower-emission than ICVs on this particular grid. Over a ten-year period, this will create a wedge representing 3.1% of carbon emissions in the policy area. If the policy area were a mid-size state with carbon emissions of 150 million tons, this policy would remove about 4.5 million tons of carbon.

Both of these models are attached to this document as spreadsheet templates to be filled out, as well as filled in with the examples in this paper. These spreadsheets allow policymakers and others in the public sphere to determine whether an electrification measure is in the best interest of their constituents and of society as a whole. Upon understanding this, they can move towards consideration of policies in this area. In the next section, I will summarize of the policy options available to advance electrification, and how effective they have been in different areas.

Policy Review

Electric vehicles have been out of financial reach for the vast majority of the population until very recently. A 2014 study found that, barring a serious reduction in interest rates on electric vehicles and/or a high gas price, many Americans would never break even on the cost of an electric vehicle (Arshad et al., 2014). Electric vehicle technology is rapidly improving and expanding in availability. This change is partly technological – the cost of batteries has fallen dramatically in recent years – and partially due to the decisions of industry leaders. This cost and technology improvement is clear to the 80% of EV users who choose to lease their cars instead of owning them outright, anticipating that future models will cost much less (Stock 2018).

Once electric cars become cost-competitive upfront, proper infrastructure could allow for rapid dissemination of EVs, bringing about massive greenhouse gas reductions quickly. The window for maximizing these benefits may be short: a report by Bloomberg New Energy Finance (Randall 2016) indicates that the upfront cost of electric vehicles will match conventional fuel vehicles in 2022. Depending on the responses of policy-makers and their work to adapt transportation infrastructure, this could mark the beginning of exponential growth for the market. There is also research that suggests consumers will expect increasingly automated vehicles to also be electric vehicles, which could help ease the transition. (Lindland 2017)

Expanding access to and use of electric vehicles requires a many-pronged approach, stretching across levels of government. A large review of electric vehicle market policies (Slowik & Nutsey 2017) found that no one policy can account for regional differences in electric vehicle usage. Instead, a network of different policies are all needed to encourage EV adoption in a metropolitan area. Customers require incentives or competitive prices to make electric car ownership accessible and attractive; public and workplace charging infrastructure to make use viable; and model availability to make acquisition easy and attractive.

Subsidies

Electric vehicle subsidies are often seen as the most logical way to encourage the mass adoption of ZEVs. The federal government offers a tax credit of up to $7,500 for purchasers of the first 200,000 EVs manufactured by an automotive company. Several states offer or have offered substantial direct subsidies as well – the largest being Colorado's incentive, which was worth an additional $5,000 for purchases (Slowik & Nutsey 2017). Some regional governments offer parking incentives for EVs or access to high-occupancy vehicles, which both serve as less direct subsidies for EV purchasers.

The efficacy of these subsidies is in serious doubt for a variety of reasons. First of all, there is considerable concern bout the cost of and distributional of benefits from these subsidies. Even with a substantial subsidy, the early EVs that have received federal tax subsidies have been expensive, and their use relegated to wealthier Americans. This is compounded by the fact that the subsidy cannot be received in the form of a refund; it ceases after payment of tax liability. Therefore, people without a $7500 federal tax liability will be unable to capitalize on the credit fully This credit has already cost the federal government over $4 billion, and if used to its full capacity, could balloon to a cumulative public cost of $17.7 billion (Lesser 2018), almost all of which would go to the financially comfortable. While this is still a fraction of social the cost of vehicle emissions, it does mean that overall social welfare may not be increased as much as is hoped, especially when we add in cross-subsidization by local governments.

Nor is it clear that subsidies are especially effective. Colorado's enormous direct subsidy was not able to move the needle substantially in the Denver area, where adoption remains stagnant at about 1% - similar to metropolitan areas with no subsidy (Slowik & Lutsey, 2017). California's more modest subsidy of $2,000 has led to much higher rates of adoption, because it has been paired with other policies, such as HOV access – a subsidy which does little damage to the government's budget (ibid)–

along with broader charging availability and sales mandates.

Some nations have been able to expand EV market penetration even further by drastically lowering the upfront cost. Norway has achieved the highest use rate in the world by lowering the typically quite high taxes and fee rates on electric cars versus other cars (Figenbaum 2016). But this drastic price reduction is not possible in most nations, where cars are not as heavily taxed. And price is not the only factor in EV adoption – several nations have even lower EV:ICV price ratios without nearly the level of market penetration Norway has achieved (Yang et al. 2016).

Those concerned about clean transportation hope that federal subsidies for early EV manufacturing are responsible for the research and development that allows the creation of affordable and consumer-friendly EV technology. Some experts have a subjective belief it is responsible for the research advances available. But whether it actually bears any responsibility for this shift, as it happens, is yet to be studied. Even so, the federal government could likely have saved quite a bit by providing grants or subsidies for R&D into battery development and other clean transportation technologies. They also have not taken the opportunity to create a more economically just policy available to a greater sector of the population, such as a tax rebate.

Ultimately, the problem with subsidies comes down to the unfortunate fact that the cost of gasoline is currently paid nowhere, and a gas tax fully incorporating the social cost of atmospheric release would be politically difficult. With the most economically efficient tools out of reach, governments feel the need instead to subsidize the socially beneficial alternatives, at considerable public cost. While subsidies may be necessary policymakers should remain wary of them and the easy benefits they seem to provide. As electric vehicles become available to more and more of the population, the distributional consequences of subsidies should be considered in their design, and alternative modes of achieving the same goals, such as direct R&D funding, should be considered as well.

Fleet Transitions

For governments, and some environmentally minded businesses, a simple start for promoting electrification is to electrify their organizational fleet of vehicles. After all, if an organization believes in the end goal of electrifying transportation, why not start by looking in the mirror? A purchasing policy setting a goal for electrification of the fleet allows an organization to reduce its carbon footprint.

So far, fleet transitions have been relatively simple to create and implement. Major cities such as New York and Seattle have announced ambitious goals for adoption of electric fleets with little challenge. For light-duty vehicles, though governments do not benefit from the available federal tax credit, middlemen can apply the credit to their purchases, and are sometimes encouraged to by government bodies.

The benefits and opportunities are especially pronounced for public transit. Because of their heavy use of fuel, buses can save more money than smaller vehicles through electrification, and a variety of models of electric buses are available to local governments. A Columbia University study for New York City found that electric buses would cost slightly less over their lifetime than conventional buses, and that each would save $1.4 million in social costs (Aber 2016).

However, the technology does not make all vehicles economically feasible to electrify. Trash collection trucks, for example, can cost twice as much as their counterparts (Nelson & Lewis 2017). Similarly, there are technological issues to be worked out in how some departments use their vehicles. For a second example, though police cars are basically light-duty vehicles, which are easy to electrify, officers are used to keeping their vehicles idling in order to run computers and other equipment using the car battery. On an electric car, this could use up a prohibitive quantity of the vehicle's charge. In an electric future, police equipment will have to use different power sources, or vehicles will have to be equipped to handle computer technologies.

Any technological fix to combat climate change through encouraging distributed consumption choices to change should be met with a healthy skepticism. At the end of the day, municipal fleets are a small fraction of a city's vehicle miles travelled. Still, fleet transitions provide some amount of support for electric vehicle development without major drawbacks. For bus and truck fleets, the potential for electrification is more substantial and meaningful.

Vehicle Mandates

Perhaps the most aggressive policy option for promoting electrification comes from California: the Zero-Emission Vehicle standard. During the composition of the 1970 Clean Air Act, California was given statutory authority to set gas mileage standards independently of the federal government, due to its pre-existing ambitious work to improve vehicle mileage and combat pollution in its cities. In the 1990s, they began a push to add on to vehicle mileage standards with a requirement that car manufacturers provide sell a certain quantity of zero-emission cars in California as well. While this policy was rolled back in the early 2000s, while the electric vehicle market stalled, it has since been substantially increased as part of the state's decarbonization plan.

Under the ZEV standard, automakers are required to obtain a certain number of ZEV credits, based on their designation as a “large” or “intermediate” auto manufacturer; smaller manufacturers are exempt. Individual cars sold may earn up to four credits, depending on the level of electrification (partial or full). Companies without sufficient credits are fined five thousand dollars per credit. These credits may be bought and sold – companies that manufacture more than their needed quantity of ZEVs can sell credits to companies that don't. This creates a bounded set of market incentives that avoid moving too far in any one direction. The automotive industry as a whole is asked to produce ZEVs, with flexibility as to which companies produce the vehicles, and with an upper limit of $20,000 on how much social value can come from an electric car's production.

States may choose to follow either the federal standards or the California standards, at their own discretion, and states following California's plan may further choose to implement the ZEV standard. Currently, nine so-called “ZEV states” participate in California's standard (CT, ME, MD, MA, NJ, NY, OR, RI, VT), together comprising over a quarter of the American auto market. Three more states (DE, PA, WA) and the District of Columbia have adopted California mileage standards but not the ZEV standard. Credit earnings and requirements are common across the entire ZEV state network – meaning some ZEV states have not seen substantial ZEV growth within their state lines.

The ZEV standards have been an effective mode of policymaking thus far. The American Lung Association's report estimates that, by 2030, the fully phased-in standards will generate $18 billion in social benefits from reduced driving pollution, across the current ten ZEV states. (Holmes-Gen and Barrett, 2016). This analysis is likely somewhat conservative on the climate end, for reasons discussed earlier in the paper. These benefits come without a cost to the taxpayer and without direct costs to car purchasers. Instead, it pushes car companies to find low-cost methods of compliance by investing in clean car technology and developing affordable ZEV models. While this makes it unpopular with the automotive industry, it runs into none of the political problems of large subsidies or other programs.

Currently, the ZEV mandate faces an uncertain future. The Trump administration is reviewing national mileage standards in an attempt to roll them back, and has challenged California's independent standards, including the ZEV states. However, the opposition to this rollback may spark enough backlash to persuade new states to switch over to California's standards and include the ZEV standard in the process. With political pressure, this challenge could turn into an opportunity for the standard.

The full implications of the standards themselves are not yet known. The policies were created with the full intent of feasibility, but more research should be conducted in the future as to whether the policies have been effective for consumers or over-burdensome to the automotive industry. From what we currently know, however, the ZEV standard shows the most promise for an economically just route to an electrified transportation system.

Charging Infrastructure

Currently, when an electric car is purchased, the driver is responsible for charging it in their own home. If the car is used for commuting and in place overnight, a standard wall plug will do. But for electric vehicles to replace all uses of ICVs, consumers must be able to charge their car at the workplace, out shopping, or even during a break in driving on the go. This requires higher-voltage chargers, which are expensive, both as equipment and in installation.

Currently, charging availability is sparse in most states – Minnesota has fewer than seven hundred statewide (Alternative Fuels Data Center 2018). The relatively sparse availability of EV charging infrastructure relative to ICV charging infrastructure (gas stations) makes potential EV owners skittish about replacement, even when costs are comparable – a phenomenon known as "range anxiety." This has resulted in something of a catch-22 for the market. Potential purchasers of EVs are scared off by the lack of charger availability, but the low adoption rate of EVs, and the low cost of vehicle charging, removes any incentive to build chargers themselves. Neither side is able to move on its own.

In hopes of pushing past this conundrum, some utilities have put money into installing electrical chargers for the public and subsidizing private installation as well. This kind of activity, however, is not always allowable on a large scale, as utilities are publicly regulated and barred from extraneous spending on infrastructure. Regulators are often worried about the cost to ratepayers, and their worry is not without merit. For example, if California utilities were to install enough chargers to keep up with projected demand for 2025, the cost would be between $48 and $59 billion (Lesser 2018). This cost would be entirely borne by ratepayers, without any graduation by income. Still, this concern over infrastructure perpetuates the previously mentioned chicken-egg problem –regulators don't want chargers without an electrical market it'll be able to serve, but the market can't get to that point without charging infrastructure.

The task has then fallen to the public sector, where governments are providing grants for charging in the name of public infrastructure development. The American Recovery and Reinvestment Act, the 2009 federal economic stimulus measure, got the ball rolling with $15 million for public charging stations. State and local governments have followed with a wide variety of charging incentives of their own. More recently, Volkswagen, in the terms of its settlement after being caught cheating on emissions tests, has agreed to put $2 billion into charging infrastructure across the country, and up to 15% of grants using settlement money may also go to such charging stations.

But the need for increased charging remains considerable. The global electric vehicle market is projected to grow tenfold in the coming decade, but charging infrastructure remains a major barrier. The scale of change and cost required in a short period of time, and the need for coordination in this change, suggests a role for government, ideally the federal government. A coordinated shift could eliminate drivers' “range anxiety” with guarantees about the availability of charging infrastructure at workplaces and roadside stops, and even make chargers easier to install at home.

There is a strong case to be made for a much stronger public sector role in developing charging infrastructure. The United States did not adopt cars en masse through technological development alone; they became prominent through investment in highway infrastructure to support them. In the same way, government should not wait for technology to shift our infrastructure out of its entrenched ways, but invest in the infrastructure for the system it wishes to see. Even if they had the same quantity of money, a distributed network of nonprofits and regulated utilities cannot achieve what government can: a clear signal to the market that electric vehicles are viable. Some states, like New York and California, have begun providing funding for charging infrastructure near the scale necessary, but there is more work to be done.

Utility Programs

Electrical utilities have an obvious vested economic interest in shifting their consumers' transportation fuel to electricity. While this provides an opportunity for an alliance between environmentalists and utilities, regulators may find the interest more questionable. It is the job of public utility regulators to limit capital purchases and extraneous spending while keeping rates down, which are at odds with utility-driven investment in electrification infrastructure. Despite this tension, regulators and utilities have worked together across jurisdictions to develop a variety of programs helping customers to electrify.

Time of use rates are a common tool to save EV drivers money, manage the increase in grid demand from electrification, and expand the capacity for clean energy, all at the same time. Under a time-of-use rate structure, consumers pay different prices for charging vehicles at different times of the day. This keeps them from plugging in a vehicle in the early evening, when the grid has its highest demand. Instead, drivers are incentivized to charge either overnight or during midday, when grid demand is typically lowest. A study of this technique as used in both California and Portland (Biviji et al. 2014) shows that these price incentives are effective in shifting when consumers charge their vehicles. By shifting the time of use, these special EV rates can not only manage load for grid providers, but also increase the use of renewable technologies. Solar power is most abundant at midday, and wind power overnight. Though neither is widely available during the time of greatest need, time of use rates can shift that need and turn electric vehicles into flexible battery technology for decarbonization of the grid.

Utilities have also used their customer base as an opportunity for advertising and outreach of the opportunity for electric vehicles. As costs fall, consumers need awareness of and reassurance about the possibilities for them to purchase electric vehicles. Utilities across the country have sent out mailers about electrical opportunities, advertised their attractive electrical rates, and held public “ride and drive events” to showcase new EV models to potential consumers. All of these are often done in partnership with local governments. However, this has not yet been done with the coordination that utilities have used to drive other industries forward. Jones et al. (2017) suggest that utilities work together for a mass program of consumer information, similar to that which took place to inform consumers about energy efficiency programming.

Fuel Taxation

It is worth discussing the issue of fuel taxation in this section, though a fuel tax has not generally been seen as an electrification policy. Progressively right-sizing the tax on fuel to fully capture the full social cost of its atmospheric release could promote price equity and electrification, but the fuel tax, as currently construed in America does no such thing. Instead, fuel taxes on both the federal and state level are a key source of revenue for transportation infrastructure. Because of this, some governments have reacted with fear and opposition to the transition away from fuel that allows for transportation funding.

This panic has led some governments to adopt contradictory policies around electric vehicles. Several states, including California, Washington, and Colorado, have both sizable credits for EV purchases *and* fees on EV ownership. This obviously undercuts the subsidy somewhat – while subsidies are intended to help with the upfront cost of electric vehicles, this erases some of the price advantage they bring, disincentivizes the purchase of used EVs, and turns a Pigouvian subsidy into a line of credit.

It is important that governments are able to routinely fund infrastructure purchases, and a gas tax allows for a user-focused payment for these public goods while still keeping them public. But as it stands, gasoline taxes only pay for seven percent of the social cost of driving (Barnard 2015). To place an additional levy on EVs ignores the public good they provide. If gasoline was taxed at its full social cost, a tax on EVs would not be so distortionary, but as things stand, it is. In addition, state and federal gas taxes combined are responsible for only one-third of infrastructure revenue (Puentes & Prince 2003), and gas tax revenues have been declining as cars have become more efficient and electric (Vock 2015). The gas tax is not the be-all, end-all source of transportation revenue it once was.

Some state governments are already beginning to realize this issue and consider alternatives thereto. Road mileage fees are one suggestion. These fees, tested out in Oregon and California, automatically charge cars for their use of the road, based on GPS data (Vock 2018). Another option is the one that the federal government, and many states, have taken by accident: reliance on general funds for transportation spending. This is often a default option – the federal government has simply avoided the problem and not raised the flat per-gallon gas tax in a quarter-century, letting it fall behind inflation. But it need not be. Governments could intentionally shift spending towards the general fund, or improve infrastructure through income taxes, recognizing that quality transportation infrastructure of all kinds is a public good, and that the public enjoys the freedom to use roads, bridges, and highways, as well as access to the commerce they promote.

A transition to electric vehicles will happen, to some degree and at some point, with or without the support of goverrnments. Instead of fighting this transition, governments have the option to plan it and prepare for its impact on revenue streams.

Recommendations

Federal Government

In environmental and infrastructural policy, the federal government has the most capacity to act. It can coordinate decisions across the entire American economy with its regulatory capacity. The federal budget is flexible because of the ability to borrow money and create an economic stimuli. Yet, despite this increased capacity, the federal government is unreliable for long-term policy development, because of the partisan polarization of everyday decision-making.

The ideal EV policy would be a coordinated full electrification of the American automotive fleet, negotiated between the federal government and the automotive industry. These sorts of negotiations already happen to ensure the feasibility of mileage standards. The federal government could adopt California's policy tool, the ZEV standard, to the entire country, with the eventual plan of total electrification of America's car fleet. Ideally, this would come alongside a plan to decarbonize the electrical grid nationwide. This pair of policies would maximize mutual benefits for clean air and combatting climate change. A clear, coordinated plan would provide certainty to automotive manufacturers, electrical utilities, and regulators, allowing them to invest confidently and heavily in a clean energy future. Funding for the transition could come from a gas tax, which can increase as alternatives to gasoline use become more accessible. Eventually, the gas tax could fully incorporate the social cost of atmospheric release.

But until such a policy is politically feasible, there is a considerable amount that the federal government can do to intervene in favor of a cleaner transportation sector. For one, the executive branch could provide support for the states on a ZEV standard, instead of rolling back federal standards and challenging California's statutory authority in the area. The legislative branch could invest heavily in grants for charging infrastructure, as they have been traditionally involved in large-scale road and transportation initiatives.

The federal government has also traditionally taken a leadership role on research and development funding. Advances in battery technology have been responsible for most of the fall in EV costs so far, and further advances could make even greater change. While companies are conducting private research into technological fronts like solid-state batteries already, negating the need for subsidies, directly publicly conducted research could be an enormous boon to technological development, if federal developments were made public intellectual property.

Lastly, the federal government should consider alternative sources of transportation revenue as gas taxes decline. Transportation funding through the general fund has become accepted and well-liked, because of the public goods that infrastructure can provide. The government should continue its policy of convienience as a smart and intentional move.

State Government

State governments play a deciding role in the development of infrastructure and the specifics of regulations within their borders. Under the American federalist system, states have considerable authority to set their own regulations within national legal frameworks. While they provide less funding directly, states make decisions about what infrastructure projects deserve priority for federal grants.

Because of all of this, state governments need to prioritize charging infrastructure heavily to win pollution reductions in their state. Unlike subsidies for private vehicles, grants for charging infrastructure generate publicly useful tools which make electric vehicles possible and generate public benefit. In this sense, they fit more within the state's role in electrification: provide the framework and let the companies supply the vehicles.

Another way states can move towards electrification is through the ZEV standard, which pushes concrete progress toward electrification at a minimal government cost. In many state rule making processes, a switch to the ZEV standard would require only executive action or review, not the time of the legislature. Bringing the ZEV standard to more states could help introduce electric models to more of the country, inspiring public interest and investment in charging and other important infrastructure. Together, states can begin to ramp up their ZEV standards in the progress towards an all-electric future.

Even more than the federal government, state governments, which are required to balance their budgets, must be ready to fund infrastructure without gas tax revenue. ZEV mandates are useful in this respect because they allow for greater planning and predictability in the decline of revenues; but revenues will fall whether or not states plan for it. States have many options to consider, each with different economic and equity implications: mileage fees, car ownership fees, car charging fees, road tolls, income taxes, sales taxes, and many more. However states decide, a deliberative and inclusive discussion on the topic is coming due across the country.

Local Governments

Different local governments can play different parts effectively in the transition, depending on their scale, politics, and state of location. The roles of counties, cities/towns, school districts, regional governing bodies, and other special districts diverge considerably. But local governments have in common their responsibility for delivering services to Americans on the ground. They therefore can make many important steps towards a low-pollution electric future.

One major step local governments can take is the electrification of bus services. Buses are large vehicles prone to heavy use of diesel. Electric buses more than pay for their upfront premium.
On top of this, buses travel primarily in dense and often poor urban communities, where the benefits from criteria pollutant reduction are much greater. It seems only just that the first Americans to receive the health boosts from electrification should be those who have borne the brunt of pain from pollution.

Electrification of local government vehicles does not have to stop with transit buses. Local governments own a wide array of fleet vehicles which would be prime candidates for electrification. This is cost effective for some types of vehicles and not others, depending on technological quirks. Light-duty vehicles are easy to replace and recharge. School buses are an ideal candidate for electrification, because of the susceptibility of both students and bus drivers to health problems from pollution, and the considerable distances they may travel.

Local governments can also plan automotive infrastructure around charging operations and provide funding for the chargers. Chargers are easier to install en masse and with proper planning ahead of time, because the wiring needed is already present. Local governments can provide this space and wiring to allow for these economies of scale.

Some municipal governments have advanced measures to require charging in new apartment buildings, through an update to the building code. While not all cities have the ability to set their own building code, those who can't have the option of requiring charging in buildings that use city development funding or loans, which includes many of a city's larger projects. However, the ability to set building codes, at least in this area, is ideal.

Utilities and Utility Regulators

Utilities have an economic interest in developing out an electric transportation sector. However, their policymaking ability is constrained by regulators, as well as financial limitations on their capacity as policy actors. When utilities and their regulators are in harmony, they can develop effective strategies for decarbonization and electrification, without the separate limitations of the political process.

Time-of-use rates are a vital and effective tool for electrification. As discussed above, these rates can manage the transition to electric vehicles for the grid, increase fuel savings for drivers, and create opportunities to generate and store clean energy. For areas where solar capacity is highest, these rates should incentivize charging during the day, and may come with grants for workplaces to install charging equipment. For areas with greater wind capacity, but less solar development, time of use rates should incentivize overnight charging.

Utilities are well positioned to enable greater charging capacity by providing wiring at charging sites, known as the "make-ready" infrastructure. Some utilities will ready a charging site for free, though this is not feasible for every utility. "Make-ready" funding reduces the cost of chargers for consumers, but doesn't go as far as a large-scale consumer investment.

Tariff-based financing is an emerging opportunity for utilities to speed along electrification. Under a tariff system, the utility would provide a car customer with the capital to upgrade to an electric vehicle, and this would be paid back over time with a tariff on the customer's utility bill. Programs like this have been implemented successfully with energy efficiency upgrades and solar panel installation; however, because cars are not tied to one utility account, cost recovery may be more difficult, and the capital investment substantial. Still, a program like this is worth exploring.

Conclusions

There are many different levels of government that can work over the long term to make electrification of the vehicle fleet technologically and commercially feasible. But their work will be made more complicated by a climate of uncertainty and confusion. Working together, governments can send more clear signals to automotive markets and give investors confidence to move forward with technologies that support climate and human health.

While the challenge for the public sector may appear daunting, it's important to remember that most of the alternatives for decarbonization are much more daunting, and less politically feasible, while coping with climate change on a global scale could be the most horrifying and taxing challenge in the modern world. Transitioning to electric vehicles is relatively low-cost and does not require new government revenue; it could work within an existing legal framework; and would minimally disrupt Americans' daily lives or established commercial patterns. Combined with renewable portfolio standards, electrification of transportation could be a game changer for America's climate planning. All that's needed is a little coordination in civil society.

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