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From Trip Data to the Energy Requirements of Personal Vehicle Travel

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Introduction

The transportation sector accounts for 28% of U.S. greenhouse gas (GHG) emissions through vehicle production, fuel production, and fuel combustion, and 13% worldwide [15,16]. Light-duty vehicles (LDVs) contribute about two thirds of those emissions [2]. LDVs are therefore a crucial element of any comprehensive strategy to reduce U.S. and global GHG emissions, particularly under growing transportation demand.

Alternative powertrain technologies, such as battery electric and fuel cell powertrains, are potential technologies to mitigate greenhouse gas emissions from LDVs. While studies exist that evaluate the emissions reduction potential of such technologies, most such studies focus on one or two vehicle models, usually compact cars, and two or three technologies. Direct comparisons across studies are complicated by differences in assumed system boundaries, fuel production pathways, and lifetime driving distance, as well as data sources for lifecycle inventories and fuel consumption values.

While the consensus of the existing literature is that electric vehicles reduce greenhouse gas emissions as compared to combustion engine vehicles with most electricity grid mixes, another challenge is achieving high electric vehicle adoption. The high upfront costs of electric vehicles as compared to combustion engine vehicles is one potential barrier to widespread adoption. Other barriers include travel constraints induced by the limited range (combined with a long charging time) and the potential impact of electric vehicle charging on the power system (combined with charger availability).

This research project is intended to compare the cost effectiveness and energy efficiency of different powertrain technologies given realistic travel behavior and technological performance. Our goal is to better understand what technological and behavioral changes would need to occur in order to reduce the carbon emissions of the personal transportation sector to the extent required by climate goals.

The project lead to two distinct deliverables: (1) a parameterized emissions and cost model that allows us to understand and compare the lifecycle emissions and costs of ownership of current light-duty vehicles on the market across all technologies and sizes, as well as the impact of various parameters on these metrics; and (2) a model for highly resolved electric and conventional vehicle energy consumption across the United States that allows better understanding of personal travel needs in the context of electric vehicle battery capacity and power system impact. We then performed additional analyses using these two models, and combined them for an evaluation of regional emissions savings and costs of electric vehicles.

The insights from this research can inform decisions made by policymakers and engineers, and provide fundamental understanding of the mechanisms underlying transportation energy consumption and technology development. These findings are relevant to consumers, and can inform their purchasing decisions and begin to help address concerns regarding electric vehicle range and performance.

Methods and findings

Lifecycle emissions and costs of light-duty vehicles

We have developed a parameterized model that allows us to estimate the lifecycle emissions and costs of ownership of any light-duty vehicle currently on the market [2]. Lifecycle emissions, measured in gCO_2eq/km, are based on inventories from The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model by developed by the Argonne National Laboratory [17], and take into account emissions from vehicle production, fuel feedstock recovery and production, and fuel combustion. Costs of ownership, measured in \$/km, take into account vehicle costs, fuel/electricity costs, and maintenance. A detailed description of this model is available in the Supporting Information of [2].

To calculate emissions and costs for a given vehicle, we feed the model with a variety of parameters. These parameters include the annual driving distance, the electricity mix and the mix of fuel production pathways for liquid fuels, fuel and electricity prices, and the typical fuel economy achieved by different cars. For these values, we use U.S. average values. For fuel and electricity prices, we use U.S. average prices between 2006 and 2016, adjusted for inflation.

To calculate emissions and costs for a variety of vehicles currently available on the market, and derive sales-weighted averages for these metrics, we have developed a database containing vehicle specification data, vehicle fuel economy testing data, and sales data for almost all light-duty vehicles offered in the U.S. The specification data and fuel economy testing data are obtained from the Environmental Protection Agency (EPA; 18), and are merged, filtered, cleaned, and corrected by hand specifically for this project. Model-level sales data were obtained from carsalesbase.com [19]. Initially, we filled our database with data for the 125 most popular vehicle models in the U.S. in 2016. We then continuously expanded the amount of data, with the database now carrying information for more than 20,000 model-trim combinations of vehicles being sold in the U.S. between 2000 and 2018.

To put the lifecycle emissions into context, we estimate carbon intensity targets for emissions from LDVs, quantified as GHG emissions per unit distance traveled (gCO_2eq/km). The targets are calculated in three steps. First, we define overall annual U.S. GHG emission targets in 2030, 2040, and 2050 based on a global emissions budget and proposed country-specific allocation of that budget. Second, we allocate a fraction of these emissions to LDVs, based on the current share of emissions among total emissions of LDVs. And third, we divide the emissions budget for LDVs by the total vehicle distance expected to be traveled by LDVs in the corresponding target year. A detailed description of this method is available in (2).

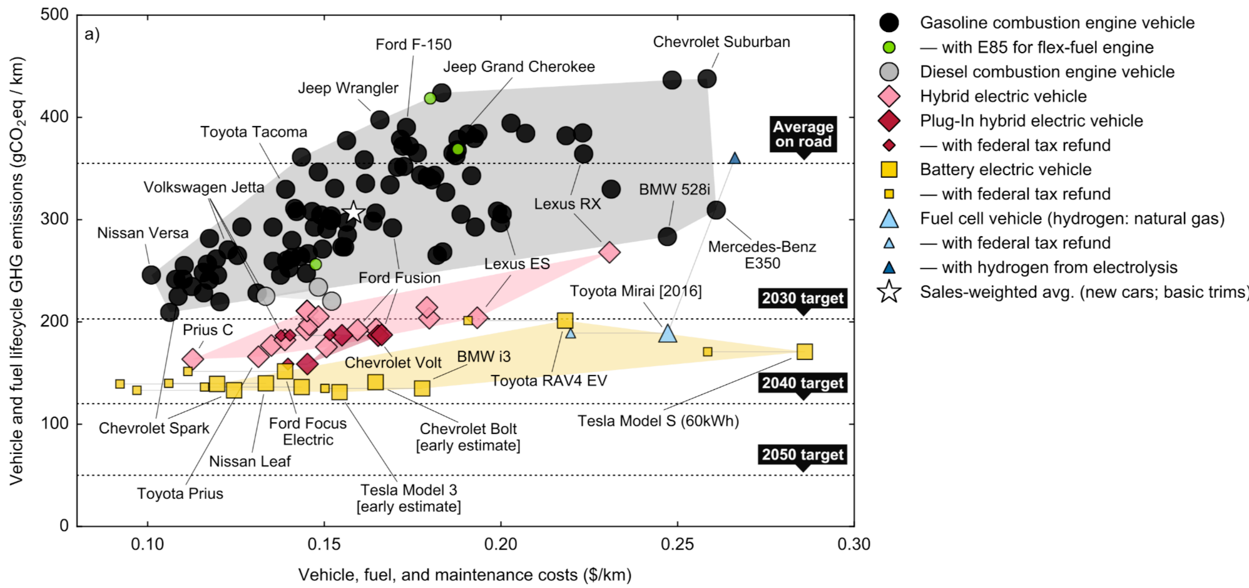


Figure 1: Cost-carbon space for light-duty vehicles, assuming a 14-year lifetime with12,100 miles driven annually, and an 8% discount rate. Shown are the most popular internal combustion engine vehicles (ICEVs; including standard, diesel, and E85 corn-ethanol combustion), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs) in 2014, as well as one of the first fully commercial fuel-cell vehicles (FCVs). For each model, the trim with the best fuel economy is analyzed. The shaded areas are a visual approximation of the space covered by these models. The emission intensity of electricity used assumes the average U.S. electricity mix (623 gCO_2eq /kWh). The FCV is modeled for hydrogen produced either by electrolysis or by steam methane reforming (SMR). Horizontal dotted lines indicate GHG emission targets in 2030, 2040, and 2050 intended to be consistent with holding global warming below 2°C.

We find that GHG emissions and costs vary considerably across popular vehicle models, both within and between powertrain technologies, with lower emissions generally corresponding to lower costs. Alternative powertrain technologies (HEVs, PHEVs, and BEVs) exhibit systematically lower lifecycle GHG emissions than ICEVs, but do not necessarily cost the consumer more. As one example, the most popular BEV, the Nissan Leaf, costs 20% less than the sales-weighted average ICEV in 2014, when considering vehicle, fuel, and maintenance costs. Even before including tax refunds, the compact version of the Nissan Leaf matches the cost of the average compact ICEV sold in 2014 (figure REF). At the same time, the Leaf has half the GHG emissions intensity of the average ICEV sold in 2014, and 38% less than the average compact ICEV sold in 2014. In contrast to the tradeoff between costs and GHG emissions reported for electricity, where electric utilities are the consumers of energy conversion technologies and fuels, there is no clear such tradeoff faced by consumers of vehicles.

Among alternative powertrain technologies and fuels, BEVs offer the lowest emissions, followed by PHEVs and HEVs, and then diesel engines and FCVs. Vehicles fueled by diesel are among the lowest-emitting ICEVs in the set examined here, while those using E85 (assuming corn-based ethanol) do not reduce emissions relative to gasoline: the gCO_2eq emissions per gallon of E85 fuel are 22% lower than those of the same of similar gasoline-powered cars (based on GREET data), but this advantage is offset by the lower fuel economies achieved with E85 in flex-fuel engines. For the one FCV model examined (Toyota Mirai), emissions reductions are only achieved when hydrogen is produced using steam methane reforming (SMR). When using hydrogen from electrolysis, the Toyota Mirai's emissions are almost on par with some of the highest-emitting ICEVs on the market.

Several currently available vehicles meet the 2030 average GHG intensity target, while none meet the more stringent 2040 and 2050 targets (figures 1 and 2). Those vehicles meeting the 2030 target include several HEVs, PHEVs, and BEVs, as well as the Toyota Mirai FCV when operated with hydrogen from SMR. None of the ICEV vehicles meet the 2030 target, although some come very close. Meeting the 2030 target would therefore require that consumer choices change well in advance of 2030 (likely by 2025 or earlier) given the time required for the operating fleet to mirror the average carbon intensity of new vehicles.

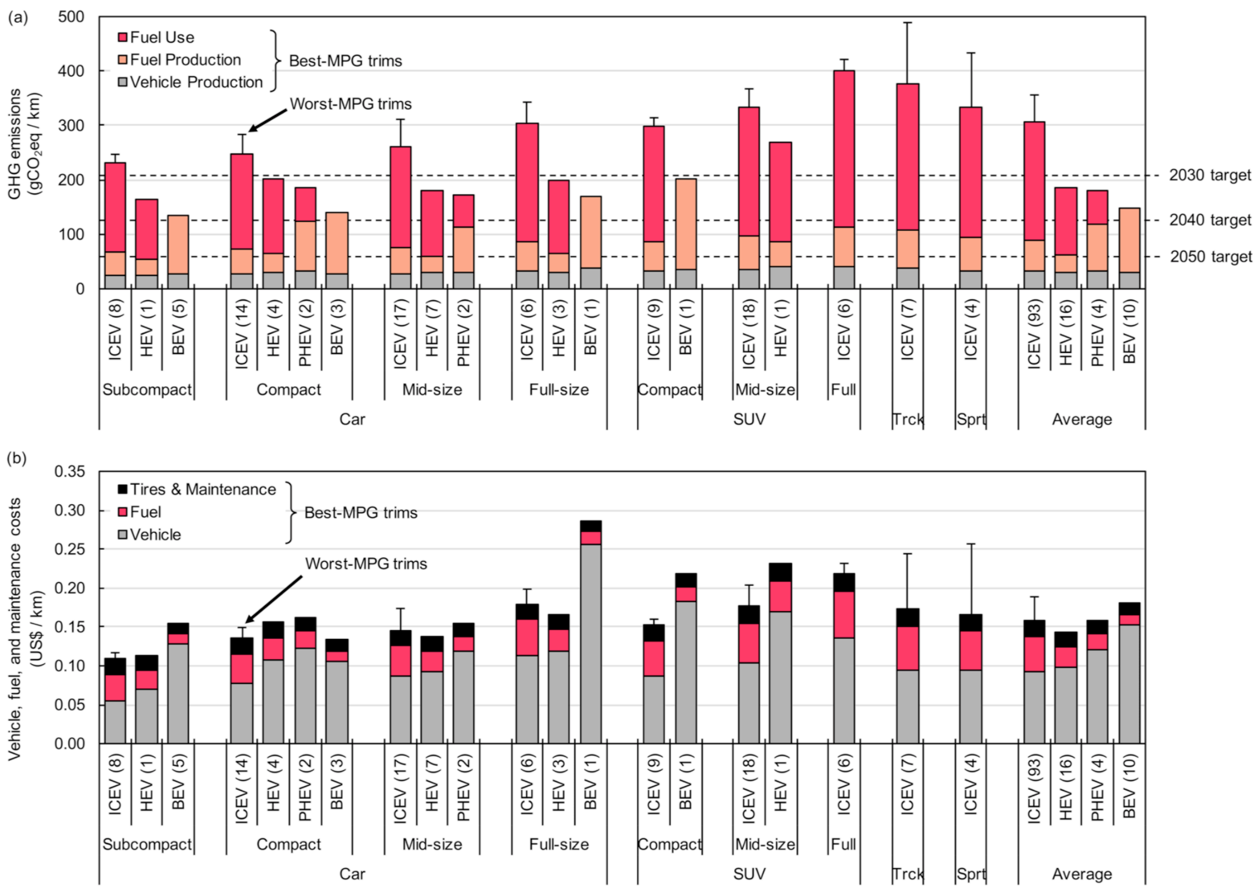


Figure 2: Sales-weighted averages by vehicle class, size, and technology of (a) GHG emissions and (b) costs for the data shown in figure 1. The shaded bars represent the averages when analyzing the trim with the best fuel economy for each model, as in figure REF. The error bars represent the averages when analyzing the trim with the worst fuel economy for each model (only ICEVs have trims with substantially different fuel economies for each model). The numbers in brackets represent the number of vehicle models considered for each group. SUV = Sport Utility Vehicle; Trck = Pickup truck; Sprt = Sports car.

Based on the model and the results shown in figures 1 and 2, we developed a website that lets consumers explore the lifecycle emissions and costs of ownership interactively. This website, available at carboncounter.com, has had more than 120,000 pageviews since its launch in August 2016. Upon its release, the website included 125 of the most popular 2016 vehicle models and was covered in a large number of news outlets, including the New York Times [11] and NPR [12]. In 2017 and 2018, we continued to develop carboncounter by updating model information, adding new models, and expanding the options for users to customize results.

In early 2018, we launched a survey on carboncounter. While the data of that survey has yet to be fully analyzed, early results suggest that many consumers have used carboncounter to inform actual purchasing decisions, and that the website may have led consumers to perceive electric vehicles as more favorable. The website may have also convinced several consumers to consider an alternative technology vehicle over a conventional combustion engine vehicle. Overall, our experience with the website suggests that there is strong demand for information such as that presented on carboncounter, and that lack of comprehensive information on electric vehicles may be one of the factors inhibiting consumers from purchasing those vehicles.

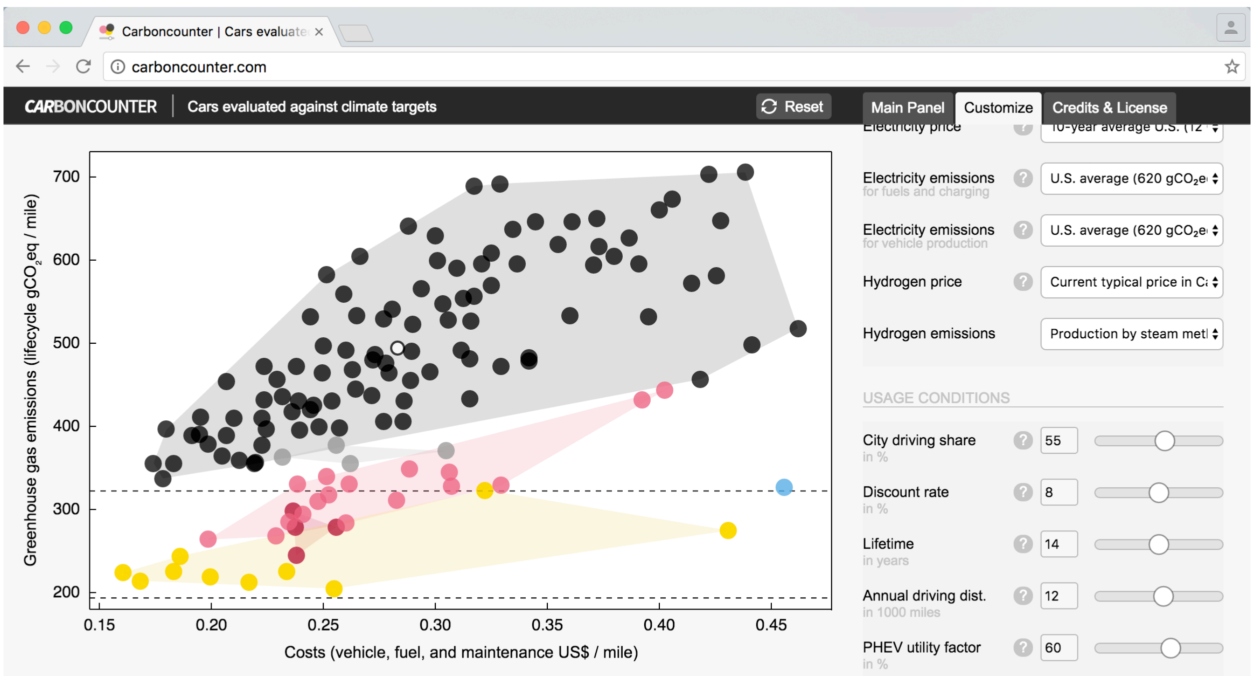


Figure 3: Screenshot of carboncounter. Carboncounter is available at http://www.carboncounter.com.

Our work on lifecycle greenhouse gas emissions and costs of ownership of light-duty vehicles, particular carboncounter, continue to inform public debate. In the fall of 2017, a letter that we wrote, informed by this work, became the most-read letter on financialtimes.com of that week [13].

Modeling fuel economy and travel energy requirements based on local driving patterns and climatic conditions using TripEnergy

For this project we finalized a model called TripEnergy [3], which combines representative travel survey data with detailed second-by-second speed profiles from GPS databases and local climate data to calculate detailed trip distance and energy consumption distributions for a given location and a given vehicle model. Our analysis takes broad and representative but low-resolution data on travel patterns and links it with high resolution, behaviorally accurate driving style data, and then translates the vehicle use patterns into energy consumption using a vehicle model trained on real vehicles. We consider tractive energy requirements, climate control auxiliary energy consumption, and powertrain conversion efficiency, all of which are calibrated to match empirical results. Unlike previous research on this topic, our method explicitly captures the stochastic nature of vehicle energy use rather than relying on average per-mile or per-day values. A detailed description of the model can be found in [3], and further analysis in [1].

We have applied this model to range constraints of battery electric vehicles, finding that a large percentage of vehicle-day energy requirements, across the U.S. and within individual cities, can be met by the Nissan Leaf, a relatively inexpensive BEV on the market now. Our results confirm the widely held belief that current BEV technology is best suited for use in urban areas, but we find that given expected technological improvement, BEVs will serve rural areas even better than current technology serves urban areas.

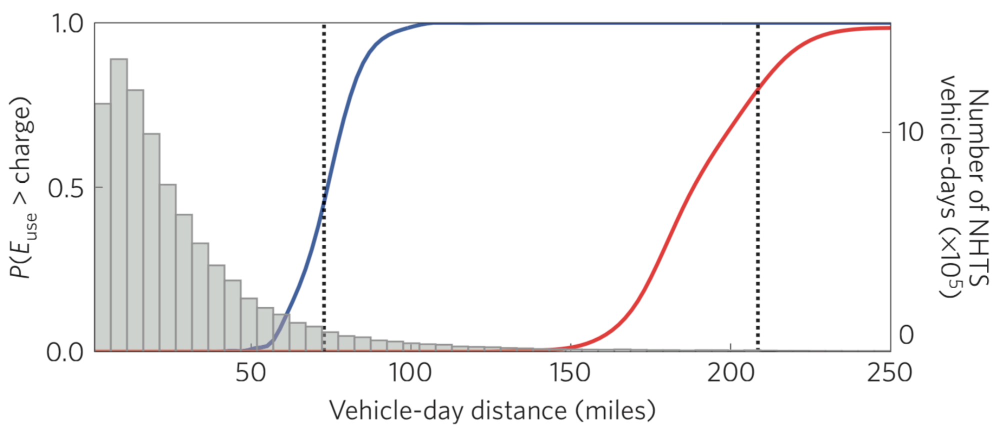


Figure 6: The probability that a vehicle travelling a given daily distance exceeds a battery energy threshold is shown for a current and future improved battery technology. Blue line: current usable battery capacity of 19.2 kWh in a vehicle modelled after the 2013 Nissan Leaf. Red line: identical vehicle with the same battery mass but 55.0 kWh usable battery capacity, based on an ARPA-E battery specific energy target. Dotted lines: ranges for the current battery capacity (19.2 kWh) and the ARPA-E target capacity (55.0 kWh) based on the EPA-estimated average vehicle fuel economy. Grey bars: histogram of nationwide vehicle-day driving distance.

We found that even a 5-year old, low-cost battery electric vehicle, the 2013 Nissan Leaf, could replace a full 87% of vehicles on the road on a given day without requiring mid-day recharging (Figure 7). This percentage is slightly higher in cities than in rural areas, but across diverse cities it remains surprisingly constant, given the variation in travel behavior and climate between them. We also found that projected improvements in battery technology will allow for adoption of electric vehicles without mid-day recharging for all but a very small number of vehicle days in the U.S. The remaining vehicle days' energy needs cannot be met, and a small number of these exist even when assuming very large increases in battery capacity. Therefore, we cannot rely only on improved battery technology to cover all vehicle days and effort must also be focused on easier mid-day charging and alternative vehicle technologies to cover this small number of high energy days. This research also serves an important academic purpose, producing an accurate picture of personal vehicle energy consumption across the U.S. that accounts for differing driving conditions and climates between locations, as well as incorporating the variability and uncertainty in energy use that is especially important for questions of range limitations.

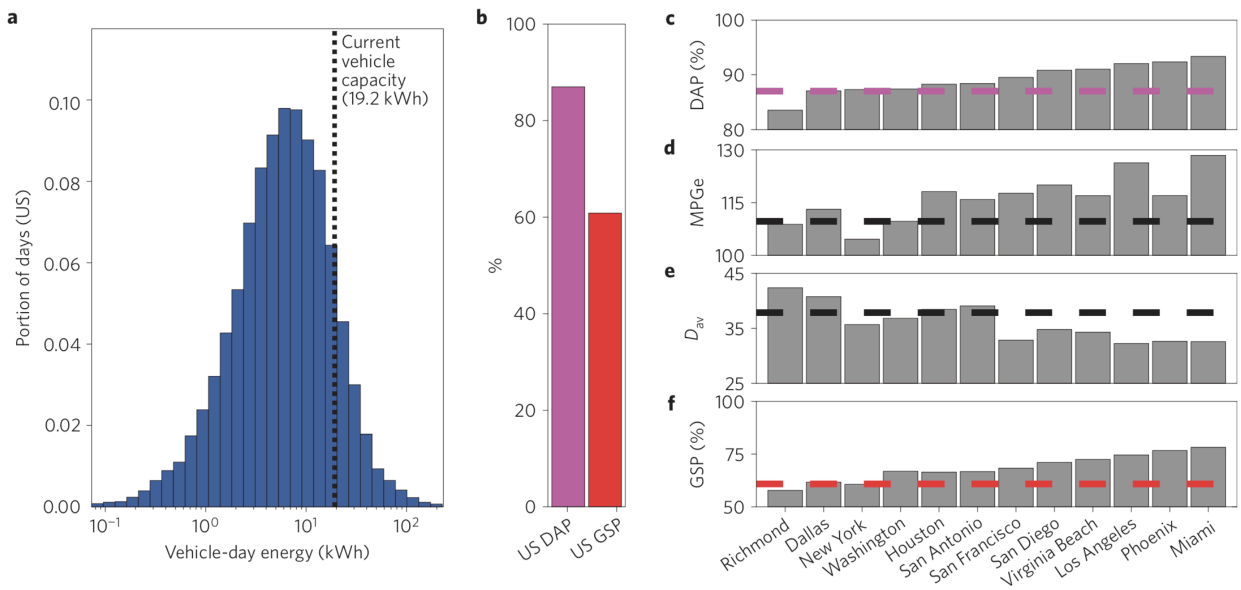


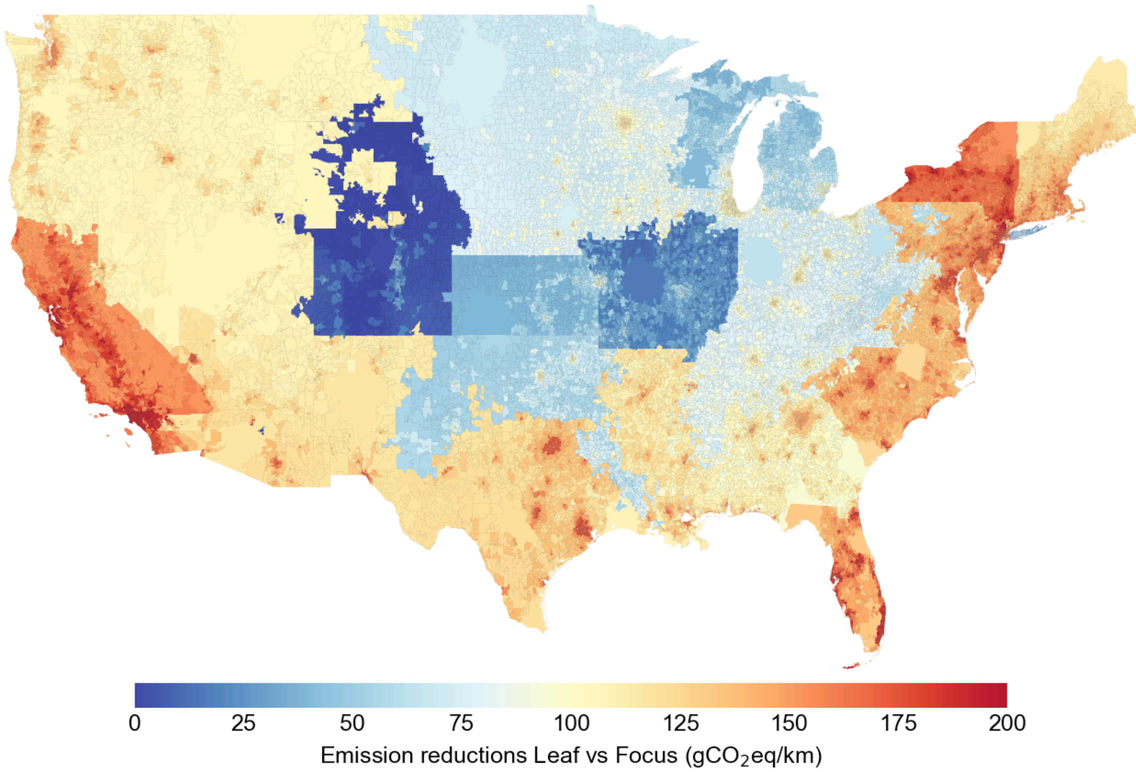
Figure 7: Energy capacity and requirements are calculated for the 2013 Nissan Leaf. **a**, Histogram of BEV vehicle-day energy consumption for the entire US (blue bars) compared with the usable battery capacity (dashed line). **b**, Daily vehicle adoption potential (DAP, purple) and gasoline substitution potential (GSP, red) across the US. **c**, City-wide values for daily vehicle adoption potential (DAP). **d**, Average fuel economy (in miles per gallon equivalent, MPGe). **e**, Average vehicle-day driving distance (in miles). **f**, Gasoline substitution potential (GSP). Horizontal dashed lines represent US averages.

Our results demonstrate the importance of considering driving behavior in estimating BEV range. While the U.S. Environmental Protection Agency (EPA) publishes a single estimated range for each vehicle, that vehicle's realized range—the distance that can be driven on one charge—is influenced by several factors that can vary from day to day. These factors include the use of auxiliary power for heating or cooling and the velocity profile of the trips taken. The EPA rated range of the 2013 Nissan is 75 miles. Our model predicts 74 miles as the median range—the distance for which half of all vehicle days could be covered on one charge. However, given variation in trip velocity profiles and auxiliary power use, our model as shown in Figure 1 produces a distribution of ranges, predicting that 1 out of 20 of 58-mile vehicle days could not be covered by existing batteries, and 1 out of 20 of 90-mile vehicle days could, attaching results to an observation of range variability that is rarely quantified. Furthermore, we find that the BEV's median range changes nonlinearly with battery capacity, because driving behavior tends to differ between short and long distance travel days. The sub-linear relationship between range and battery capacity is due to the longer vehicle days containing more long distance highway driving—trips for which BEVs have a lower fuel economy than for city trips. This finding, arising directly from trip characteristics in the National Household Travel Survey [20] and GPS datasets, illustrates the value added by our model and suggests that what defines 'typical' BEV use will change as battery technology improves.

Regional differences in lifecycle emissions and costs of ownership

By combining the lifecycle emissions and cost model with TripEnergy, we are able to evaluate the regional heterogeneity in lifecycle greenhouse gas emissions and costs of ownership of driving different types of vehicles [3,6]. Instead of using U.S. average parameters for electricity mix, fuel and electricity price, annual driving distance, and fuel economy, we customize these values on a state, metropolitan area, or zip code level, depending on the granularity of the available data. For modeling region-specific fuel economy of different cars based on where they are driven, we use TripEnergy. Detailed information on how we model regional emissions and costs will be available in [6].

We find that the difference in emissions and costs between an internal combustion engine vehicle (here: 2017 Ford Focus) and an electric vehicle (here: 2017 Nissan Leaf) varies considerably across the country (Figure 8). For emissions, and largest contributor to this variation, is the electricity mix, as visible by the outlines of the different regional grids. This is followed by regional driving patterns and traffic conditions, which typically vary between urban and rural areas. Local climate only has a moderate impact on the difference in emissions and costs between the Leaf and the Focus, as both a hot climate in summer and a cold climate in winter decrease the fuel economy of both types of vehicles, albeit to a different extent (for instance, cold weather affects electric vehicles more, because the heat for warming up the cabin is not free). For costs, variation in the electricity price, the gasoline price, taxes and fees, and fuel economy affect the difference between the Leaf and the Focus all to a similar extent, with the variation in fuel economy (caused by driving patterns and local climate) contributing the most overall. Our findings show that where electric vehicles are being sold, how they are being used, and which internal combustion engine vehicle models they replace, has a considerable impact on effective emission reductions achieved by electric vehicles in the United States and worldwide.


0
25
50
75
100
125
150
175
200
Emission reductions Leaf vs Focus (gCO$_2$eq/km)

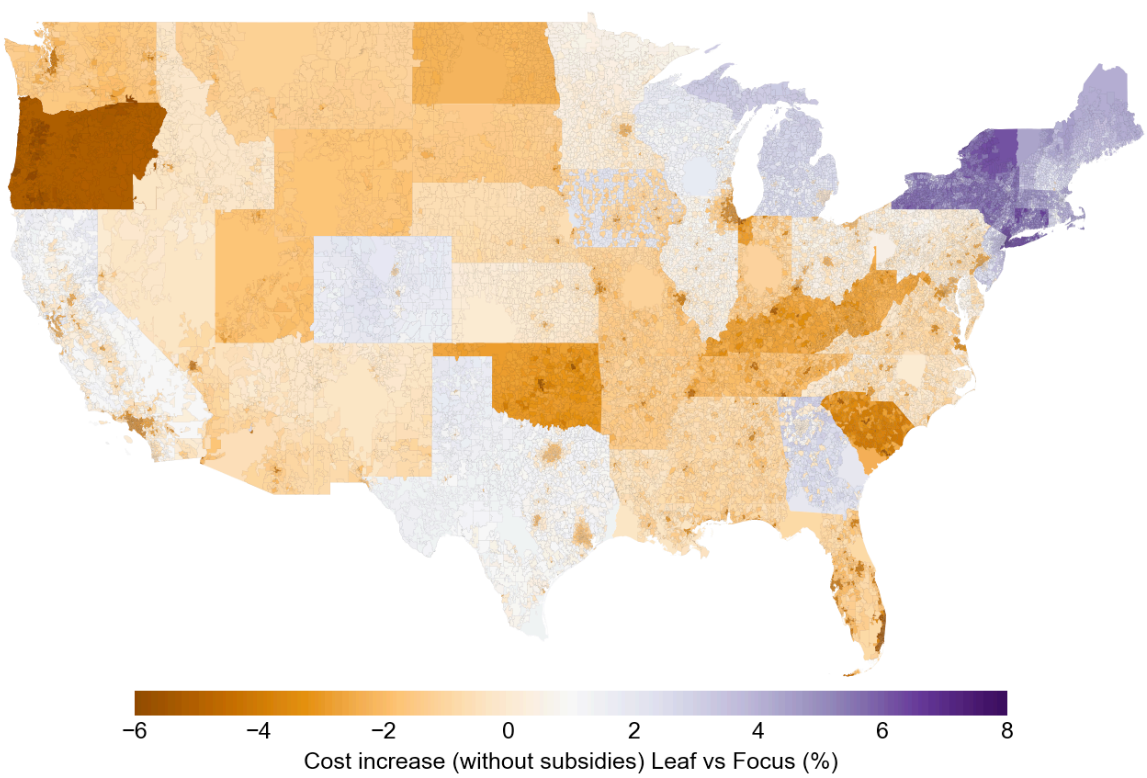

−6
−4
−2
0
2
4
6
8
Cost increase (without subsidies) Leaf vs Focus (%)

Figure 8: Estimated difference in lifecycle greenhouse gas emissions (top) and costs of ownership (bottom) between a Nissan Leaf and a Ford Focus across the United States. Region-dependent parameters considered for emissions include electricity mix, annual driving distance, and fuel economy. Parameters considered for costs include gasoline price, electricity price, annual driving distance, vehicle sales taxes and registration fees, and additional annual fees on electric vehicles. The fuel economy varies with local climate and with local driving patterns and traffic conditions, and is modeled using TripEnergy [3]. Preliminary results.

Electrification of high-energy travel days

In looking at the potential for widespread battery electric vehicle adoption with TripEnergy, we have found a heavy tail of long-distance driving days that will be difficult to cover with BEVs, even with large improvements to battery technology and charging availability (Figure 7). This suggests that supplementary services, such as car sharing services, may be necessary to cover these days.

To evaluate BEV daily adoption potential when personal vehicles are complemented by a shared vehicle, we examine a contingency scenario where a shared vehicle replaces the personal vehicle for the longest home-based tour of a high-energy vehicle-day. A home-based tour is defined as a tour that starts from home and ends at home, potentially with multiple trips in between. We choose a tour instead of a trip because it is convenient for the traveler to use the same vehicle for the entire tour without the need to switch vehicles between trips. Also, if a shared vehicle is only used for part of the tour and a personal vehicle is used for the rest, the personal vehicle will not be at the same location at the start and end of the tour. This might cause inconvenience to the travelers if they need to use the personal vehicle again. Due to the lack of location data, we are not able to identify tours that are not home-based. This analysis is described in detail in [14]. Using this approach we are able to estimate by how much BEV adoption potential would increase if travelers have access to another vehicle or expanded charging infrastructure, for the high-energy days when the day's energy requirement cannot be met by a BEV on one charge.

Impact of charging electric vehicles on the grid

As a final component of this project, we have used the energy model described previously (TripEnergy) to study potential interactions between a fleet of battery electric vehicles (BEVs) and the electricity grid, which itself is needed to undergo a technological transformation in order to meet climate goals. This research has included development of a charging decision model, estimating when drivers will choose to charge their electric vehicles given constraints on access to charging infrastructure and trip energy requirements, assuming different preferences about charging location and time. This allows us to create profiles for the aggregate grid demand of a fleet of electric vehicles, across the U.S. or in specific states or metropolitan areas. Because historical electric grid demand and weather data are available in many sub-markets, we are able to compare estimated BEV grid demand to historical data on specific historical days. Weather information is particularly important, despite generally not being covered in the literature, because BEV energy use and underlying electricity consumption vary greatly with temperature. As a result, days with the highest residential electricity use (the hottest days of the summer) also tend to be days with some of the highest expected BEV energy use, due to climate control energy use in vehicles. There is also a great deal of variability from day to day in solar resource availability that will be correlated with electricity demand and BEV charging use. In a lower-carbon future, these three factors—BEV charging, solar photovoltaic (PV) generation, and electricity demand from other sectors—will all interact in complex and potentially unexpected ways. A detailed description of the model will be available in [7].

Conclusions and recommendations

We find that the least emitting cars also tend to be the most affordable ones within and, in many cases, even across different powertrain technologies. And while the average carbon intensity of vehicles sold in 2014 exceeds the 2030 climate target by more than 50%, most available (P)HEVs and BEVs meet this goal. A primary takeaway for car buyers is that vehicle decarbonization compatible with future climate targets can only be achieved by transitioning away from ICEVs, principally to hybrid and battery EVs. We find that with today's options, the average consumer is able to choose (P)HEVs and BEVs at little to no additional cost over similarly-sized ICEVs. Our analysis helps highlight the extent of cost-carbon savings that car buyers forego by opting for traditional ICEVs over alternative lower cost, lower carbon technologies.

Our experience with carboncounter suggests that there is high demand for better information on emissions and ownership costs of different car models by consumers, especially in the context for comparing different technologies against each other. It also suggests that relatively simple tools that provide a toolbox to consumers that lets them explore these aspects themselves in an interactive manner can change their perception and attitude towards different vehicle technologies. We therefore recommend that policy measures to increase the adoption of electric vehicles entail informational programs for consumers.

The region-specific analysis of the emissions and cost savings of electric vehicles over combustion engine vehicles could further inform such informational programs. We find that both the difference in emissions and in costs between electric vehicles and combustion engine vehicles varies significantly across the country, meaning that these differences are not just highly dependent on the vehicle models (as suggested by the initial cost-carbon work), but also on specific location. The highest emission reductions, usually at the lowest costs to the consumer, are achieved by electric vehicles in regions where the electricity grid is relatively clean, where there is heavy traffic and average trip speeds are therefore slow, where annual driving distance is relatively high, and where the climate is mild to warm. Urban metropolitan areas in California, where most electric vehicles have been sold so far, belong to this group of locations.

Nonetheless, vehicles in rural areas will have to be electrified as well if we aim to achieve mass electrification of our LDV fleet. Because BEVs operate less efficiently under typical rural driving conditions, thought should be given as to how to produce BEVs that will appeal outside of the typical urban market and how to mitigate the strain on the electric grid and potential carbon emissions that will arise from massive electrification of transportation in rural areas.

Our findings on range constraints of electric vehicles has led to a better understanding as to how BEVs will fit into the transportation and energy networks as technology continues to improve. We argue that we cannot rely only on improved battery technology to cover all vehicle days, and that instead effort must also be focused on easier mid-day charging or alternative vehicle technologies to cover this small number of high energy days.

Our examination of BEV charging loads suggests that, while workplace charging infrastructure is not the most important factor in increasing the effective range of BEVs to meet the needs of high energy days, it can be critical in allowing BEV charging loads to be shifted to better match aggregate electricity supply and demand. Our research shows that investment in inexpensive Level 1 charging infrastructure and the workplace, especially if paired with pricing schemes or incentives that maximize its utilization, will take advantage of behavioral patterns on work days and lead to aggregate charging patterns that roughly align with solar resource availability. Precise results differ from city to city and depend on the relative rate of adoption of BEVs to installation of PV. Results suggest that in cities with sharper evening peaks in demand like Dallas, TX, earlier installation of workplace charging infrastructure is important, while in cities like New York, NY, with flatter demand profiles benefit from earlier investment in PV. Regardless, in scenarios with high BEV adoption and high PV penetration, increasing the amount of BEV charging that takes place at the workplace is a surprisingly effective way of mitigating both peak demand and overgeneration issues.

Project Outputs

Journal publications

[1] Needell ZA, McNerney J, Chang MT, Trancik JE, Potential for widespread electrification of personal vehicle travel in the United States, Nature Energy, 2016, link.

[2] Miotti M*, Supran GJ*, Kim EJ, Trancik JE, Personal vehicles evaluated against climate change mitigation targets, Environmental Science & Technology, 2016, link. *Authors contributed equally.

[3] McNerney J*, Needell ZA*, Chang MT, Miotti M, Trancik JE, TripEnergy: Estimating personal vehicle energy consumption given limited travel survey data, Transportation Research Record: Journal of the Transportation Research Board, 2017, link. *Authors contributed equally.

[4] Needell ZA, Trancik JE, Efficiently simulating personal vehicle energy consumption in mesoscopic transport models, forthcoming in Transportation Research Record: Journal of the Transportation Research Board, 2018.

[5] Wei W, Needell ZA, Ramakrishnan S, Trancik JE, Potential for increasing electric vehicle adoption through charging infrastructure expansion, *in review*.

[6] Miotti M, Trancik JE, Evaluating regional greenhouse gas emissions and costs of personal vehicles, *in preparation*.

[7] Needell ZA, Trancik JE. From peak demand reduction to storage for renewables: shifting electric vehicle loads with workplace charging. *in preparation*.

Patents

[8] Trancik JE, Needell ZA, and McNerney J, 'TripEnergy', US Patent Application, No. 62/374952, US20180045526A1 (2018)

Selected newspaper articles

[9] The Guardian. Electric cars could drive the future – but not without old-fashioned vehicles (https://www.theguardian.com/environment/2016/aug/15/electric-cars-internal-combustion-engines-mit-report)

[10] Washington Post. 'Range anxiety' is scaring people away from electric cars — but the fear may be overblown (https://www.washingtonpost.com/news/energy-environment/wp/2016/08/15/range-anxiety-scares-people-away-from-electric-cars-why-the-fear-could-be-overblown/)

[11] New York Times. An App to Help Save Emissions (and Maybe Money) When Buying a Car (http://www.nytimes.com/2016/09/28/science/smartphone-app-car-emissions.html)

[12] NPR. It May Not Cost You More To Drive Home In A Climate-Friendly Car (http://www.npr.org/2016/09/27/495534164/it-may-not-cost-you-more-to-drive-home-in-a-lower-emission-car)

[13] The Financial Times. Reality is that most EVs emit less CO2 than petrol cars over their lifetimes (https://www.ft.com/content/d14b6c8a-c61e-11e7-b2bb-322b2cb39656).

Presentations

Miotti, M., Supran, G., Kim, E. & Trancik, J.E. Evaluating the Climate Change Mitigation Potential of Personal Vehicle Technologies. International Society for Industrial Ecology (ISIE) 2015 Conference, Surrey UK.

Miotti, M., Supran, G., Kim, E. & Trancik, J.E. Using a parameterized LCA to evaluate over 120 current passenger vehicle models against climate change mitigation targets. Presentation at: LCA XV; October 7 2015; Vancouver, Canada.

Miotti, M., Supran, G., Kim, E. & Trancik, J.E. Personal Vehicles Evaluated Against Climate Change Mitigation Targets. Poster Session Presented at: MIT Transportation Showcase; February 17 2016; Cambridge MA.

Miotti, M., Supran, G., Kim, E. & Trancik, J.E. Personal Vehicles Evaluated Against Climate Change Mitigation Targets. Poster Session Presented at: Energy Efficiency & Renewable Energy (EERE) Day at MIT; March 17 2016; Cambridge MA.

Miotti, M., Supran, G., Trancik, J.E. Carboncounter.com: An Interactive Website to Evaluate Personal Vehicles Against Climate Targets. Interactive Digital Exhibition presented at: MIT Energy Night, MIT Museum; October 16th 2016, Cambridge MA.

McNerney J, Needell ZA, Chang MT, Miotti M, Trancik JE, TripEnergy: Estimating personal vehicle energy consumption given limited travel survey data, Transportation Research Board Annual Meeting 2017, Washington DC.

Miotti, M., Trancik, J.E. Evaluating the emissions and costs of light-duty vehicles. International Society for Industrial Ecology (ISIE) 2017 Conference, Chicago IL.

Wei, W., Needell, Z.A., Ramakrishnan, S., Trancik, J.E. (2017, Oct.). Potential for increasing electric vehicle adoption through charging infrastructure expansion. Poster session presented at the MIT Energy Night, Cambridge, MA.

Miotti, M., Needell, Z.A., Trancik, J.E. Quantifying reductions in personal vehicle energy consumption due to driving style changes. Transportation Research Board Annual Meeting 2018, Washington DC.

Needell, Z. A., and Trancik, J. E. Efficiently simulating personal vehicle energy consumption in mesoscopic transport models. Transportation Research Board Annual Meeting 2018, Washington DC.

Wei, W., Needell, Z.A., Ramakrishnan, S., Trancik, J.E. Potential for increasing electric vehicle adoption through charging infrastructure expansion. Transportation Research Board Annual Meeting 2018, Washington DC.

Miotti, M., Trancik, J.E. Leveraging data to estimate localized emissions and costs of personal vehicles. Poster presentation at 2018 Gordon Research Conference Industrial Ecology and oral presentation at 2018 Gordon Research Seminar Industrial Ecology.

Dissertations

Wei, W. (2017). Vehicle activity patterns and electrification potential. Master's thesis, Massachusetts Institute of Technology, Cambridge, MA.

Website

Carboncounter|Cars evaluated against climate targets. http://www.carboncounter.com. Launched 2016-09-27. Last updated 2018-03-02 (with 2018 vehicle model data and additional parameters).

Additional References

(15) Sims, R. et al. Chapter 8. In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Edenhofer, O. et al., Eds.; Cambridge University Press: Cambridge, United Kingdom, 2014.

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