Title

Charging the Future: Assessing the environmental impact of a road user charge with mandatory electric vehicle participation

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Assessing the environmental impact of a road user charge with mandatory electric vehicle participation

A comprehensive project submitted in partial satisfaction of the requirements for the degree in Master of Urban and Regional Planning.

by
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Executive summary

Transportation financing has historically relied on revenue from the gas tax. In recent years, however, the gas tax has faltered in its ability to support transportation projects. Policymakers and planners are currently searching for options to either supplement or replace the gas tax, one of them being a road user charge (RUC). With RUC being a reasonable solution to the funding crisis, many states, including California, have implemented pilot programs to explore its feasibility. While pilot programs and research often mention electric vehicles (EVs) and plug-in hybrid electric vehicles in their scope, most do not acknowledge how carbon emissions may change when adding a price to driving, since EVs do not currently pay for their road use. In order to address this gap, this project relies on a carbon model with three financing scenarios:

- Scenario 1: Existing conditions
    - Internal combustion vehicles (ICVs) pay gas tax. EVs do not pay for road use
- Scenario 2: Dual funding scheme
    - ICVs pay gas tax, EVs pay RUC
- Scenario 3: Universal RUC system
    - All vehicle types pay RUC, complete replacement of gas tax with RUC

Results indicate that the optimal funding solution to address funding and climate goals is a dual funding scheme (Scenario 2), which yields the least amount of carbon emissions in both the short and long run. Surprisingly, a universal RUC system (Scenario 3) produces the most carbon emissions, because an outright removal of the gas tax will incentivize consumers to buy less fuel efficient vehicles. Results also imply that there are environmental benefits to pricing EV drivers for their road use, since their carbon footprint declines when paying a RUC.

These results inspire four recommendations, which are as follows:

1. Establish federal guidance with a dual funding scheme as the suggested solution to address the transportation funding crisis and to support national climate goals.
2. Replicate the model in other states.
3. Adopt a dual funding model in California.
4. Develop supportive policy for EVs and PHEVs in California.

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Acronym list

CBO	Congressional Budget Office
CO2	Carbon dioxide
DOT	Department of Transportation
EPA	United States Environmental Protection Agency
EV	Electric vehicle
GHG	Greenhouse gas emissions
HTF	Highway Trust Fund
ICV	Internal combustion vehicle
Mpg	Miles per gallon
NHSTA	National Highway Traffic Safety Administration
PHEV	Plug-in hybrid electric vehicle
RUC	Road user charge
SB	Senate Bill
SUVs	Sports utility vehicle
US	United States
VMT	Vehicle miles traveled

1 | Introduction

American transportation finance has relied on federal funding from the Highway Trust Fund, namely through the gas tax, as the main revenue source for transportation projects. However, the diminishing purchasing power of the gas tax has forced states to increasingly turn to alternative forms of transportation funding for state and local projects. The most popular, and arguably the most feasible, of these alternatives is the road user charge (RUC). A RUC system has the potential to either supplement the gas tax or replace the gas tax altogether. With this new funding scheme comes a number of questions and challenges related to implementation, especially as new vehicle technologies, like electric vehicles (EVs) saturate the market. This research paper seeks to tackle two related questions:

1. Does a road user charge impact carbon emissions from driving?
2. Given the environmental ramifications of different funding schemes, what is the ideal transportation financing solution going forward?

In order to address these questions, I will first contextualize the American transportation funding crisis and current solutions to this crisis. I will provide a review of existing literature on these solutions, identifying particular gaps in the literature that guide my research questions. With this background, I identify California as an appropriate landscape to project carbon emissions based on different funding scenarios. Next, I will detail my research methodology, which uses quantitative analysis in the form of a carbon model, which I built from California's EMFAC tool. In this section, I also describe high level assumptions and logic models that guide my carbon projections. I then reveal my results, qualified by limitations and key uncertainties. Next is a discussion of the results and four recommendations based on research findings. Finally, I conclude with a summary report and call to action for future research.

2 | Background

Historic forms of transportation financing have centered around the gas tax and its ability to raise revenue from those burning gas on the roads. The gas tax has mostly supported American roads, but is faltering in its ability to act as the main revenue generator for transportation projects. In response, academics and practitioners are considering alternative funding mechanisms to potentially replace the gas tax, like a road user charge (RUC) system. The following section contextualizes the current funding crisis and details road user charging as a treatment option.

Existing transportation funding conditions: the gas tax

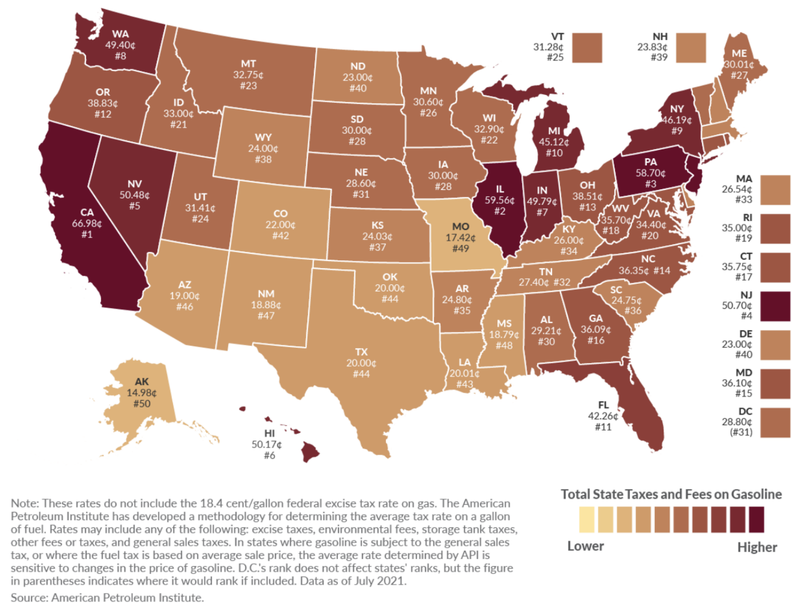
How the gas tax works

Generally, funding sources can be characterized as either user fees or general taxation. The gas tax is an example of a proxy user fee. A user fee is a fee in which those using the service are the ones who pay for it (Kulash 2001). The gas tax is a type of user fee by adding a tax to fuel, thereby charging gasoline-powered vehicles for their use of the road. However, the gas tax is only a pseudo-user fee, because the tax is based on how much gas a driver burns. This means that those driving all-electric vehicles are not charged for their use of the road, because they are not burning gas. Thus, this user tax charges the majority of individuals who benefit from the roads to use that service, roughly linking use with cost and revenue. This creates a complex challenge for the future of road funding, since electric vehicles (EVs) are not taxed for their use of the road.

American transportation funding has heavily relied on gas taxes imposed at both the federal and state levels (Nigro and Burbank 2012). The intricate nature of road funding begins at the federal level, where the government acts as the main facilitator for most American transportation investment. Revenue from these gas taxes are then funneled into the Highway Trust Fund (HTF), which redistributes funds to states and localities for various transportation projects, such as bridges, highways, and streets (Gifford 2009).

Federal gas taxes are fixed to a certain cent-per-gallon structure, which currently holds at 18.4 cents per gallon (NCSL 2021). Along with a federal gas tax, states impose their own gas taxes in addition to the federal gas tax to supplement their own transportation projects. These taxes vary based on state policy (Figure 1). Local governments may also add on gas taxes. On average, additional local and state gas taxes add 30 cents per gallon to total taxes paid at the pump (Nigro and Burbank 2012).

Figure 1. Total State Taxes and Fees on Gasoline, July 2021 (cents per gallon)



What the gas tax funds

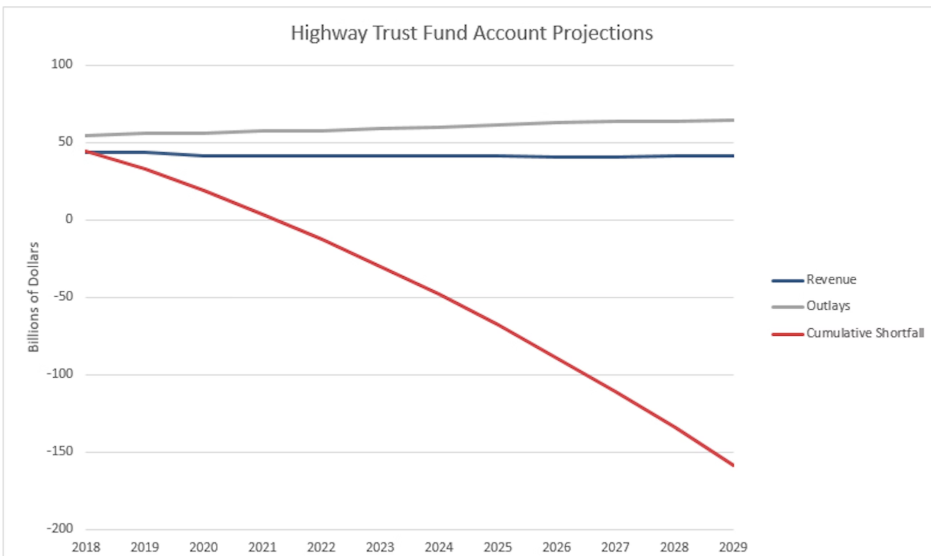
As discussed above, gas taxes (both federal and state) are a major source of financing for transportation in the US. Serving as the main revenue source, the HTF was originally conceived to guarantee funding for highways (Brown, Morris, and Taylor 2009). The HTF has since expanded to also fund public transit (namely bus and rail systems), cycling, pedestrian, and ferryboat projects (Nigro and Burbank 2012). Regardless of such expansion, the majority of funds (about 80%) remain devoted to the Federal-Aid Highway Program for road funding (Davis 2020).

In general, state and federal gas tax revenue goes toward larger projects that are regional in scale, like highways, freeways, and railroads. The Department of Transportation allocates funds to states and localities via grants and formulas to fund their project, in a form of top-down planning (Gifford 2009). These logistical components surrounding the gas tax have made it a vulnerable funding system. With some of the HTF dedicated to alternative modes of travel and its continued emphasis on top-down capital planning, among other factors, states are interested in a RUC because the gas tax's organizational structure no longer serves financing needs today, making it susceptible to fiscal challenges.

Current issues

Today, highway financing is in crisis: its current form faces a number of challenges, endangering federal gas taxes as a main funding source in the future. Three main hurdles have caused gas taxes to waver in their utility for transportation funding: the increasing fuel efficiency of vehicles; a diminishing popularity of the gas tax among voters; and, the declining purchasing power of the gas tax, because it is not linked to inflation (Taylor 2017). These challenges are reducing the federal gas taxes' ability to fund transportation projects (Figure 2), which places a greater fiscal burden on states and local governments.

Figure 2. Highway Trust Fund Account Projections, 2018-2029



Source: Congressional Budget Office, January 2019

Increased automobile efficiency, which comes from more efficient internal combustion vehicles (ICVs) and new technologies like electric vehicles (EVs), hybrids, and other alternative fuel vehicles, reduces revenue from both federal and state gas taxes (*Ibid.*). Since federal gas taxes are fixed per gallon, and as vehicle miles traveled (VMT) continues to grow, more efficient vehicles mean that gas tax revenues are not keeping pace with the rise in driving (*Ibid.*). This aggravates the existing problem, since some drivers are contributing to rising VMT without paying for their use of the road.

These issues are further compounded by the rapid adoption of EVs. Currently, EVs make up less than 1% of all cars, sports utility vehicles (SUVs), and light-duty trucks in the US (Cage 2022). However, in 2022, EVs grew in their share of new vehicles sold by an order of two-thirds, up to 5.8% of all new car sales (Colias 2023). Of this share, 40% of all zero emission vehicles (ZEVs), which include all-electric vehicles and plug-in hybrid electric vehicles (PHEVs), were sold in California (Office of Governor Gavin Newsom 2023; IEA 2022). In California, EV adoption is far higher than national sales; in 2023, 18.8% of all new cars sold in California were ZEVs (*Ibid.*). The American push towards EVs is in line with the rest of the world where in 2022, EVs made up 10% of all new car sales globally (Boston 2023). In fact, this fast-paced adoption is expected based on the S-shaped curve theory of technology adoption, in which technology adoption starts slowly and quickly grows due to an accelerated growth in innovation (Arribas-Ibar, Nylund, and Brem 2021; Briscoe, Trewhitt, and Hutto 2011).

The United States (US) aims to achieve carbon neutrality by 2050 and intends to capitalize on this growing momentum of EV adoption to reach its climate goals (*Ibid.*). Further policy supports this goal: President Biden's Executive Order 14037 Strengthening American Leadership in Clean Cars and Trucks requires half of all new car sales to be hybrid, electric, or fuel cell by 2030 (Federal Register 2021). If this policy comes to fruition, EVs could make up about two thirds of all vehicles on the road by 2050 (*Ibid.*). Currently, these electric, hybrid, and alternative fuel vehicle drivers either pay little, or no, gas tax and therefore avoid a user tax for their driving. Without a user fee, EV drivers save between $1,250-$2,650 per year (*Ibid.*). This is highly regressive when considering higher income individuals are more likely to drive EVs (Davis and Sallee 2020). Thus, without a user fee, higher income individuals are virtually subsidized to buy EVs and drive more due to the lack of price signals. This creates a clear link between transportation inequity and mobility, because we can assume that minimal price signals encourage higher income individuals to have higher VMT, cause more congestion, and subsequently emit more carbon.

As previously mentioned, the HTF is now funding other transportation projects and goals beyond highways. Along with funding infrastructure for public transit, ferries, freight, and active transportation, the HTF began supporting climate action goals like air quality targets, recreational trails, and historic resources in 1983 (Nigro and Burbank 2012). HTF funds from federal gas taxes have been spread out among many more projects than originally intended, reducing their impact.

Another roadblock is a lack of political will, which stems from competition with health and welfare for state and federal funds, political gridlock to embolden gas taxes, and voter distaste for increased taxes (Detwiler 2012). Though many drivers support climate efforts, political support for a gas tax is waning, perhaps because of a disconnect amongst voters, in which gas taxes are not viewed as a user fee. However, consistent tax increases are one of the only solutions to keep federal gas taxes alive and well in light of recent funding shortfalls. Yet regular tax increases are politically contentious, causing legislators to ignore this as a solution altogether (Taylor 2017).

In addition, the federal gas tax has faltered in its purchasing power because it is not linked to inflation. Currently, the gas taxes' real value has been consistently declining, because it has remained frozen at 18.4 cents per gallon since 1993. The 18.4 cent per gallon tax rate is not worth as much today as it was in 1993. If the federal gas tax was tied to inflation today, in 2023, it would rise to 36 cents per gallon (Phillips Erb 2022). Without a link to inflation, the federal gas tax will continue to dwindle in its purchasing power.

One final challenge concerns the regressiveness of a gas tax. Gas taxes are flat taxes rather than variable taxes, meaning that the excise tax is the same for all drivers regardless of income. This puts a greater fiscal burden onto lower income households compared to higher income households, raising an important concern related to transportation equity.

Additional funding sources to supplement the federal gas tax

The looming highway funding crisis has forced states and localities to consider additional funding mechanisms to supplement the federal gas tax. Modifications to the gas tax, along with special fees for PHEVs and EVs, are additional funding sources that would allow the gas tax to remain in place.

Modifications to gas tax

Many states are now making up for funding shortfalls by increasing their own gas taxes. In the last 10 years, 33 states have implemented policies to increase their gas taxes. Most of these increases were a rise to state gas taxes, though Colorado enacted a "fee" rather than a tax (NCSL 2021). Importantly, 16 states kept or enacted a variable rate structure, which allows the tax to vary based on the wholesale price of fuel and/or inflation (ARTBA 2017). This divergence from a fixed tax to a variable tax, namely tying the gas tax to inflation, enables states to address major funding shortfalls mentioned previously (specifically the diminishing purchasing power of the gas tax).

Another major hurdle previously identified is the lack of voter support for the gas tax. In the last decade, three states have sought out voter support for the gas tax, ultimately exemplifying the unpopularity of the gas tax amongst voters. In Missouri and Michigan, voters rejected increases to their state gas taxes (NCSL 2021). In 2013, Massachusetts voters approved linking the gas tax with inflation (known as indexing), which theoretically raises the purchasing power of the gas tax. However, in 2015, a ballot initiative passed to repeal this indexing (NCSL 2021).

Special fees for Plug-in Hybrid and Electric Vehicles

In order to overcome funding discrepancies as they relate to alternative fuel vehicles, some states, including California, now mandate special fees for plug-in hybrid and electric vehicles (Igleheart 2022). These special fees place an additional registration fee, on top of existing registration fees, onto qualifying hybrid and electric vehicles (Igleheart 2022). Special fees are a step in the right direction in an effort to more accurately price driving based on use of the roads, though they are not enough on their own as a long-term solution. However, special fees may discourage EV use by further increasing the cost of purchasing and operating an EV, especially if coupled with a user fee for EV drivers.

A feasible alternative: road user charge system

The recent influx of state gas tax increases may be symptomatic of the cracks in our current transportation funding scheme. As such, these state-level gas tax increases divulge a larger possible shift away from a federal gas tax and towards statewide financing solutions, since the reliance on federal gas taxes has led to funding shortfalls. In fact, states' solutions to these transportation funding crises have gained substantial ground, like a road user charge (Urban Institute n.d.). Road user charges can work in a number of different ways, though a mileage-based system is most prevalent in the US. This report will assume that a RUC system employs a mileage-based RUC system, or VMT fees.

VMT fees are a type of user fee, meaning that those who use the service are the ones paying for it. It does so by tracking the amount of miles traveled by the vehicle, and charging drivers based on how much they drive (Kirk and Levinson 2016). RUC systems can use a variety of approaches to track VMT, however in virtually all scenarios, vehicles would be required to have VMT tracking technology to monitor driving. A VMT fee system must incorporate capabilities to track mileage, collect fees, and ensure the security of both fees and user privacy (Sorensen, Ecola, and Wachs 2012).

Mileage-based systems have a wide range of technical design choices, the simplest of which ensure greater privacy while more advanced systems require more user information (*Ibid.*). The most elementary approach would employ an odometer to track VMT. These periodic odometer checks may occur during annual vehicle registration (*Ibid.*). Most other technologies require an on-board unit (OBU). The simple OBU would tally miles traveled. This information could then be processed and charge drivers a fee per mile, which could be imposed at gas stations or billing through the mail (*Ibid.*). More complex systems equip OBUs with cellular location data or GPS, raising privacy concerns (*Ibid.*). Otherwise, smartphones could track VMT as a lower cost option, though it still compromises a certain level of user privacy (*Ibid.*). Collected revenue would be redistributed within jurisdictions for transportation funding use (Kirk and Levinson 2016). In most scenarios, these fees would be sent to the HTF and also directly to states (*Ibid.*).

RUC systems are especially attractive because they can serve a dual purpose as both a replacement or supplement to the federal gas tax and as a revenue generator. This also makes RUC systems an attractive solution to politicians and planners because of its funding role. Furthermore, RUC programs' technological flexibility enable further environmental benefits and opportunities to change travel behavior by using pricing to manage travel behavior. These environmental benefits can be further compounded by charging EVs for their road use.

Current status of RUC in the United States

As of October 2022, the following 14 states ran or currently operate a RUC pilot program: California, Colorado, Delaware, Hawaii, Kansas, Minnesota, Missouri, New Hampshire, Ohio, Oregon, Texas, Utah, Washington, and Wyoming (NCSL 2022). Of these 14 states, 9 (California, Colorado, Missouri, New Hampshire, Ohio, Oregon, Utah, Washington, and Wyoming) have enacted legislation since 2013 to raise state gas taxes (NCSL 2021). These pilot programs range in their scale, timeframes, and purpose. For example, Oregon leads the nation with an ongoing RUC pilot program, OreGo, which has been in operation since 2015 and continues to expand its volunteer base with thousands of participants (Oregon DOT n.d.). On the other hand, Colorado's four month pilot program had around 100 volunteers (RUC America n.d.).

California serves as a meaningful example of the dichotomy in existing RUC conditions in the US. California is on one end of the spectrum, exemplifying the major strides American transportation planners and politicians have made to implement RUC through its extensive pilot program and enthusiasm to address subsequent questions and concerns. California, the national leader in EV adoption, also poses a unique challenge for considering EVs in a widespread adoption of a mileage-based RUC system.

RUC progress in California

RUC America is an organization of member states with a goal of broadening RUC systems in the US. RUC America organizes participating states into three tiers: Tier 1 States with Policy Enacted to Implement RUC Programs, Tier 2 States Testing RUC Pilot Programs, and Tier 3 States Researching RUC (RUC America n.d.). California is categorized as a Tier 2 state (*Ibid.*).

California is a leading state in RUC exploration. Senate Bill (SB) 1077 (passed in 2014) guides RUC research and testing in California. SB 1077 granted California the ability to establish the Road Charge Technical Advisory Committee to assess the feasibility of a RUC system in a greater legislative effort to find sustainable funding options as the gas tax defaults on its ability to fund California's roads (CalSTA and Caltrans 2017). Included in the legislation are privacy requirements, general policy direction, and permission to conduct a pilot program (California Senate 2014).

California ran a nine-month road user pilot program in 2016 and 2017 with over 5,000 vehicle participants, making California's program the largest in the nation behind Oregon (CalSTA and Caltrans 2017). There were several key findings made during the pilot program, such as an 86% user satisfaction rate with the mileage reporting system (*Ibid.*). The pilot program report also contained critical next steps for future implementation including feasibility studies for pay-at-the-pump system options, testing revenue collection and flow, use of in-vehicle telematics to track mileage, public-private partnerships to stay current with technology innovations, and logistical planning for a statewide RUC program (*Ibid.*). California has since made strides to address next steps identified from the 2017 pilot program, like implementing a four phase demonstration that tests pay-at-the-pump and EV charging station systems and considers other transportation technologies like autonomous vehicles, ridesharing, and usage-based insurance (California Road Charge n.d.). California also began a new pilot program in March 2023 focused on public/private roads with an emphasis on user privacy (*Ibid.*). Additionally, UC Berkeley is partnering with Caltrans to assess RUC systems through an equity lens, focusing on how a RUC program may affect underserved communities (*Ibid.*).

California is also a unique landscape for RUC implementation because of its high EV adoption rate. According to the US Department of Energy, California made up 39% of all EVs registered across the US in 2021 (US Department of Energy 2022). California is also investing heavily in publicly available EV charging infrastructure (CALeVIP n.d.). Due to this high EV demand in California, along with strong commitments to expanding EV adoption in the state, California poses an interesting problem when considering road user charge as more drivers are projected to switch to an EV.

3 | Literature review

As the United States looks to address the transportation funding gap created from the diminishing gas tax, politicians and planners have increasingly sought out alternative funding mechanisms. Various funding alternatives are prevalent throughout existing literature, as the gas tax is no longer sufficient as a stand-alone transportation funding source. While there are a number of financing options, many researchers are considering road user charges (RUC) to make up for lost revenue.

A general consensus is forming around RUC, with many studies working out the logistics and roadblocks for implementation. With rising EV adoption, many suggest that a RUC system shall be supplemental to the gas tax to increase transportation funds. Though a RUC system could completely replace the gas tax, some are advocating for a system in which EVs pay user fees and ICVs continue to pay the gas tax (Atkinson 2019; Chandra et al. 2021; Davis and Sallee 2020). Atkinson advocates for this approach when considering the role of a RUC system either as a revenue generator or as a means of changing travel behavior. For a RUC program to serve as a revenue generator, the simplest solution would be to supplement the existing federal and state gas taxes (paid for by ICVs) with a RUC for EVs (Atkinson 2019).

Though EVs are identified as contributing to diminishing transportation funds, there is limited research on a RUC that systematically includes EVs. Most literature identifies EVs as a part of the funding problem, yet there is a disconnect in which EVs are not considered within the set of solutions and projections to support implementation. This literature review underscores the lack of adequate conversation around EVs as they relate to future RUC implementation and missed opportunities to include EVs in environmental projections of RUC systems. A 2020 study by Davis and Sallee at UC Berkeley makes an effort to better incorporate EVs within a RUC system and serves as a basis for the scope of this research. Building on UC Berkeley's study, a RUC system should price EVs based on miles driven. This raises a larger question of whether ICVs should continue paying the gas tax or pay a mileage-based RUC as well. This research can serve as a bridge towards further study by addressing central concerns posed in UC Berkeley's research.

Lack of EV discussion in the literature

Existing literature uncovers extensive issues related to RUC implementation. However, literature that adequately and realistically includes EVs as a part of the financing solution is surprisingly thin. One study from the University of Iowa explores logistical implementation of a mileage-based RUC system. This study pinpoints four main roadblocks for widespread implementation including: privacy concerns for road users related to data recording and retention; transition from the gas tax to a RUC system (specifically as vehicle fleets turn over from motor fuel powered to electric); the federal government as a secure, effective clearinghouse that protects millions of accounts; and, the need to establish federal policy that enables states and regions to develop their own financing policy initiatives (Forkenbrock 2005). Another example from the Congressional Research Service similarly lists barriers for RUC systems, like high costs for program establishment and enforcement, administrative challenges, and setting user fee rates (Kirk and Levinson 2016). These studies recognize EVs when contextualizing the problem of a diminishing gas tax, but nowhere acknowledges EV adoption as a challenge to RUC implementation. This exemplifies a knowledge gap, where studies explicitly state how EVs contribute to the financing crisis, but fail to address how solutions to this funding crisis will include EVs going forward.

Several pilot programs across the country identified key learning opportunities for implementation of a dual funding system approach. Oregon and California demonstrate innovative, yet infeasible pilot programs, because they assume that a RUC system will completely replace the gas tax. Oregon is leading the nation in its innovative RUC pilot program, OreGo. Effective since 2015, OreGo began to allow some EVs and high mile per gallon (mpg) vehicles (40 mpg or more) to participate in its RUC program in 2020 (Oregon DOT 2022; Oregon DOT n.d.). OreGo is the most innovative and extensive RUC pilot program in the nation, classified by RUC America as a Tier 1 state (RUC America 2022). OreGo is considered the gold standard of RUC programs in the United States as it has remained operational for over seven years, codified a statewide RUC program, and included EVs in its program (*Ibid.*). Even so, OreGo does not consider a system in which ICVs continue to pay a gas tax and EVs pay a user fee. Instead, the pilot program operates under a system where all drivers transition to a RUC. OreGo is an anomaly in comparison to the rest of the nation, as Oregon is known for its progressive transportation policy and planning. This raises questions about scalability when looking at Oregon as a blueprint for other states.

This is also the case in California, whose state-led 2017 pilot program ignored EVs and only recently began to consider how EVs can participate in a user system (CalSTA and Caltrans 2017). Following the pilot program, California is now working to address key recommendations to facilitate statewide implementation. For example, to ensure seamless transition and to maintain a positive user experience, California is considering mandating drivers pay user fees at the pump and at EV charging stations (to mimic current conditions where drivers pay gas taxes at the pump) (*Ibid.*). However, this solution is incredibly optimistic because similar to Oregon, California's next steps in RUC implementation operate under the assumption that all drivers will pay a user fee rather than the gas tax.

Even though these are leading pilot programs, these programs illustrate breaches in the literature for nationwide RUC implementation. An outright removal of the gas tax is unrealistic in many states depending on political context (conservative states may be less likely to adopt a RUC system for many reasons like privacy concerns), geography, and EV adoption rate, among other factors. For example, the US Department of Transportation states that Minnesota is not interested in replacing the gas tax, but instead supplementing it with alternative funding sources (Federal Highway Administration n.d.). Aforementioned research suggests that in those states, it may be more politically feasible to develop a dual funding scheme, in which ICVs continue to pay state gas taxes, while EVs are mandated to participate in a RUC system. In this case, Oregon and California, both good examples of large scale pilot projects, lack nationwide models because they both fail to consider a dual funding scheme. Without concurrent funding models, a slew of additional concerns arise, pointing to environmental issues such as the rebound effect, detailed below. This leaves unanswered questions for concurring financing systems, related to EV adoption and behavioral economics, that could actually minimize environmental benefits of a RUC system and possibly even worsen carbon emissions.

Current environmental projections for RUC systems

While consideration of EVs within a RUC system is minimal, some academic literature have begun to include EV participation and identify subsequent concerns. Atkinson presents an argument opposing a RUC system, in which mandating EV participation would discourage vehicle adoption, specifically because additional user fees may disincentivize EV adoption, ultimately harming the environment (Atkinson 2019). However, further analysis refutes this claim, pointing to studies proving that a RUC system would reduce vehicle miles traveled (VMT). More specifically, the author cites that "a number of studies suggest that an RUC system would lead to reduced driving, in part because of the behavior-economics effect of consumers realizing they are paying for the mile, but also because congestion pricing would lead to mode switching" (*Ibid.*).

One study from Resources for the Future projects various transportation policy implications on VMT in the Washington DC metropolitan area. In this scenario, their "VMT tax" is most analogous with a RUC, as this user charge is essentially a tax on how much driving one does. These projections found that a VMT tax would reduce total estimated VMT in the region by 18.8 million miles per day (Safirova, Houde, and Harrington 2007). Another study in the Upper Derwent Valley of the United Kingdom estimated that a RUC system would reduce the demand for driving by up to one third (Takama and Preston 2008).

In conversation with one another, existing literature points in favor of a RUC system, in which a user fee would have positive environmental implications, as it would reduce VMT and subsequently minimize driving's carbon footprint. However, these studies leave room for debate, as they do not explicitly target EVs in their discussion and analysis of environmental impacts. Existing research ignores nuances specifically associated with EV adoption, like the rebound effect, a behavioral phenomenon in which individuals increase their consumption because of perceived or real efficiency (Victoria Transport Policy Institute n.d.). In the context of EV adoption, the rebound effect manifests as drivers of efficient vehicles driving more than they otherwise would have, thereby increasing personal VMT. This is a pivotal facet to consider, and points to a need to explicitly assess environmental implications of a RUC system that includes EVs. Thus, there is a discrepancy in the literature as it specifically relates to EV participation in a RUC program, as it is unclear whether it could possibly worsen environmental conditions.

UC Berkeley Research

While the vast majority of literature fails to consider EV drivers, one 2020 study from UC Berkeley initiates the conversation on EV participation in a mileage based road user program. The UC Berkeley research is particularly prominent, because it is the first to critically assess a RUC system that includes mandatory EV participation. As a proxy fee for driving, the gas tax fails to adequately represent all of the externalities imposed from driving. In their study, Davis and Sallee find that a mileage-based fee better accounts for the externalities associated with driving.

Since ICVs impose far more externalities for their road use, the more gas is undertaxed, the less appropriate it is to levy a RUC onto EVs, because market efficiencies require a greater price effect on ICVs. Davis and Sallee conclude with a recommendation to maintain the gas tax and charge a uniform RUC to encourage EVs while charging for externalities associated with road use, such as non-tailpipe air pollution. They qualify that these externalities are less associated with the damage that results from driving on highways, which comes more from trucks and weather, but rather the maintenance that is needed for actually using the road (Davis and Sallee 2020). Consequently, the UC Berkeley report delineates a number of environmental concerns that stem from mandatory EV participation. As such, this research project builds on the UC Berkeley study and aims to answer many of the study's concerns.

This study seeks to determine the optimal road financing solution, and whether EV drivers should pay for their road use, by analyzing how price effects influence travel behavior and carbon emissions, especially as EV adoption grows. Based on 2017 data, EV adoption is estimated to reduce gas tax revenue annually by $75 million at the federal level and $174 million at the state level, for a total combined revenue loss of $249 million. This accounts for an approximate 5% reduction in combined state and federal tax revenue, which was $52 billion in 2019 (Urban Institute n.d.). The majority of this revenue loss comes from relatively few states. For example, California forgoes about $90 million in gas tax revenue per year from EV drivers (Davis and Sallee 2020).

In an attempt to better understand the ramifications UC Berkeley posed related to EV participation in a RUC system, the study sheds light on subsequent environmental implications. A tradeoff exists: if EV drivers are required to pay a user fee, they may be inclined to replace their EV with an ICV in order to realize cost benefits, since EVs are generally more expensive and would incur additional user costs from a RUC program. This is because motor fuel taxes contribute to the operating cost of the vehicle, thus incentivizing EVs. This would have environmental ramifications, as EVs are far more efficient vehicles with a lower carbon footprint. On the other hand, mandatory RUC participation could reduce VMT and carbon emissions for EVs, since they would be taxed based on their use of the roads. However, without this price effect, EVs may be encouraged to drive more than they otherwise would have, as they are not impacted by price signals and may drive more due to the rebound effect (*Ibid.*).

While the UC Berkeley research alludes to this conundrum, little research apart from Davis and Sallee's has yet to successfully weigh these implications on the carbon footprint, or reflect how shifts in pricing may influence fleet composition for ICVs. Furthermore, it begs the question of the role of a RUC program- should a RUC system solely act as a revenue generator or as a tool to shift travel behavior? Since driving can pose a number of negative impacts on communities, like congestion, crash injuries and fatalities, and air quality impacts, it is pivotal that funding sources aim to target those imposing such externalities onto marginalized communities. Without this link, there is little chance that drivers would change their travel behavior.

Next steps

While many questions remain unanswered, this research attempts to fill in some particular gaps, specifically by assessing how a mandatory RUC for EVs would change driving behavior, and thus carbon emissions. This research furthers Davis and Sallee's 2020 study, which implies that ICVs should continue to pay state and federal gas taxes while EVs pay a mandatory road user fee. It seeks to consider the environmental tradeoffs mentioned in their study to determine whether mandatory EV participation in a RUC program would affect carbon emissions by EVs.

4 | Research design and methodology

Carbon model

Quantitative methodology is centered around the following research question: what are the environmental implications of a RUC system that requires electric vehicle (EV) participation? This research question will reveal how driving behavior, and subsequently carbon emissions, may change when employing a RUC scheme for EVs. In order to address this overarching question, I developed a carbon model to project carbon emissions resulting from vehicle miles traveled (VMT). The model estimated carbon emissions in 2035 for three different scenarios:

1. Scenario 1: Existing conditions (gas tax for vehicles that burn gas)
2. Scenario 2: Dual funding scheme (partial RUC adoption: vehicles burning gas continue to pay the gas tax while EVs pay a mileage-based RUC)

3. Scenario 3: Full transition to a mileage-based RUC system and an elimination of the gas tax

While building my carbon model, I was inclined to ask myself: would a change to the gas tax (its removal, coupling with a RUC charge, or some other modification.) actually influence consumer behavior? Research suggests that significant changes in gas taxes may in fact affect consumer behavior when it comes to driving. Increases to state gas taxes manifest as a rise in the retail pump price. When the retail pump price rises modestly, there is little impact on consumer behavior. However, over half of the gas tax increase falls onto the consumer at the pump (Premo Black 2015). This implies that large enough changes to the gas tax, and subsequently significant changes to the way drivers are priced for their driving, would likely result in a change to consumer behavior. A 2022 study supports this idea, where recent surges in gas prices caused over two-thirds of American drivers to significantly reduce their driving (Gross 2022).

I relied on the California Air Resources Board's EMFAC2021 (v1.0.2) Emissions Inventory for VMT data. The EMFAC tool projects emissions for various on-road vehicles in California in a larger effort to assess air quality (CARB n.d.). Within the tool, I selected on-road emissions statewide from 2000-2035. I chose annual data for the following categories: light duty automobiles (LDA), light duty trucks (LDT1 and LDT2), and MCY (motorcycles). Output units were tons/year. To visualize this took, please use the link below to the virtual EMFAC tool: https://arb.ca.gov/emfac/emissions-inventory/1feaa7fd255baaef6fdd508c0871cfc78a278617

Fleet categories

In each scenario, I projected carbon emissions by vehicle type based on the Congress of the United States Congressional Budget Office (CBO)'s vehicle classifications. The CBO distinguished vehicles as either cars or light trucks. There were four car categories: subcompact/2 seater car, compact car, midsize car, and large car. Large trucks were also separated into four categories: minivan, SUV, pickup truck, and passenger or cargo van (Austin 2008). I chose to differentiate between vehicle types because of my goal to assess fleet changes in Scenario 3. I expected that a replacement of the gas tax with a RUC would likely reduce the cost of operating a gas-intensive internal combustion vehicle (ICV) while having little impact on more fuel efficient vehicles. Changes in price signals for fuel efficiency may encourage a change in fleet composition, like a rise in light trucks and reduction in cars, because transitioning to a RUC scheme makes more energy-intensive vehicles cheaper. Thus, the clarification of vehicle type was critical to produce a more accurate estimate of carbon emissions in Scenario 3 because it reflects changes to consumer behavior as a result of price signals and therefore overall shifts in fleet composition.

Elasticity as a proxy for pricing

There is no existing model to forecast a shift away from a gas tax towards a road user charge system in any capacity. Additionally, most models projecting carbon emissions may consider changes to VMT, but they do not consider fiscal changes to driving and their subsequent impact on travel behavior. In order to illustrate consumer behavior changes as a result of new pricing mechanisms, I applied short and long run gas tax elasticities as a pseudo-pricing variable. Gas tax elasticities reflect changes in consumer behavior of gasoline based on price. Based on University of Pennsylvania's Wharton School of Business Budget Model, the short run demand elasticity of gasoline consumption and expenditure when federal and state tax revenue changes is -0.07 (University of Pennsylvania 2022). University of Pennsylvania's Wharton School of Business Budget Model also includes a long run gas tax demand elasticity. When considering changes to federal and state revenue, gasoline consumption has a long run demand elasticity of -0.40 (University of Pennsylvania 2022). These elasticities allowed me to project VMT changes, and therefore carbon emission changes, based on shifts in pricing.

Carbon modeling assumptions

A series of assumptions were made in order to develop a carbon model that can estimate CO_2 emissions for driving under different pricing schemes. High level assumptions are stated in this section, while more meticulous assumptions and methodology are detailed in Appendix 1.

Along with the assumption of elasticity as a proxy for pricing, including the specific short and long run elasticities applied to the carbon model, another major assumption relates to vehicle fuel type classifications. I separated carbon emission calculations based on fuel type: ICV or EV. The EMFAC tool divided vehicles based on four fuel types: diesel, gasoline, all-electric, and plug-in hybrid electric vehicle (PHEV).

ICVs were regarded as including: diesel-powered vehicles, gasoline-powered vehicles, and half of all PHEVs. EVs included: all-electric vehicles and half of all PHEVs. PHEVs were split between ICVs and EVs because they are found to use 30-60% less fuel than ICVs, depending on the make, model, and year of the vehicle (US Department of Energy Office of Energy Efficiency and Renewable Energy n.d.). This range is dependent on the type of PHEV. Some PHEVs rely entirely on electricity until the battery is about empty- after that point, the vehicle switches to its internal combustion engine, relying on petroleum. These vehicles would represent the higher end of fuel savings. On the other hand, blended mode PHEVs use a mix of both gasoline and electricity, even when the battery is fully charged. This means that it uses more gasoline, representing the lower end of fuel savings (US EPA 2023). Data from the National Highway Traffic Safety Administration (NHTSA) found that when looking at electric-only ranges of 10-60 miles for PHEVs, the middle ground electric-only range would reap 50% fuel savings compared to ICVs (Kliesch and Langer 2006). In order to account for these differences, I assumed that PHEVs would use 50% less fuel than ICVs, allowing me to split PHEV VMT in half between ICVs and EVs.

Further, I assumed that PHEVs will not need to pay both a gas tax and a RUC, as this would likely discourage individuals from buying PHEVs. In Scenario 2, which simulates a dual pricing scheme (gas tax and RUC), I assumed that PHEVs would pay a RUC and would no longer pay the gas tax. This assumption was based on Oregon and Utah's RUC programs, which both orient their RUC schemes towards EVs and PHEVs (along with high mile per gallon vehicles in Oregon) (Oregon DOT n.d., Utah DOT n.d.).

Another important assumption relates to EV adoption in 2035 (i.e. the percent of EVs within new car sales). EV adoption was calculated to reach 100% by 2035. This was based on California's Advanced Clean Cars II regulations, which seek to achieve 100% electric new car sales by 2035 (CARB 2022). In order to calculate EV technology adoption from 2000 to 2035, I applied a S-shaped technology curve, which implies slow initial technology growth followed by fast-paced adoption from innovation (Arribas-Ibar, Nylund, and Brem 2021; Briscoe, Trewhitt, and Hutto 2011).

5 | Carbon model results

High level outcomes: comparing scenarios 1, 2, and 3

Between the three pricing scenarios, Scenario 2 produces the least amount of carbon emissions both in the short and long run. Scenario 2 yields slightly lower carbon dioxide (CO2) emissions than Scenario 1 in both the short and long run. Scenario 3 produces the highest amount of carbon emissions (both in the short and long run) due to expected fleet composition transitions following an outright removal of the gas tax. Figures 3, 4, and 5 visualize the results from the carbon model at a high level.

Figure 3. Total short run carbon dioxide emissions in 2035

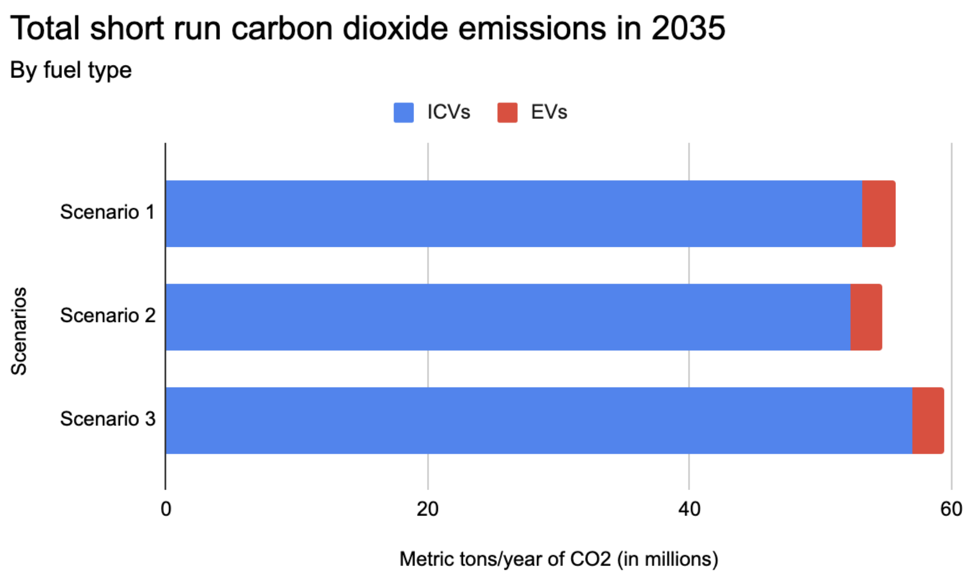


Figure 4. Total long run carbon dioxide emissions in 2035

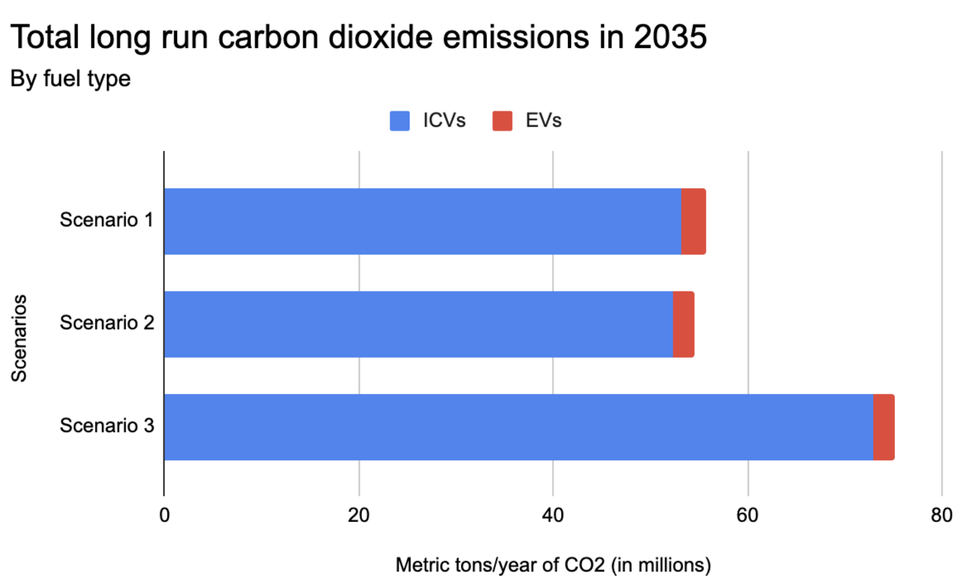
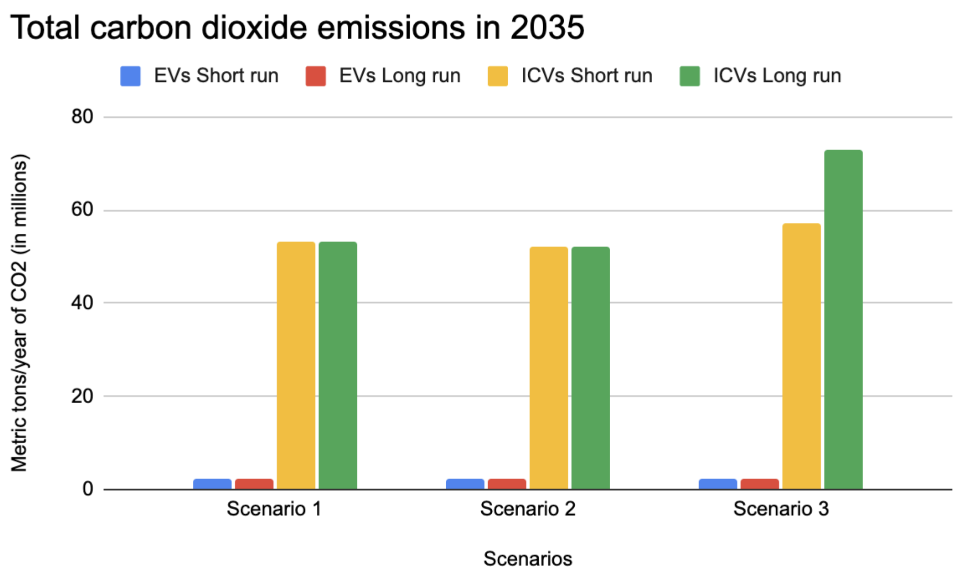


Figure 5. Total carbon dioxide emissions in 2035, consolidated



In Scenario 3, high carbon emissions are especially prevalent for light trucks, with RUC incentivizing higher market share of ICV light trucks. Thus, replacing the gas tax with a RUC scheme for ICVs emits more carbon dioxide. Scenario 3 emissions rise even more in the long run, painting a clear longer term picture of carbon emissions. Within this timeframe, drivers adjust to price differences over these longer periods of time, settling into long run consumer behavior. In the long run, the pricing shift from a gas tax to RUC for ICVs exacerbates vehicle inefficiencies and climate externalities, underscoring the role of pricing in influencing travel behavior. With lower fiscal barriers, there is a market shift towards more inefficient vehicles, causing carbon emissions to skyrocket in the long run (adding almost 20 million metric tons/year of carbon dioxide) compared to Scenarios 1 and 2. In fact, these emission increases are only attributed to the pricing reduction for ICVs when switching from a gas tax to a RUC scheme. As mentioned in the limitations and key uncertainties section, these results are limited by a lack of data to project changes to fleet composition for EVs. However, with a price effect on EVs in Scenarios 2 and 3, we would theoretically expect a slight reduction in EV use and a marginal increase in ICVs. This would only exacerbate the rise in carbon emissions in Scenario 3 (and even Scenario 2).

In contrast to ICVs, carbon emissions decline for EVs in Scenarios 2 and 3 when adding a price to driving. This effect is present both in the short and long run, with more drastic declines in the long run. This is an important finding, because it implies that there are environmental benefits to pricing EV drivers for their road use. This provides an area of opportunity to reduce driving's carbon footprint while filling the funding gap, since EV drivers will supply new revenue for transportation funding through RUC while facilitating a decline in carbon emissions.

Changes to ICV fleet composition based on pricing

For all eight vehicle types, there is a decline in carbon emissions for ICVs in Scenario 2 compared to Scenario 1. This decline is attributed to the RUC price effect on PHEVs. In Scenario 1, PHEVs pay a gas tax for the gas they consume. However, in Scenario 2 and 3, PHEVs are assumed to no longer pay a gas tax and instead pay a RUC. This reduces carbon emissions for ICVs in Scenarios 2 and 3, since PHEV VMT is no longer accounted for with ICVs. The reduced carbon footprint for ICVs between Scenario 1 and Scenario 2 are important to note, but stem from assumed, and later recommended, policy that would exempt PHEVs from paying a gas tax in Scenario 2. In other words, while there is a decline in carbon emissions from Scenario 1 to Scenario 2, they are associated with the price effect on EVs rather than relating to ICVs.

For most vehicle types, Scenario 3 yields the highest carbon emissions in both the short and long run, with noticeable increases in the long run, likely due to shifts in vehicle market share. Figures 6 and 7 provide a macro-level breakdown of carbon emissions for ICVs based on vehicle type in the short and long run.

Figure 6. Total carbon dioxide emissions for ICVs in the short run

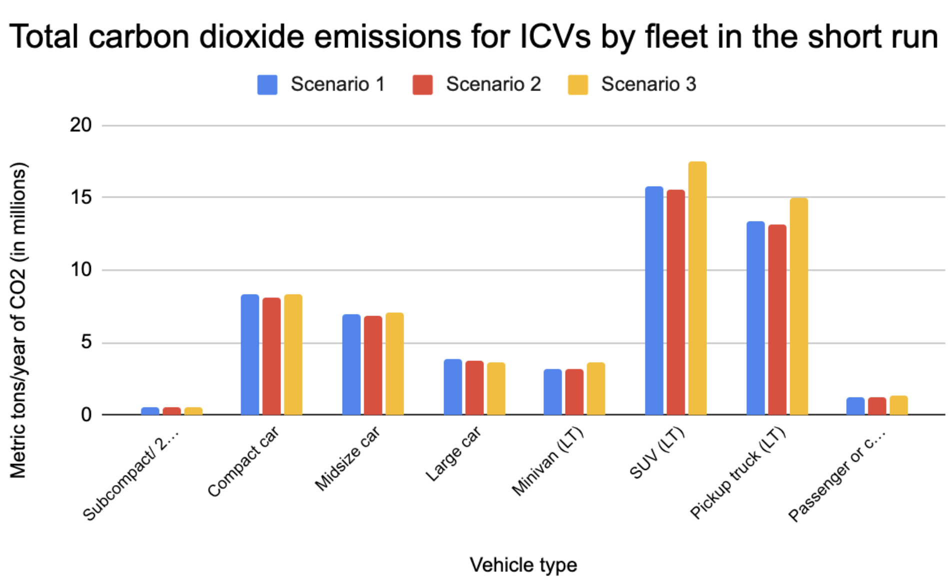


Figure 7. Total carbon dioxide emissions for ICVs in the long run

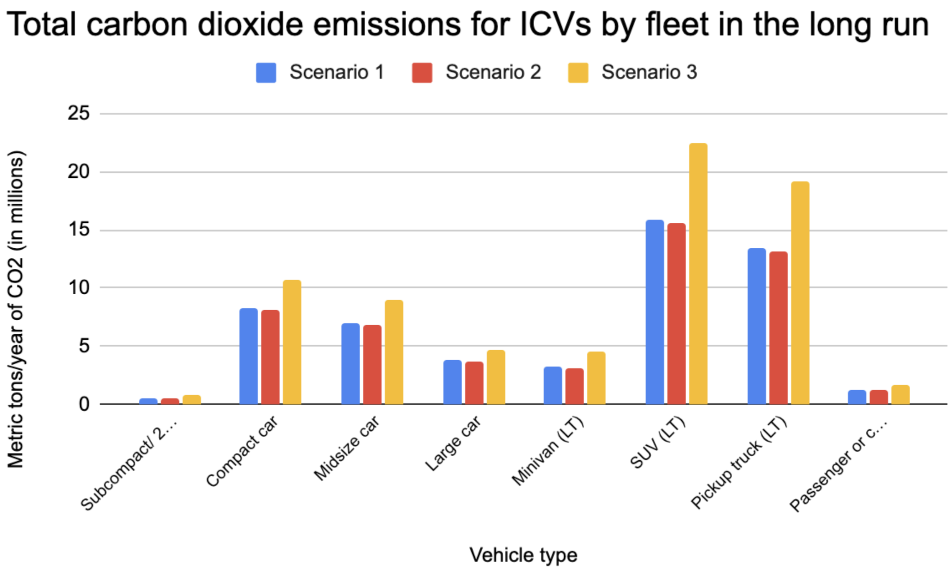


Table 1 and 2 list changes to carbon emissions from Scenario 1 (existing conditions) to Scenario 3 (widespread RUC scheme with the removal of the gas tax) and Scenario 2 (dual pricing scheme) to Scenario 3.

Table 1. ICVs: percent change of carbon emissions from Scenario 1 to Scenario 3

Vehicle type	Short run percent change	Long run percent change
Cars:		
Subcompact/ 2 seater car	-1.5%	26.0%
Compact car	1.3%	29.5%
Midsize car	1.0%	29.2%
Large car	-3.7%	23.2%
Light trucks:		
Minivan	11.2%	42.3%
SUV	10.8%	41.8%
Pickup truck	11.9%	43.2%
Passenger or cargo van	10.7%	41.6%

In table 1, short run changes to driving behavior, reflected in carbon emissions, are modest, with some slight decline for subcompact/ 2 seater cars and large internal combustion cars. Increases in carbon emissions are low for compact and midsize internal combustion cars. However, even in the short run, light trucks (minivan, SUV, pickup truck, and passenger or cargo van) yield noticeable increases in carbon emissions. In the long run, all cars and light trucks have substantial increases in carbon emissions, when replacing the gas tax altogether with a RUC scheme. This is partly attributed to the shift in fleet composition that is expected when changing the pricing mechanism for ICVs.

Table 2. ICVs: percent change of carbon emissions from Scenario 2 to Scenario 3

Vehicle type	Short run percent change	Long run percent change
Cars:		
Subcompact/ 2 seater car	0.3%	28.3%
Compact car	3.1%	31.9%
Midsize car	2.8%	31.6%
Large car	-1.9%	25.5%
Light trucks:		
Minivan	13.3%	44.9%
SUV	12.9%	44.4%
Pickup truck	14.0%	45.8%
Passenger or cargo van	12.8%	44.2%

Table 2 shows similar results to table 1. In the short run, shifting from Scenario 2 to Scenario 3, which only changes the pricing for ICVs away from a gas tax to RUC, does not produce substantially higher carbon emissions for cars in the short run. Like table 1, light trucks have a significant rise in carbon emissions even in the short run. In the long run, all ICVs (cars and light trucks) emit far more carbon.

Tables 1 and 2 indicate that removing the gas tax and replacing it with RUC skyrockets carbon emissions. This is likely due to the fact that gas taxes serve as a proxy for vehicle efficiency, with less efficient vehicles paying more in gas taxes. Replacing the gas tax with RUC removes incentives to purchase a fuel efficient vehicle, since all drivers pay a fixed cent per mile driven rather than paying for gasoline consumption, which varies based on vehicle efficiency. This encourages individuals to drive less fuel efficient vehicles, triggering less efficiency within fleet compositions, thus raising carbon emissions.

6 | Limitations and key uncertainties

Research findings are limited by a number of factors. All assumptions listed both in the methodology section and the appendices provide key uncertainties, since lived travel behavior, fleet changes, and other assumptions are based on historical data to project future changes. This in itself yields uncertainty within the research findings. One calculation in particular relied on the assumption that plug-in hybrid electric vehicles (PHEVs) used 50% electricity and 50% gas. However, this metric varies by specific vehicle and year of production, so this assumption serves as an aggregate measure. Other aggregate assumptions relate to driver behavior and price signals, which may vary between drivers. There is no way to perfectly predict how individuals may change their travel behavior or potentially switch vehicles, not just because each individual has different preferences and values, but because a RUC charge has not yet been implemented. As such, there is no sure way to reveal how a RUC may change travel behavior and fleet composition exactly, leading to some uncertainties.

Relatedly, the research findings have uncertainty when relying on changes to fleet composition. As mentioned in the methodology section, fleet compositions are based on historical data to project variation in vehicle fleets. Fleets are almost guaranteed to change if the gas tax disappears, encouraging some individuals to purchase less fuel efficient vehicles. This is similarly based on consumer preference, which is difficult to capture. Vehicles may also become even more efficient, which could further change consumer vehicle choice. Thus, fleet composition poses another key uncertainty.

Regardless of this uncertainty, the carbon model captures changes to fleet composition for internal combustion vehicles (ICVs) based on historical data. This projection in itself is limited by available data. Scenario 2 sought to reveal carbon emissions based on pricing increases for electric vehicles (EVs) and no price effect for ICVs. Scenario 3 projected carbon emissions based on the same price increase for EVs and a price decrease for ICVs (since transitioning from a gas tax to RUC would make driving cheaper for ICVs). My fleet composition estimate is based on a Congressional report's findings on the effect of increasing the price for road use on fleet composition. In their report, they estimated the effect of a 20 percent increase in the price of gasoline on U.S. market shares of new passenger vehicles. There was no available data on the reverse, a decrease in the price of gasoline on market share. In order to determine the effect of a price decrease for using the roads (for Scenario 3), I reversed the signs (from positive to negative or negative to positive, depending on the metric) for average price effect. This provides notable uncertainty because it assumes that market share would change synonymously, in the opposite direction, for a price decrease as a price increase. For example, the CBO found that with a 20% price increase in gasoline, SUVs would decline by 1.2% in their market share. I flipped the sign, indicating that a 20% price decrease in gasoline would yield a 1.2% increase in the market share of SUVs. This makes sense theoretically, because if it were cheaper to drive gas-guzzling cars, more people would likely own one. Thus, this methodology is in line with what is expected of consumer behavior, though it may not be entirely accurate as an assumption.

This type of data was not available for EVs (all-electric vehicles and plug-in hybrid electric vehicles) and thus the CBO report could not be applied. It did not seem appropriate to employ the average effect of a price increase for EVs in Scenarios 2 and 3 since light trucks are half of the vehicle types in the CBO report, and there are virtually no light truck EVs on the market yet. Applying the CBO market share shifts would only show a decline in EVs and would not accurately reflect the displacement of previous EV drivers based on price increases. Attempting to reflect the change in market share of EVs based on pricing increases alone would yield negligible results, since EV drivers make up such a small fraction of drivers on the road. One may expect that pinpointing shifts away from EVs towards ICVs due to price increases would yield slightly higher carbon emissions, though it would only be a marginal increase. As such, the results are skewed by these discrepancies in fleet composition shifts.

Another limitation of particular importance is the use of elasticity as a proxy for price changes. As detailed in the methodology section, a more accurate projection would encompass travel behavior based on switching from a gas tax to a RUC or adding a new charge (a RUC charge) for EVs using a RUC pricing metric. However, this data does not yet exist, since RUC has not been implemented on a wide scale and has yet to supplement or replace any gas tax.

Further, these results are limited by the assumption that PHEVs would transition from paying any gas tax to a RUC in a dual funding scheme (Scenario 2). With RUC programs likely in the hands of state legislation, states would have the authority to create their own rules within a RUC scheme, so it is unclear whether they would require PHEVs to pay both gas taxes and a RUC. Likely, states would not require PHEVs to both, since PHEVs pay for part of their use of the road through the gas tax. There is little guidance on how different states may address PHEVs in a dual funding scheme, thus limiting the accuracy of the carbon model from this lens.

Finally, it is critical to note that these research findings are California-specific. Any effort to replicate these results in other states or nationwide would require application of the United States Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES) tool, which provides data for other states.

7 | Discussion and recommendations

Major takeaways

Results from the carbon analysis, based on elasticity projections, provide two distinct directions for future transportation financing. Both supplemental funding schemes, which require a road user charge for electric vehicles (EVs) (Scenario 2 and 3), are expected to fill in the road funding gap detailed in the literature review section. Choosing between a dual funding scheme (Scenario 2) and a complete replacement of the gas tax with RUC (Scenario 3) therefore becomes an issue of state and federal climate goals. For states like California, with ambitious goals to cut air pollution by 71% by 2045 (Office of Governor Gavin Newsom 2022), a dual funding scheme is the clear winner. However, a more sophisticated universal RUC scheme which customizes RUC fees based on vehicle class and fuel type, charging less fuel efficient vehicles higher user fees per mile, can achieve the same climate goals. If states do not highly value climate improvements and instead aim for a simple funding solution for all vehicles, an outright replacement of the gas tax might be easiest. However, there are other concerns with an abolishment of the gas tax which complicate ease of implementation, like political feasibility, climate externalities, and equity concerns related to environmental justice.

Recommendations

Recommendation #1: Establish federal guidance with a dual funding scheme as the suggested solution to address the transportation funding crisis and to support national climate goals

Based on the results of the carbon analysis (relying on elasticity) and national climate goals, the best path forward is a dual funding scheme, with internal combustion vehicles (ICVs) continuing to pay the gas tax while EVs pay a road user fee. The main difference from our existing financing system is that a dual funding scheme requires *all* vehicles to pay for their road use in some way. Universal fee requirements reduce driving's carbon footprint by adding a price to driving for all vehicles. However, the carbon analysis also implies that completely removing the gas tax altogether and replacing it with a uniform mileage-based RUC would drastically increase carbon emissions. This reveals an important lesson about the implications of financing systems in spurring vehicle fleet changes.

A dual funding scheme incentivizes fuel efficient vehicles regardless of the type of fuel they use. In this scenario, ICVs are encouraged to drive fuel efficient vehicles because drivers are paying taxes for their gas consumption. More efficient vehicles will require less payment in the form of gas taxes. Individuals are still incentivized to purchase EVs. Though EV drivers are incurring an additional cost in the form of a road user fee, these fees are less than gas taxes.

In a universal, uniform RUC financing system, the pricing effect causes serious climate ramifications as it encourages changes to fleet composition. For ICVs, an outright replacement of the gas tax with RUC may encourage drivers to purchase less efficient vehicles, since their user fees are based solely on mileage rather than fuel consumption. This means that some drivers may make the switch from more fuel efficient to less efficient ICVs (i.e. buying that dream Ford F-150 now that fees come from mileage instead of fuel consumption). Additionally, it may encourage individuals driving EVs to switch to ICVs, since many EVs are still more expensive on the aggregate than ICVs (Baldwin, Richie, and Vanderwerp 2022). These expected fleet changes manifest as significantly higher carbon emissions, since there is little incentive to drive fuel efficient vehicles with a 100% RUC financing scheme.

Considering these climate ramifications, the federal government should establish guidance for states as they seek to fill in transportation funding gaps. With many states piloting RUC systems, the federal government should encourage states to adopt a dual funding scheme and discourage states from abolishing the gas tax altogether. As the United States seeks to drastically cut its carbon footprint in many arenas, it is critical that future road funding support climate goals rather than exacerbate the climate crisis. The federal government should clearly underline the dangers of replacing the gas tax with RUC and instead advocate for a dual funding scheme. Not only would a dual funding scheme boost equity, with all drivers paying for their road use, but it reflects a more accurate price of driving compared to a complete replacement of the gas tax.

Recommendation #2: Replicate the model in other states

Within federal guidance on a dual funding scheme, the federal government should suggest that states conduct further analyses to support this report's research findings. California is a vanguard for innovative road financing and transportation policy. This model relies heavily on California's leadership in RUC piloting, the state's progressive and unique eagerness to adopt EVs, and its distinct public accessibility to statewide vehicle miles traveled (VMT) and carbon data tools. As mentioned in the methodology section, California operates its own tool to project transportation related emissions, the EMFAC tool. Beyond California, the United States Environmental Protection Agency (EPA) employs the Motor Vehicle Emission Simulator (MOVES) tool to assess both statewide and nationwide VMT and transportation related emissions. While these research findings present a clear picture for California, and RUC implementation would likely occur at the state level, California's carbon savings, through a dual funding scheme, is an impetus for further research beyond California. There would likely be differences in data, policies, and mobility elements from state to state, making it most appropriate for each state to replicate the California model within their own landscape.

Regardless of the results, states will still have to consider the overarching challenge of closing the transportation funding gap in a way that considers federal climate goals. However, state climate initiatives, or the lack thereof, may influence their choice for a future funding scheme. In other words, the desired outcome of future transportation funding to either simply reach revenue neutral or as a tool to manipulate travel behavior will dictate whether states adopt a dual funding scheme or universal RUC. In order to accurately understand the implications of different road financing schemes in other states, researchers must replicate these financing scenarios in other states using the EPA's MOVES tool.

Recommendation #3: Adopt a dual funding model in California

In order to determine next steps and recommendations from these results, it is important to be clear about California's goals in addressing funding shortfalls. With state goals to bridge the funding gap while simultaneously reducing carbon emissions, this research suggests, with relative confidence, that California should implement a dual funding scheme. A dual funding scheme, where ICVs continue to pay the gas tax while EVs pay RUC, acknowledges funding gaps by adding a pricing element to driving EVs. Not only does this encourage greater transportation equity, as all drivers are now paying for their use of the road in some capacity, but it will add new revenue streams that can supplement the gas tax. A dual funding scheme will also reduce California's carbon footprint by adding a price to driving for EVs, thus reducing VMT slightly. When considering the other funding options modeled, it is clear that a complete replacement of the gas tax with RUC will drastically increase California's carbon footprint. Alternatively, relying on existing conditions (where EVs do not pay any road user fees) fails to recognize the funding crisis and poses an equity concern since EVs do not pay any fees or taxes for their use of the road.

This research relies on VMT projections solely based on elasticity, informing the choice of a dual funding scheme as the recommended financing solution. However, a universal RUC system may be possible, even considering climate goals, when adding customized RUC fees based on vehicle class and fuel type. For example, in a more sophisticated system, RUC fees could be charged at vehicle registration renewal, allowing fees to be tied to the vehicle's specific classifications. High emitting vehicles could be charged higher RUC fees, incentivizing the purchase of fuel efficient vehicles. In this way, the link between fuel efficiency and pricing remains intact, where those imposing more externalities (i.e. emitting pollutants into the air) pay more to do so.

Both solutions, either a dual funding scheme or a variable universal RUC system, address existing concerns and even encourage further EV use. Mileage-based road user fees are still lower than gas taxes. 2022 research found that currently, drivers are paying 12 cents per mile on average, including gas taxes (Glaeser, Gorback, and Poterba 2022). A dual funding scheme would require EVs to pay a road user fee of about four cents per mile (Glaeser, Gorback, and Poterba 2022), a third of the average price per mile to drive an ICV. As such, while EV drivers are incurring new driving fees, they are still comparatively less than those imposed onto ICVs through the gas tax.

Recommendation #4: Develop supportive policy for EVs and PHEVs in California

As a follow-up to recommendation #3, California must craft policies that will still incentivize drivers to purchase EVs and plug-in hybrid electric vehicles (PHEVs) despite the new user fees. This includes policy that ensures that these fuel efficient vehicles are only paying a road user charge without any additional fees. These policies will support California's climate goals by incentivizing fuel efficient vehicles.

Currently, PHEVs pay gas taxes for the gas they use. However, for ease of implementation and as a means of supporting purchase of fuel efficient vehicles, policy should exempt PHEVs from paying gas taxes so that these drivers are not paying multiple user fees on their vehicle. Otherwise, drivers may opt to purchase a less fuel efficient vehicle. This policy recommendation is in line with the carbon model I developed, which assumed that PHEVs would transition from a gas tax to RUC. This policy would ensure that PHEVs are still paying for road use, but may encourage purchase of PHEVs through cost savings (since mileage-based user fees are cheaper than gas taxes).

Similarly, California must produce supportive policies that eradicate special fees for PHEVs and EVs. As mentioned previously, California is one of many states that charges certain PHEVs and EVs a special fee in addition to registration fees. These special fees are imposed in an effort to bridge the transportation funding gap. However, in order to further incentivize purchase of fuel efficient vehicles, California should remove these special fees. This is particularly important for PHEVs. Without such policies, PHEV drivers could be paying three user fees: gas taxes, road user charges, and special fees. This would certainly hinder market share for this vehicle type.

One obvious concern is the implementation of such policy. How might PHEVs be exempt from paying gas taxes at the pump? Policy can address this roadblock by subtracting gas taxes paid at the pump from RUC bills. This can be done through an algorithm that calculates gas taxes paid based on mileage, make, model, and year of the vehicle, and receipts for gas purchase.

8 | Conclusion

Faced with several hurdles, from technological innovation to the diminishing purchasing power of the gas tax, traditional transportation finance mechanisms are failing to support current and future mobility needs. Recent research indicates that a road user charge (RUC) system may be best suited to address these fiscal shortfalls, though the literature has yet to identify how RUC may interact with current financing mechanisms and influence fleet composition. This research simulated the effect of a RUC scheme on vehicle miles traveled (VMT), carbon emissions, and fleet composition to find the ideal financing scenario that will close the funding gap and prioritize climate goals. Results from the carbon model suggest that a dual funding scheme, where internal combustion vehicles (ICVs) continue to pay the gas tax and electric vehicles (EVs) pay a RUC, is the optimal solution to the funding crisis. Four recommendations will further this research:

1. Establish federal guidance with a dual funding scheme as the suggested solution to address the transportation funding crisis and to support national climate goals.
2. Replicate the model in other states.
3. Adopt a dual funding model in California.
4. Develop supportive policy for EVs and PHEVs in California.

Strong consideration of a RUC scheme is imperative as planners and politicians search for a solution to the transportation funding crisis. However, with transportation being the largest emitter of greenhouse gas emissions, it is vital that these leaders understand the implications of implementing new pricing schemes on driving and use it to their advantage to fight climate change.

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Appendices

Appendix 1A: Carbon Modeling Assumptions

<table>
<tr><th>Carbon Modeling Attribute</th><th>Description of Assumption</th></tr>
<tr><td>1. Target on-road fleet-wide fuel economy</td><td>Target fleet-wide on-road fuel economy was set at 49 miles per gallon (mpg) based on the US Department of Transportation NHSTA’s April 1, 2022 announcement to increase target on road fuel economy from 40 mpg to 49 mpg (NHTSA 2022).</td></tr>
<tr><td>2. Light vehicle sales, EV GHG emissions, new vehicle mpg on road, and % vehicles surviving in 2035</td><td>Data for these metrics came from Transportation Energy Database (TEDB) (TEDB 2022).

I had to project light vehicle sales after 2020, since the TEDB only had data until 2020. I assumed that light vehicle sales in 2021 grew 3.4% from 2020 levels, as an article from AP News recently found this growth rate for 2021. For 2022-2026, I assumed that light vehicle sales returned back to the TEDB's 1970-2020 average growth rate of 0.7%, as sales begin to return to pre-pandemic levels (Krisher 2022).</td></tr>
<tr><td>3. Carbon content of gasoline</td><td>I calculated the carbon content of gasoline to be 8,921 grams of CO2 per gallon of gasoline by multiplying 2,433 (the carbon content for gasoline blendstock (TEDB 2022)) by 44/12 (since CO2 has an atomic weight of 44 and carbon atoms have an atomic weight of 12) (US Department of Energy Office of Energy Efficiency and Renewable Energy n.d.).</td></tr>
<tr><td>4. ICV vehicle fleet data</td><td>In order to project fleet changes as a result of various road pricing schemes, I extracted data from the Congress of the United States Congressional Budget Office (CBO) and the United States Environmental Protection Agency (EPA).
Estimated effect of a price increase on US average market share and average effect of increase for new passenger vehicles:
The CBO report estimated the effects of a price decrease, so I assumed that the positive and negative signs would simply flip for a reversal to a price increase.
Source: Austin 2008
Mpg for 2021
Cars
I assumed that large cars would be classified as Car SUV, applying the Car SUV mpg of 32.4.
I assumed that subcompact/ 2 seater cars, compact cars, and midsize cars had a mpg of 33.7. All vehicle types had a general mpg range of 30-35. The EPA listed sedan/wagons to have a mpg of 33.7, so I chose this number because sedans/wagons are classified under these vehicle types and because 33.7 is about in between 30-35</td></tr>
</table>

	mpg. ■ Source: US EPA 2022 ○ Light trucks ■ The EPA had more clear breakdowns of mpg for light trucks. ■ I assumed my minivan category was synonymous with the EPA's minivan/van category under trucks, with a mpg of 27.3. ■ I assumed my SUV category was synonymous with the EPA's truck SUV category, with a mpg of 24.1. ■ I assumed my pick up truck category was synonymous with the EPA's pickup truck category, with a mpg of 19.3. ■ I assumed my passenger or cargo van category was synonymous with the EPA's minivan/van category under trucks, with a mpg of 27.3. ■ Source: US EPA 2022
5. All electric vehicle and PHEV vehicle fleet data	Less explicit data was available for all electric vehicles and PHEVs. In order to create comparisons to ICV fleet data, I made multiple assumptions based on data from the CBO report, the International Energy Agency (IEA), and the EPA fuel economy search engine. Appendix 1B includes a table with the assumptions made regarding vehicle type for all electric and PHEV data. For each vehicle type, in order to find the average mpg in 2021 for all electric and PHEV cars, I noted each vehicle's mpg listed on the EPA's fuel economy search engine for the specific vehicle type, year, and fuel type. I used mpg for combined city and highway. I then took the average of each vehicle class's mpg from these lists to produce mpg for 2021. I applied average market share metrics from the IEA. Sources: Austin 2022; IEA 2022; US Department of Energy Office of Energy Efficiency and Renewable Energy n.d.
6. Calculating new VMTs in scenarios 2 and 3 with road user charge schemes	I applied the price elasticity of demand equation to project new VMTs in both the short and long run for four fuel types: diesel, gasoline, electric, and PHEV. Price elasticity of demand equation: $e_{(p)} = \frac{dQ/Q}{dP/P}$ where

	$e_{(p)}$ = price elasticity Q = quantity of the demanded good P = price of the demanded good Source: BCcampus n.d. This formula required me to calculate the changes in price to find the price effect of replacing the gas tax with a road user charge. Prices were drawn from Glaeser et al., who estimated fuel costs for ICVs, all-electric vehicles, and PHEVs when transitioning from a gas tax to a price per mile driven (i.e. a road user charge) (Glaeser, Gorback, and Poterba 2022).
7. Fleet change projections for EVs	The carbon model does not account for changes in fleet composition for EVs based on price increases (addition of RUC) because data for EVs does not exist.

Appendix 1B: All Electric Vehicle and Plug-in Hybrid Electric Vehicle Fleet Assumptions

CBO classification (Austin 2008)	**IEA classification (IEA 2022)**	**EPA classification (US Department of Energy Office of Energy Efficiency and Renewable Energy n.d)**
Subcompact/ 2 seater car	Small car	Small car Sports car
Compact car	Half of medium car count	Family sedan
Midsize car	Half of medium car count Crossover	Upscale sedan Luxury sedan Station wagon Hatchback
Large car	SUV Large car	SUV