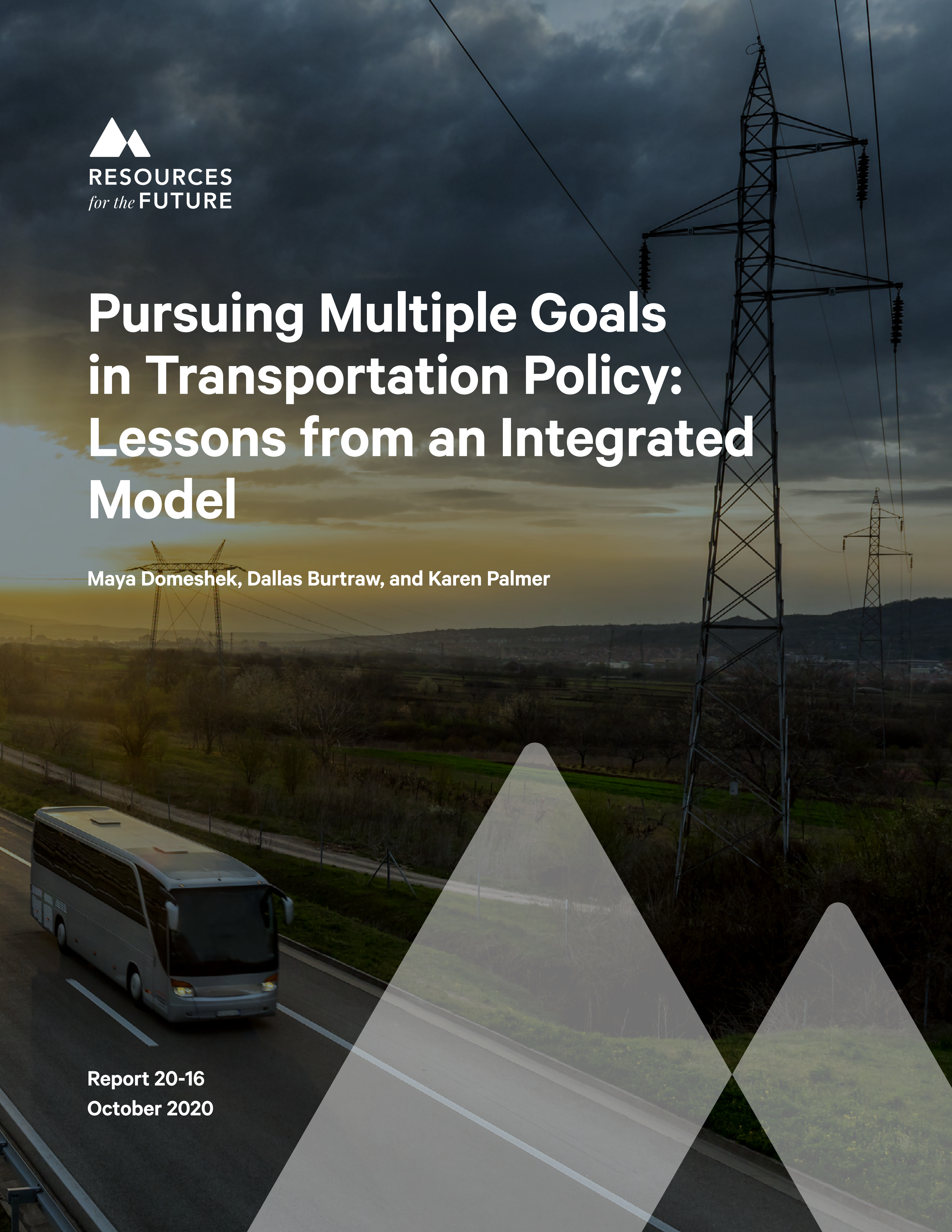

RESOURCES *for the* FUTURE

Pursuing Multiple Goals in Transportation Policy: Lessons from an Integrated Model

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Karen Palmer has been a researcher at Resources for the Future for over 25 years. Dr. Palmer specializes in the economics of environmental regulation and public utility regulation, particularly on issues at the intersection of climate policy and the electricity sector. Her work seeks to improve the design of incentive-based environmental and technology regulations that influence the electric utility sector and to help inform the ongoing transition of the electricity sector. To these ends, she explores new designs for policies targeting carbon emissions, analyzes efficient ways to promote use of renewable sources of electricity and energy efficiency and investigates market and regulatory reforms to pave the way for long-term de-carbonization of electricity supply and electrification of the energy economy. She is co-author of the book, Alternating Currents: Electricity Markets and Public Policy, published by RFF Press. **palmer@rff.org**

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Introduction

The existential threat of climate change requires changes in our transportation networks nearly as dramatic as those that occurred a century ago with the advent of the internal combustion engine. These changes will likely include electrification of vehicle fleets, expansion of non-personal-vehicle travel, and changes in land use. This report is motivated by the efforts of 13 jurisdictions in the Northeast and Mid-Atlantic that are developing the **Transportation and Climate Initiative (TCI)** to pursue this transportation transformation. The initiative involves three essential policy elements: carbon pricing on transportation fuels, investment of carbon revenues to promote cleaner transportation, and coordinated regulations. Although climate change is the main driver of this initiative, these jurisdictions have multiple transportation-related goals they hope to achieve. Importantly, the success of these initiatives will hinge on their ability to address more immediate community-level transportation sector concerns, such as environmental quality, transportation access, and affordability.

This report is not an analysis of TCI, which is being coordinated in an extensive modeling project led by the **Georgetown Climate Center**. Rather, it is intended to inform the decision process that TCI states will pursue. We exercise a modeling platform representing many of the Northeast and Mid-Atlantic states in the TCI region. We examine a set of transportation policy options, including carbon pricing and the use of carbon revenues, and we look at their performance along metrics relevant to multiple goals—carbon reductions, criteria pollution reductions, vehicle-mile changes, transportation availability, and distribution of costs across households. The model is not intended to identify a single best policy or set of policies but rather to highlight opportunities and trade-offs among multiple transportation goals that can inform a collaborative transportation planning process. We do not address the role of regulations, the third essential element of TCI transportation policy.

We identify five main lessons from this effort.

1. **Policy alternatives have varied cost-effectiveness for carbon and other air pollution reductions.** In general, vehicle electrification programs, especially of trucks and buses, offer the largest near-term reductions in carbon and conventional air pollutants. The location of the replaced vehicles will have a large effect on the health benefits achieved from these reductions.
2. **The financial effects of policies differ across types of households.** Policies that support public transit tend to benefit households that use transit or live in areas where transit is available, whereas policies that support vehicle purchases tend to lower expenditures for households that purchase new vehicles. Targeted policies, such as those that add transit where little is available or support electric vehicle use for households that would not ordinarily buy new vehicles, can change this distribution of financial benefits.

3. **Some policies have a relatively greater transformative effect, while others yield greater short-term emissions effects.** Policies that are transformative are those that lead to changes in capital expenditures by governments and households or that change land-use decisions. Policies that provide current-year incentives—for example, public transit fare subsidies—have more immediate, but not necessarily long-lived, benefits.
4. **Outcomes are always uncertain, but the magnitude and source of uncertainty vary across policies, and some of the potentially most potent policies are also the most uncertain.** For example, housing policies intended to change density and land use may have a large effect on environmental outcomes, but because they are indirect, they are more uncertain. Conversely, vehicle policies map into relatively predictable carbon and air pollution outcomes.
5. **Many benefits (and costs) that cannot be easily quantified remain important to community-level outcomes.** Many outcomes cannot be easily measured, and even the policies whose benefits and costs can be measured in aggregate will have different outcomes, depending on where and how they are implemented. Accounting for these effects will require community-level input and will also build community-level support.

Following the policy framework under consideration in TCI, we assume that revenue for the various policy options we explore is raised through an auction of emissions allowances in a cap-and-trade program covering transportation fuels. A similar policy framework is already in place in California and Quebec. A price on carbon emissions would provide an incentive to reduce gasoline and diesel fuel use, and the auction revenue, potentially along with other federal and state funds, could stimulate and coordinate the much larger private sector investment that is ultimately necessary to shift the transportation sector away from fossil fuel use. The third essential element of transportation policy, not addressed here, is regulations governing vehicles, fuels, roadways, transit, and land use: these are crucial for creating a setting that invites private sector investment.

In the next sections we briefly describe our model and the policy scenarios we investigate. We then report findings. We conclude by emphasizing that this type of research does not identify a solution to the transportation planning challenge, but it can facilitate the regulatory negotiations and collaborative engagement that are necessary to finding a solution.

Modeling

We model transportation policy alternatives in a framework representing the Northeast census region, which includes the six New England states plus New York, New Jersey, and Pennsylvania. The model is premised on the idea that every transportation policy has environmental, health, and economic outcomes, each of which is distributed differently across the population. The model characterizes the effects of pricing carbon and various government transportation investments on household and commercial transportation usage, household expenditures, emissions of carbon dioxide (CO_2), and local air quality (in emissions of nitrogen oxides, NO_x). The model characterizes the distribution of expenditure effects between metropolitan and nonmetropolitan households, across income groups, and across households with different patterns of transportation usage. Together, the multiple outcomes of each policy pathway shed light on contributions to the multiple goals of transportation policy and reveal trade-offs. See the appendix for further description of the model.

Policy Scenarios

We quantified more than a dozen policy pathways to arrive at several findings, presented below. The policies we investigate take effect in 2022 and are evaluated over a 10-year period. The policies include an emissions price sufficient to raise $1 billion in carbon revenue, and expenditure programs directing that revenue to various purposes. This program ambition could be scaled up, and policy types could be combined in various ways. Scenarios that are discussed here are listed in Table 1.

Table 1. Policy Scenarios

Policy Type	Policy Case	Price/ Investment	Details
Carbon Price	Emissions price for transportation fuels (CO_2Price)	\$3.51 per MT CO_2	Sufficient to yield \$1 billion in revenues; yardstick for all investment policies
Light-Duty Vehicles	Electric light-duty auto subsidies (EVLightAuto)	\$5,503–\$4,287 per vehicle	Incentive to move new-car buyers from gasoline to electric
	Electric light-duty truck subsidies (EVLightTruck)	\$4,986–\$3,933 per vehicle	Incentive to move new light-duty truck buyers from gasoline to electric
Buses	Electric heavy-duty truck subsidy (EVHeavyTruck)	\$46,980 per vehicle	Incentive for electric heavy truck over diesel truck
	Expansion of diesel bus service (DieselBusExpansion)	\$446,300 per bus	Add new routes, with ridership equal to average ridership in region
	Expansion of electric bus service (EVBusExpansion)	\$833,700 per bus	Add new routes, with ridership equal to average ridership in region
	Increase in diesel bus frequency of service (DieselBusFrequency)	\$446,300 per bus	Add diesel buses along existing routes, with ridership determined by elasticity of passenger trips with respect to frequency
	Increase in electric bus frequency of service (EVBusFrequency)	\$833,700 per bus	Add electric buses along existing routes, with ridership determined by elasticity of passenger trips with respect to frequency
	Electric bus subsidy (EVBus)	\$387,400 per bus	Incentive to choose electric bus over diesel bus at time of fleet turnover
Transit Fares	Rail transit fare subsidy (RailFare)	\$0.24–2.68 per passenger trip	Increase ridership along existing routes with subsidy to new and existing passengers
	Bus transit fare subsidy (BusFare)	\$0.30–1.60 per passenger trip	Increase ridership along existing routes with subsidy to new existing passengers
Land Use	Land-use density incentive (LandUse)	\$3,000 per household	Reduce VMT of a household by moving it from a lower density area to a higher density area.

EV = electric vehicle; VMT = vehicle miles traveled

Findings and Lessons

We emphasize that because of rough geographic mapping and substantial uncertainty around many of the parameters we quantify, our findings are illustrative only. We examine the results to arrive at the following five main findings.

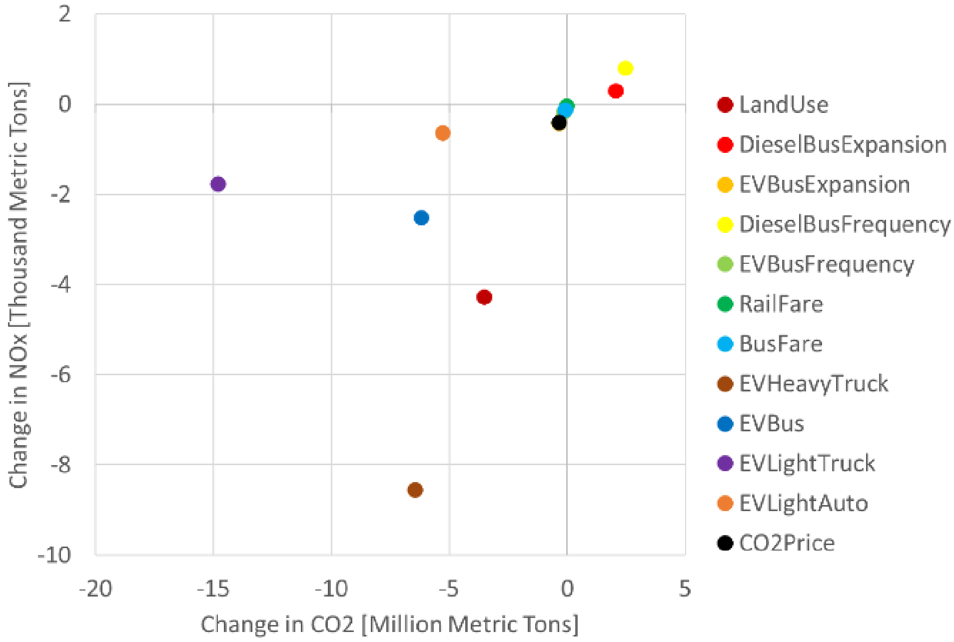
1. Policy alternatives yield different cost-effectiveness for carbon and air pollution reductions.

The potency of policies in achieving carbon reductions varies. However, for some policies, emissions reductions for CO_2 and conventional air pollutants are negatively correlated; that is, emissions of CO_2 may go up while other emissions go down, or vice versa. In Figure 1, policy outcomes in the southwest quadrant represent reductions in both CO_2 and NO_x. Electric heavy-duty trucks and land-use changes achieve the greatest reduction in NO_x; electric light trucks achieve the greatest reduction in CO_2. Electric buses achieve a mix of these two outcomes. The benefits of pollution reduction from buses, heavy-duty trucks, and light-duty vehicles may occur in different locations and benefit different populations and may have greater or lesser health benefits because of the concentration of populations nearby. Note that although all policies begin in 2022, the land-use policy pathway has a four-year lag before any results manifest, and the emissions reductions from land-use change will continue to increase even after 2032.

Electric School Buses

One policy that has the potential to reduce carbon and criteria pollution while guaranteeing health benefits to a vulnerable population is school bus electrification. The California Air Resources Board provided funding to the Ukiah Unified School District in Mendocino County to replace three diesel school buses with fully electric buses. This pilot program reduced emissions and exposure among young children. The program is part of a larger **Rural School Bus Pilot Project** that has funded more than 60 new school buses in California, an investment that is expected to reduce emissions by roughly 10,000 million tons of CO_2 per year.

Figure 1. Comparison of Changes in CO_2 and NO_x Emissions, 2032

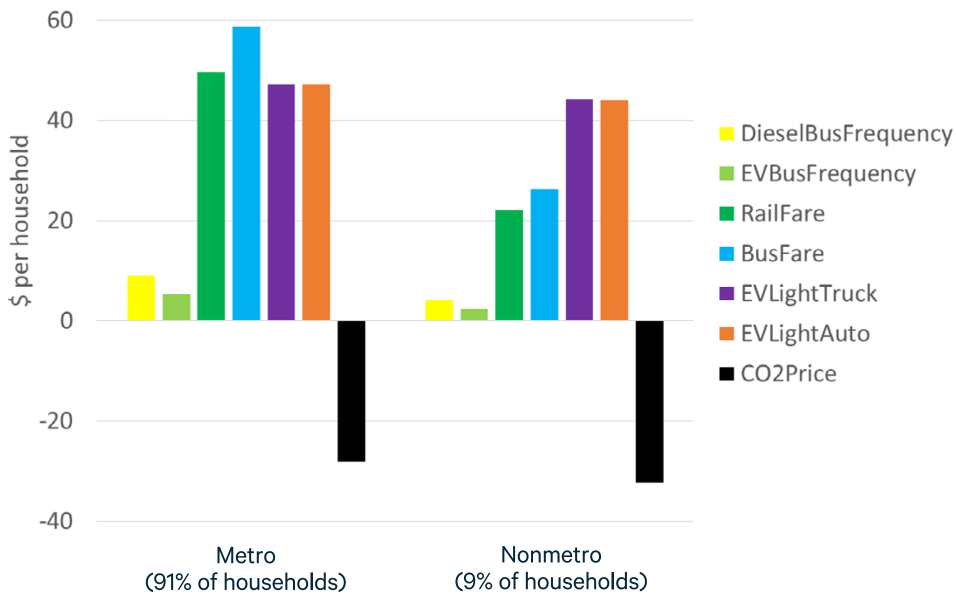


Conversely, expansion of the frequency of transit service with diesel buses can lead to an increase in both CO_2 and NO_x. If all the additional buses purchased to increase frequency were full and if all those new riders would otherwise have taken a personal vehicle, then the policy would yield a net reduction. However, because buses run, on average, far below capacity and new riders are drawn from a variety of transit options (walking, bicycling, taking trips that otherwise would not have been taken), the net effect is negative. Nonetheless, this policy could have significant benefits for transportation access in underserved communities—an important trade-off for policymakers. Increasing transit frequency with electric buses would yield both CO_2 and NO_x reductions because gasoline light-duty vehicle travel is replaced with zero-emissions travel. But the transit access benefit from increasing frequency with new electric buses is less than that of doing so with diesel buses because the same amount of money buys fewer electric buses.

2. The financial effects of policies vary across types of households.

Policies that support public transit lower out-of-pocket household expenditures in areas with existing transit users and to households that rely more on transit. Analogously, policies that support vehicle purchases tend to provide pocketbook benefits in areas and to households with greater vehicle ownership. This difference shows up most strongly for transit-related subsidies, where benefits per household accrue mostly in metropolitan areas (Figure 2). In contrast, the benefits per household for vehicle purchase subsidies accrue roughly equally across metropolitan and nonmetropolitan areas: even though a larger portion of households in nonmetropolitan areas drive personal vehicles, the lower average household income in these areas leads to fewer purchases of new vehicles that qualify buyers for an electric vehicle subsidy.

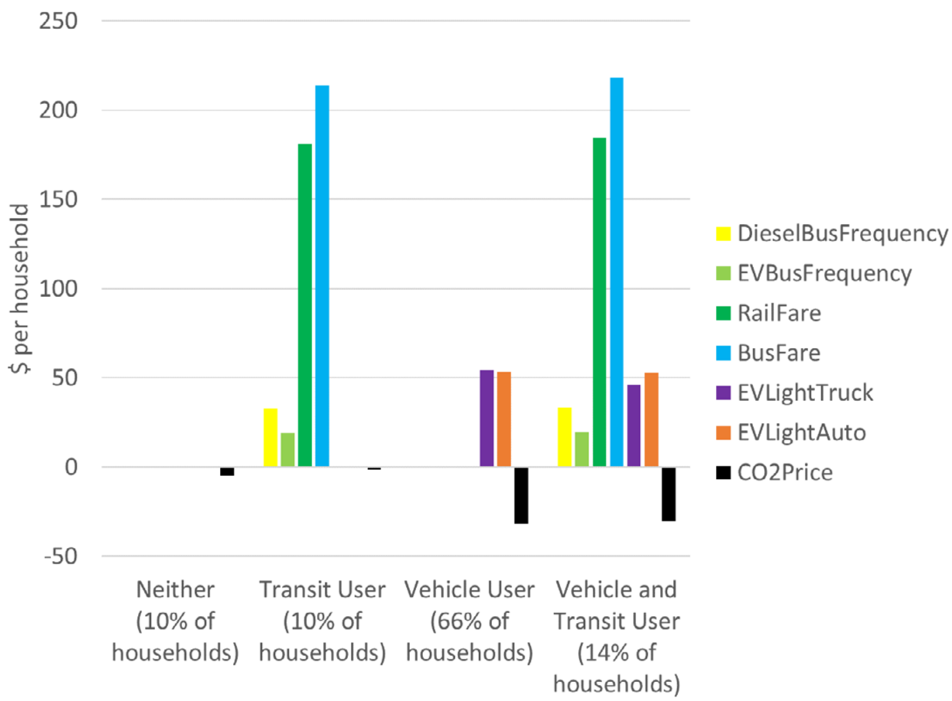
Figure 2. Household-Level Effects, by Region of Residence, 2022



Notes: Benefits per household for transit subsidies are twice as large in metropolitan areas compared with nonmetropolitan areas and are about equal for electric vehicle subsidies. Nonmetropolitan households spend more on fuel than metropolitan households and thus experience greater losses from the carbon price.

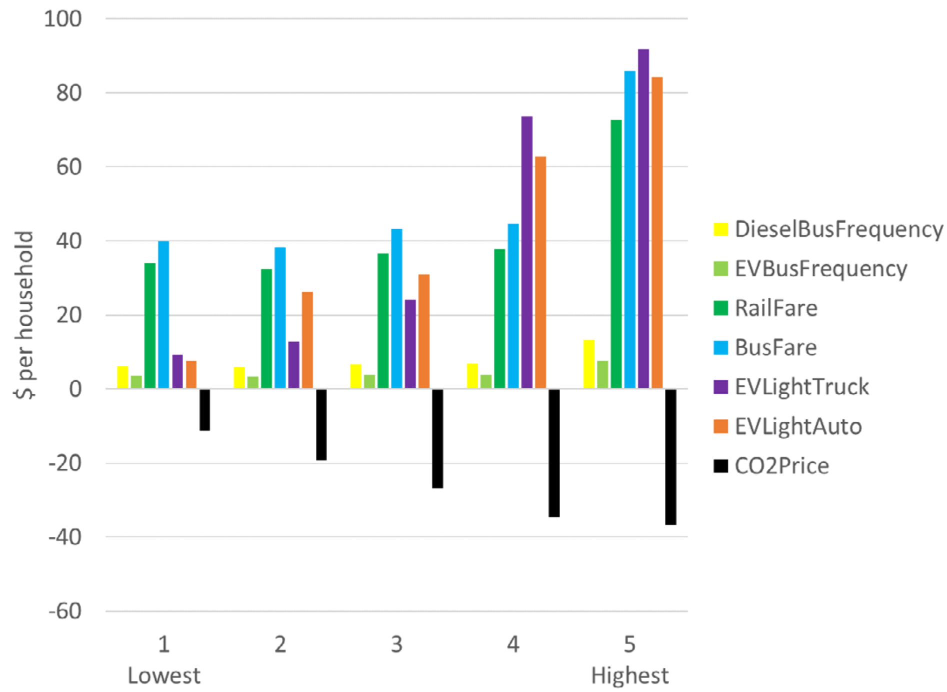
The difference in benefits between transit and vehicle subsidies varies substantially across households based on their transportation patterns (Figure 3) and across income groups (Figure 4). In general, wealthier households always realize greater benefits from subsidies because they spend more money on both transit and new vehicles. For lower- and middle-income households, transit subsidies lead to greater benefits than vehicle subsidies. The relative benefits of transit and vehicle subsidies are about equal in the third quintile, but the wealthiest households benefit the most from transit subsidies because of greater ridership in urban transit systems.

Figure 3. Financial Effects for Various Policies across Households Grouped by Transportation Use Categories, 2022



Notes: Policies that affect public transit costs benefit transit users, and policies that affect vehicle costs affect vehicle users.

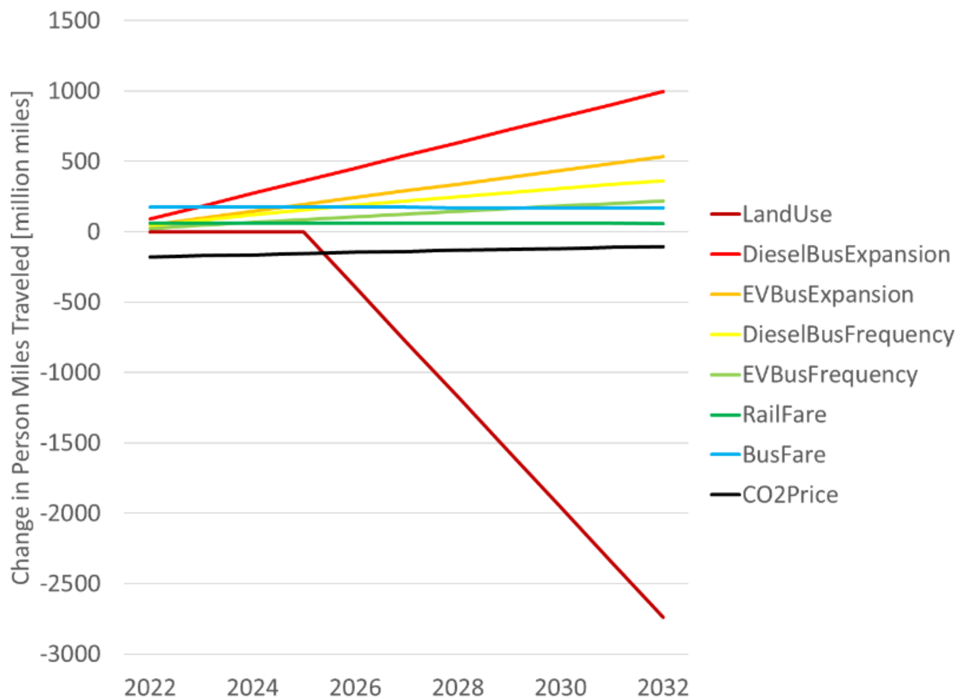
Figure 4. Financial Effects for Various Policies across Income Quintiles, 2022



Notes: Transit fare subsidies yield comparable benefits across the bottom four quintiles and greater benefits for the top quintile. Electric vehicle subsidies accrue primarily to the top quintiles.

Not all economic effects are easily monetized and distributed to households. Total person miles, which include transit, biking, walking, and driving, may serve as an imperfect proxy for people's access to transportation options, an important aspect of their economic well-being. Figure 5 illustrates that expanded diesel bus service and bus frequency yield the most significant increase in passenger miles traveled. The change in total person miles traveled is from additional trips, reflecting increased transportation access with an increase in public transit. In contrast, land-use changes have the biggest effect in reducing person miles traveled through higher density and improved planning.

Figure 5. Net Changes in Total Person Miles Traveled



Notes: Policies that make public transit more available increase person miles; Land use change decreases person miles by moving households to denser areas. Only policies expected to result in a change are displayed.

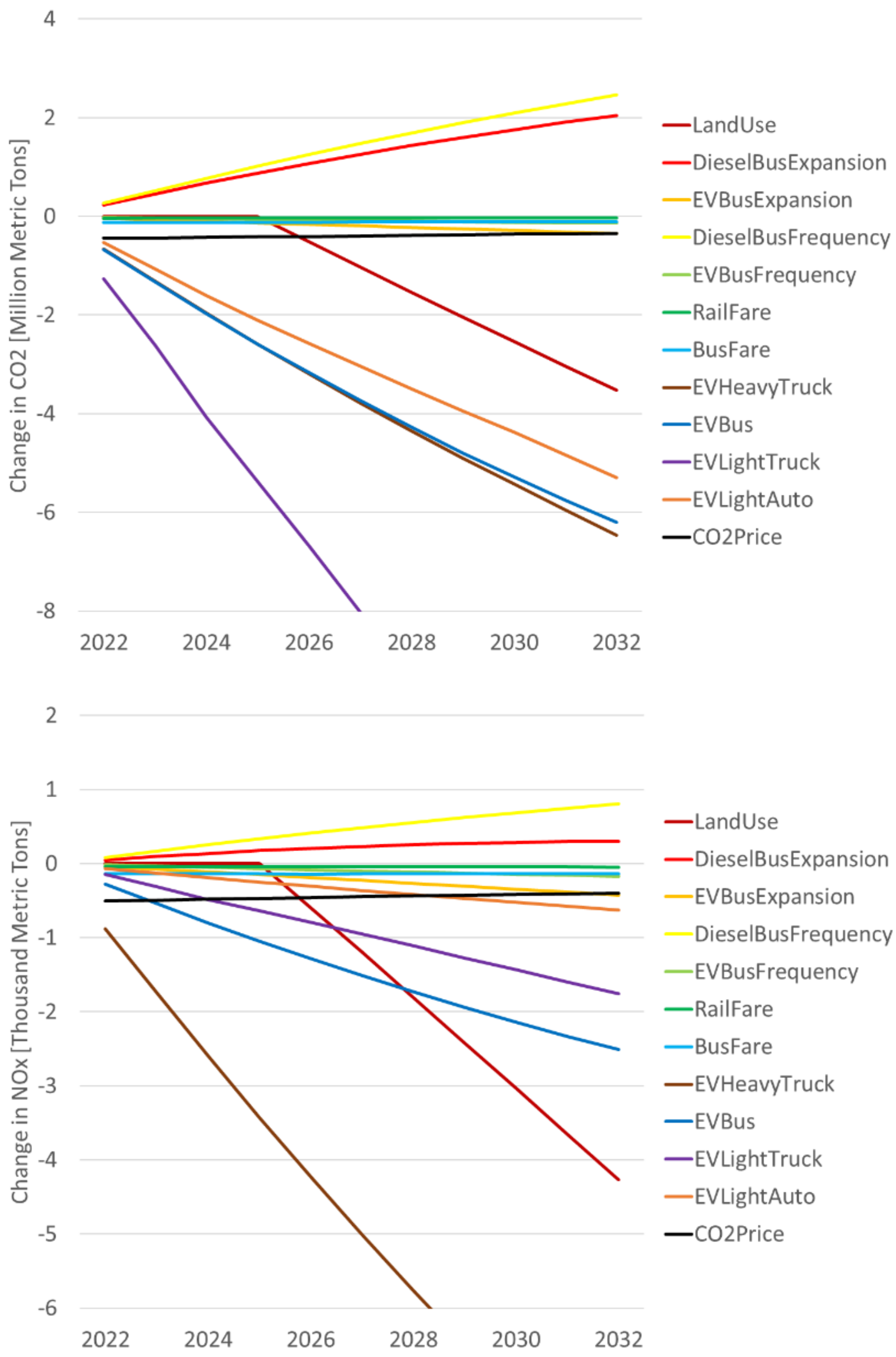
Rural EV Ride-Shares

A recent **report** by the Union of Concerned Scientists and MJ Bradley and Associates (Lowell et al. 2020) highlights the potential to increase clean transportation access in rural communities through nontraditional programs like EV car-share and ride-share programs. Such programs offer benefits to households who might not be able to take advantage of subsidies for new electric vehicles and might not have access to public transit. In particular, the report mentions the **Green Raiteros Rideshare Program** in California's San Joaquin Valley, which provides rides to connect households in the city of Huron with essential services in Fresno.

3. Some policies are transformative, and others have greater short-term benefits.

Transformative policies are those that lead to changes in capital expenditures by governments and households, or to changes in land-use decisions. The effects of these policies may not be evident in the first year(s) of implementation, but with persistent investment over the years, they are cumulative. Figure 6 illustrates the change in CO_2 emissions over time. Increasing diesel bus frequency increases emissions cumulatively. Replacement of diesel buses with electric buses reduces emissions in a roughly symmetric way. Purchase subsidies for electric light-duty automobiles and trucks also reduce emissions cumulatively. Land-use changes are quite potent but take time to appear.

Figure 6. Changes in CO_2 and NO_x Emissions over Time



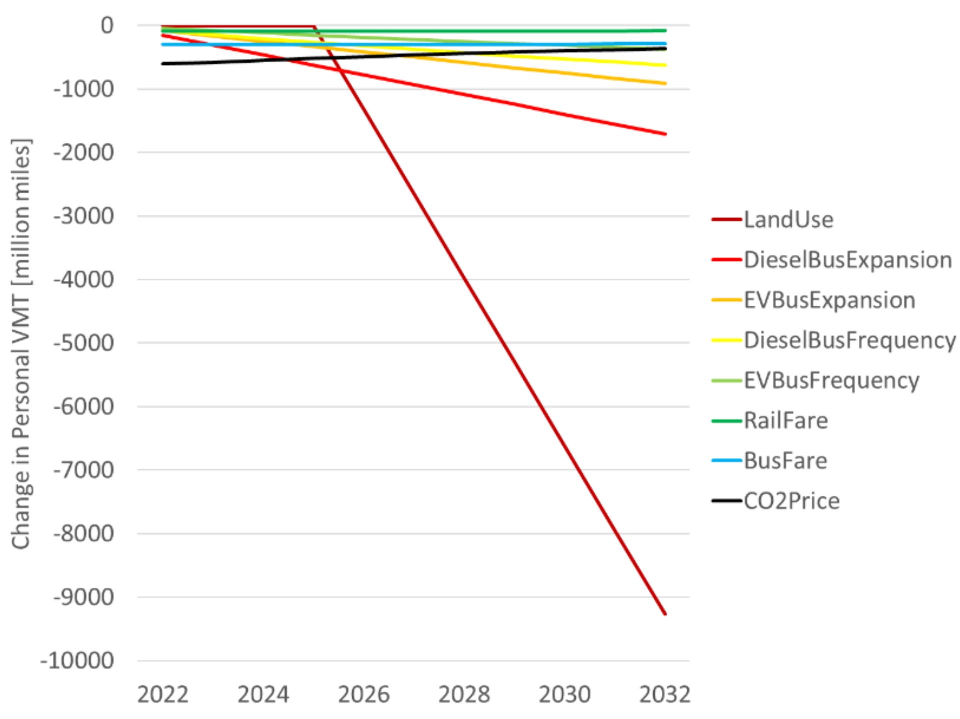
Notes: Policies that encourage capital purchase decisions by households, businesses, or transit agencies have the largest cumulative effect over time.

Some policies direct revenues to current-year incentives—for example, by subsidizing public transit through fare reductions. These effects may be felt right away, but when funding changes for current year incentives, the impact of these policies is immediately affected. In our model these effects are short term and do not cumulate over years. If fare reductions were durable, they could influence land-use decisions related to housing and other forms of development, locking in long-term effects.

The cumulative effect is also evident in the lower panel of Figure 6, showing changes in emissions of local air pollutants like NO_x.

The change in emissions over time is partially a reflection of changes in vehicle miles traveled (VMT) in personal vehicles (Figure 7). The carbon price and transit fare policies yield immediate VMT reductions. Bus transit expansion reduces personal VMT as more buses are added over time. Land-use changes take several years to show effects, but those effects cumulate and by the end of the decade begin to yield the largest reductions in VMT of all the policies.

Figure 7. Changes in Personal Vehicle Miles Traveled



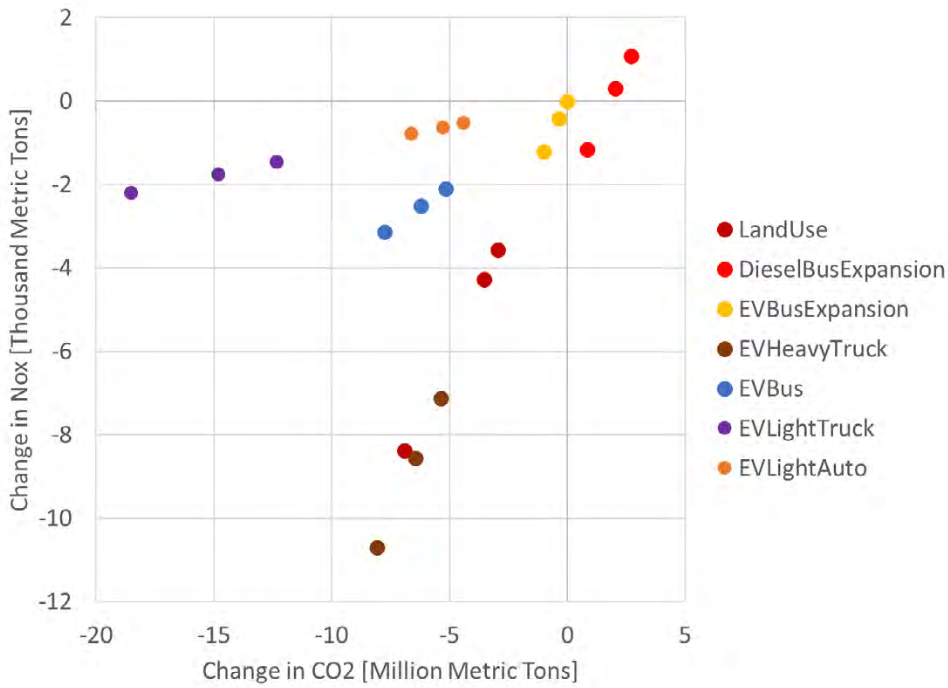
Notes: Expansion of transit and land-use policy yields reductions in personal vehicle use.

4. Some of the potentially most potent policies are also the most uncertain.

Changes in the timing of policy effects, illustrated above, impart implicit uncertainty about how other changes in the economy may affect anticipated policy outcomes. Explicit uncertainty about the effects of policies is even more ubiquitous. To illustrate some of this uncertainty, we varied the parameters for (1) the costs necessary to prompt a substitution to electric vehicles, (2) the reduction in VMT to be expected from land-use changes, and (3) the prior travel modes of households that choose to take newly available public transit. The results are illustrated in Figure 8. Because we primarily examine uncertainties with respect to a single parameter, the range of possible outcomes appears linear, but representation of multiple uncertainties would create nonlinear ranges of outcomes.

We observe in Figure 8 that the policies with the greatest expected reductions in emissions tend to have the greatest uncertainties. Vehicle electrification and changes in land use tend to promise the greatest expected changes in CO_2 but also have the widest range of possible changes. Two of these policies, electrification of heavy trucks and land-use changes, exhibit the greatest expected NO_x emissions reductions and associated localized air quality benefits; however, they also exhibit the greatest uncertainty about NO_x emissions reductions. The apparent trade-off between reductions in greenhouse gases (CO_2) and local air pollution (NO_x) is informed by a consideration of the certainty of these benefits. In contrast, electrification of buses yields a range of midpoint estimates of reductions in CO_2 and NO_x and has a relatively smaller range of uncertainty.

Figure 8. Example Range of Uncertainty in Model Outcomes



Notes: These results represent uncertainty around the costs to subsidize electric vehicles, the reduction in VMT expected from land-use changes, and the prior travel modes of households that switch to public transit because of expanded transit.

5. Many effects can be enumerated but cannot be easily measured or quantified.

Several aspects of transportation policy outcomes are not represented well in the model but may be very important to outcomes at the community level. For example, expansion of transit service, which has relatively lesser effects on emissions (Figure 8), may have large community-level benefits in transportation access that are hard to quantify.

The model represents outcomes in aggregate, but implementation will happen in specific locations with characteristics that differ from the average. Additional buses can increase the average frequency or total service area of the transit system, but that change will have different effects on different populations in different parts of the same city or town. We show that on average, an additional diesel bus does not divert enough riders from personal vehicles to yield a net emissions reduction, but on some routes, a bus might divert more drivers. Similarly, we calculate aggregate criteria emissions changes from replacing conventional vehicles with electric vehicles, but the location of the vehicles replaced will yield different levels of health benefits to different populations. The health benefits associated with electrifying buses are different from those associated with electrifying cars because the communities and neighborhoods where these transit options appear can have very different compositions and physical layouts.

Many policy pathways are not easily quantifiable. Reduction in VMT or replacement of conventional vehicles with electric, for example, may reduce noise in a neighborhood, which may have health benefits for residents and educational benefits for local students. Increasing transit service in a neighborhood may give residents greater access to jobs and essential services but might also raise property values, which may benefit homeowners and municipal budgets but be harmful for renters. Effects like these are not straightforward to quantify but are likely to be important aspects of policy outcomes.

Finally, some effects can be either beneficial or harmful, depending on the context. For example, a reduction in VMT because people live closer to jobs and shops may be beneficial, but a reduction in VMT because of higher fuel costs would not. A similar logic applies to a carbon price that discourages driving and increases walking. Such an outcome has health benefits, but they may not be experienced as benefits by someone who must walk because of a loss of affordability or transportation access. Conversely, a policy that makes public transit more available may create health disbenefits by diverting some pedestrians to public transit, but those travelers may experience the change as a benefit.

The mix of quantitative and qualitative modeling in this exercise supports an accounting of the full range of potential effects of policy. Community consultation will enable a fuller accounting of these hard-to-quantify effects and will build the community-level support necessary to adopt and implement policies.

Community Air Monitoring

The **Equity Toolkit**, published by Green for All (Fort 2019), argues that a transportation cap-and-invest program should prioritize criteria pollution reductions in communities that bear a disproportionate pollution burden, often as a result of discriminatory government policies. The toolkit suggests as a model California's Community Air Protection Program (AB617), which helps establish community air monitoring networks in high-pollution communities to determine the chief sources of pollution and make Air Quality Mitigation Plans to address those sources. Community air monitoring can identify highly localized sources of pollution that cannot be represented in regional modeling.

Conclusions

Transportation policies can be evaluated across multiple criteria, including environment, health, and economic impacts. For each endpoint, the effects will generally be distributed unevenly across different types of households. Policies that provide an economic benefit to one type of household may have little economic benefit for another. A good example of this heterogeneity is the distribution of outcomes from electric vehicle subsides compared with bus fare subsidies, which also have very different cost-effectiveness in achieving emissions reductions. Some policies may even increase emissions. Moreover, the benefits accrue differently to households with different incomes. Increasing the frequency of public transit with diesel buses may improve transportation access but may also increase emissions and reduce physical activity, harming health. Further, each of these outcomes is uncertain, with substantial variation among households even within a group of apparently similar households.

Because any one policy affects different households in different ways, a portfolio of policies may better enable policymakers to provide benefits to all types of households. Multiple policies could be simultaneously enacted to achieve a desired distribution of outcomes. For the policies illustrated here, implemented at a modest level, the effects of combining policies are likely to be additive. A mix of policies will yield a mix of benefits and of distributional outcomes. More ambitious policies will begin to alter this calculus, however: for example, as electric vehicles constitute a greater share of the vehicle fleet, substitution away from private vehicles will have smaller emissions effects.

The suite of policies we illustrate is varied but falls short of the full range of options available to state and local governments. Many policies can be enhanced by coordination with other government functions, or by using incentives to leverage private sector cooperation and investment. For example, policies supporting truck purchases could be organized to address long-haul transport on the I-95 corridor, or goods distribution for harbor and airport facilities and retail distribution centers. These varied approaches may have concentrated local benefits.

This analysis has several limitations, a few of which we highlight here. Emissions associated with electricity generation are not included in the analysis, although some observers note that expanded electrification of the transportation fleet may accelerate investment in renewable energy, reducing the average emissions intensity of **electricity generation**. Characterizing the distributions of health effects requires significantly more geographic specificity than this model is capable of. Improving bus transit in one part of a city will benefit different types of households versus improving bus transit in another part of the city, and expanding public transit anywhere will improve a system's network and connectivity; quantifying such benefits is beyond this research, however.

We emphasize that not all pathways can be measured, but that does not mean their effects are zero. For example, a policy that improves the connectivity of a neighborhood to the surrounding region may boost transportation access, improving the quality of life for residents. However, it may also increase rents and displace low-income residents. Hence, community-level engagement remains central to achieving outcomes that benefit everyone. Studies of the distributional effects of transportation policy can inform policymakers and communities as they decide which transportation policies to pursue, but studies cannot replace public participation in transportation decisions.

Appendix: Approach to Modeling

The Integrated Transportation Policy Model is built in the Analytica software, a platform that facilitates collaboration by means of a visual user interface. We characterize households by income level,[1] transportation usage, and by residence in metropolitan (91 percent of households) and nonmetropolitan areas (9 percent of households) using data from the Consumer Expenditure Survey.[2] Baseline projections from the National Renewable Energy Laboratory's Electrification Futures Study (Jadun et al. 2017 and Mai et al. 2018) provide information about transportation fuel consumption and fleet composition in the absence of further policies. The Annual Energy Outlook 2019 (U.S. Department of Energy 2019) provides baseline vehicle price and fuel price information, and baseline characteristics of the region's public transit systems come from the National Transit Database of the U.S. Department of Transportation (2018). Responses to policies that the model can represent include changes in the use of public transit, changes in vehicle miles traveled in private vehicles, and the composition of the vehicle fleet. Any policy-driven increase or decrease in the use of a transportation mode causes a commensurate decrease or increase in the use of other transportation modes through mode diversion factors.[3]

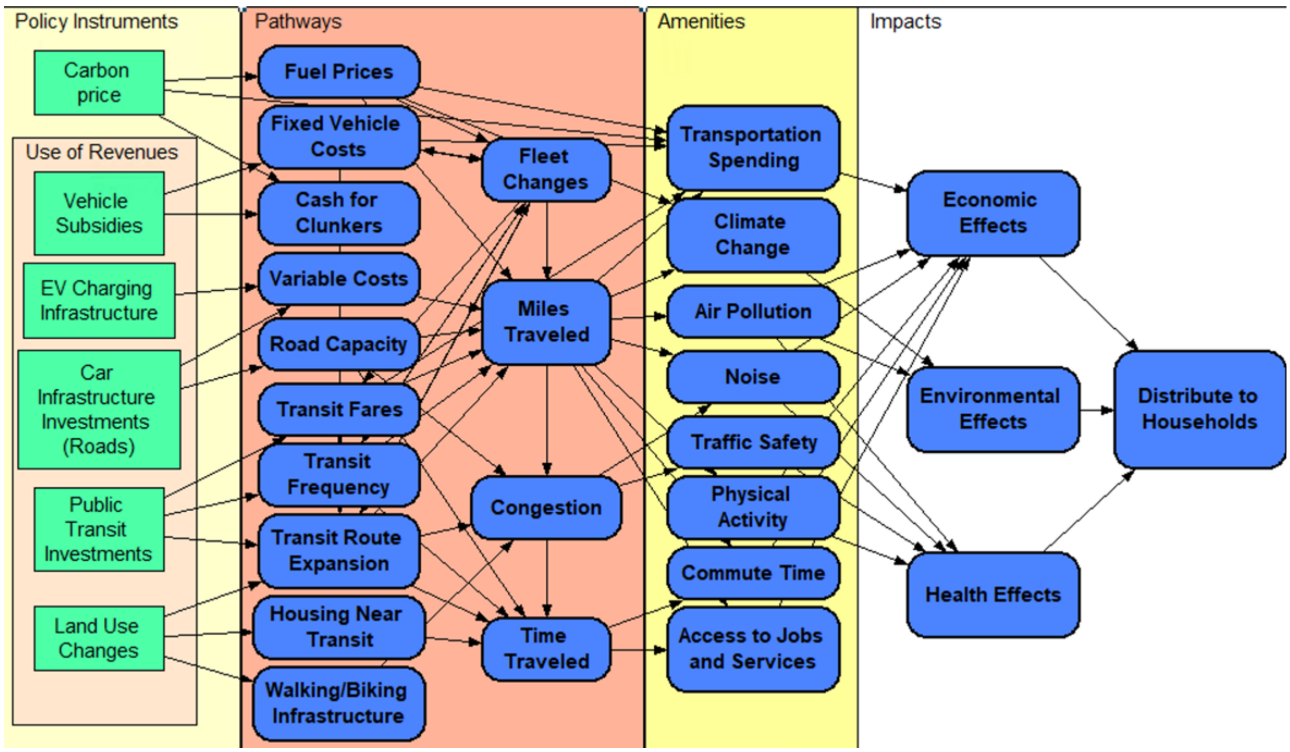
Figure A illustrates the structure of the model. The left-hand column lists policy instruments, including a carbon price and potential use of revenues. The expansive third element of transportation policy, regulations, is not explicitly modeled. The next collection of items includes direct and some secondary pathways of these policies, represented as modules that embody smaller submodels. These pathways affect the amenities listed in the next column, which can be categorized as economic, environmental, and health outcomes affecting households. Many of the effect pathways are described in quantitative ways, based on the literature and our reasoned judgments; several are directional only, describing qualitative effects that have not been quantified. This framework illustrates both the quantitative and qualitative effects for the model user's consideration.

1 Household income is organized by quintile at the region level, normalized by the square of household size.

2 The Metropolitan Statistical Area designation comes from the Office of Management and Budget. Metropolitan Statistical Areas contain at least one urbanized area with 50,000 or more inhabitants and include both population centers and adjacent suburbs.

3 The parameters in the model were developed before the COVID-19 pandemic. Effects of the pandemic on transit ridership and other assumptions in our model are highly uncertain, but the nature of the trade-offs is likely still relevant.

Figure A. Influence Pathways and Endpoints in the Integrated Transportation Policy Model



We can illustrate operation of the model by focusing on an example, public transit investments. A public transit investment might provide a fare subsidy, expand transit to new routes, or increase transit frequency along an existing route. In the transit frequency pathway, additional buses are purchased to decrease the waiting time between buses. These additional buses increase the fuel consumption, emissions, and mileage of the transportation system. As the frequency of buses increases, some trips that would originally have been made by light-duty vehicles are instead diverted to public transit, reducing emissions from light-duty vehicles. These emissions may or may not offset the increase in emissions from the additional buses, depending on the type of buses purchased. Increases in transit frequency yield changes in emissions of CO_2, which has climate effects, and conventional air pollution including nitrogen oxides NO_x and particulate matter, which has health effects. The increase in transit frequency also offers a time savings benefit that is distributed to households based on their share of expenditures on transit. Other important outcomes are illustrated qualitatively but not quantified, including, for example, the value of increased physical activity and the reduction in traffic congestion associated with a shift from personal vehicles to transit.

- Emissions price for transportation fuels (CO_2Price)
    - Change in gasoline and diesel consumption determined by own-price elasticity (0.15); change in electricity consumption determined by cross-price elasticity (0.6).[4]
    - All subsectors covered by the carbon price, but buses (public, school, and inter-city), passenger rail, and freight rail are not responsive to it.
    - The criteria pollution factor is for average vehicles of each type and does not change over time.[5]
    - Fuel expenditure changes are distributed to households based on their share of fuel expenditures.[6]
- Electric light-duty auto and truck subsidies (EVLightAuto + EVLightTruck)
    - The cost to subsidize an electric light-duty vehicle is the difference between the sticker price of the cheapest new conventional vehicle and the cheapest new electric vehicle using Annual Energy Outlook 2019 price projections (Department of Energy 2019b).
    - Uncertainty cases involve a subsidy that is 20 percent higher and 20 percent lower.
    - To replace a conventional vehicle with an electric vehicle, we replace the annual fuel use of an average conventional vehicle with the annual fuel use of an average electric vehicle. This means that the annual miles traveled of the subsidized electric vehicle may not be the same as those of the vehicle it replaces.
    - Criteria pollution factor is for a new 2020 vehicle of each type.[7] This factor does not change over time.
    - Subsidies are distributed to households based on their share of spending on new vehicles.[8]

4 Fuel price elasticities come from Litman (2019).
5 Average criteria pollution factors come from U.S. DOT (2018).
6 Expenditure shares are created by the RFF Incidence Model using data from the U.S. Bureau of Labor Statistics (2010-2016).
7 2020 criteria pollution factors come from U.S. EPA MOVES model.
8 Expenditure shares are created by the RFF Incidence Model using data from U.S. Bureau of Labor Statistics (2010-2016).

- Electric heavy-duty truck subsidy (EVHeavyTruck)
    - The cost to subsidize an electric heavy truck is the difference in sticker price between a new diesel heavy truck and a new electric heavy truck.[9] This value is constant over time in the model.
    - Uncertainty cases involve a subsidy that is 20 percent higher and 20 percent lower.
    - Criteria pollution factor is for a new 2020 vehicle of each type.[10] This factor does not change over time.
- Expansion of electric and diesel bus service (EVBusExpansion + DieselBusExpansion)
    - An additional bus increases the service area of the transit system by the number of miles traveled by the average bus in the fleet.
    - The cost to add one bus to the system is the sticker price of a new electric or diesel bus.[11]
    - The new bus uses the same amount of fuel as the average bus of that fuel type in the fleet.
    - The elasticity of demand for passenger trips with respect to bus service miles is assumed to be 1.[12] This means that the new bus adds the same number of passenger trips to the transit system as the average existing bus.
    - We assume that 35 percent of additional passenger trips taken on buses as a result of the service expansion would previously have been taken by personal vehicle and that 12 percent would not otherwise have been taken at all.[13]
    - Uncertainty cases assume that 100 percent of additional passenger trips taken on buses as a result of service expansion would previously have been taken by personal vehicle (the greatest reductions) or that 100 percent would previously not have been taken at all (the fewest reductions).
    - The criteria pollution factor for the miles traveled by the new bus are for a 2020 bus.[14] The criteria pollution factors for the personal vehicle miles that are reduced because people have switched to buses are the average criteria pollution factors for light-duty trucks and autos.[15] Neither of these factors changes over time.

9 Heavy truck sticker price come from Hall and Lutsey (2019).
10 2020 criteria pollution factors come from U.S. EPA MOVES model.
11 The sticker prices of new buses are from Johnson et al. (2020).
12 Transit use elasticities come from Litman (2019).
13 Diversion factors come from Dunkerley et al. (2018).
14 2020 criteria pollution factors come from U.S. EPA MOVES model.
15 Average criteria pollution factors come from U.S. DOT (2018).

- Increase in electric and diesel bus frequency of service (EVBusFrequency + DieselBusFrequency)

  - An additional bus decreases the average headway (time between buses on the same route) in the transit system.[16]
  - The cost to add one additional bus to the system is the sticker price of a new electric vehicle or a new diesel vehicle.[17]
  - The new bus uses the same amount of fuel as the average bus of that fuel type in the fleet.
  - The elasticity of demand for passenger trips with respect to bus frequency is assumed to be 0.5.[18] This means that the new bus adds fewer passenger trips than the average existing bus.
  - We assume that 35 percent of additional passenger trips taken on buses as a result of the service expansion would previously have been taken by personal vehicle and that 12 percent would not otherwise have been taken at all.[19]
  - The criteria pollution factor for the miles traveled by the new bus are for a 2020 bus.[20] The criteria pollution factors for the personal vehicle miles that are reduced because people have switched to buses are the average criteria pollution factors for light-duty trucks and autos.[21] Neither of these factors changes over time.
  - We assume that time saved as a result of increased bus frequency is the difference between baseline bus headway and policy case bus headway multiplied by the original number of bus trips in the system. This is likely an overestimate.
  - We value time savings at one third of a $10 hourly wage and distribute it to households based on their share of public transit expenditures.[22]

- Electric bus subsidy (EVBus)

  - The cost to subsidize an electric bus is the difference in sticker price between a new diesel bus and a new electric bus.[23] This value is constant over time in the model.
  - Uncertainty cases involve a subsidy that is 20 percent higher and 20 percent lower.

16 Average headway is calculated using the methodology described in National Academies of Sciences (2013).

17 The sticker prices of new buses are from Johnson et al. (2020)

18 Transit use elasticities come from Litman (2019)

19 Diversion factors come from Dunkerley et al. (2018).

20 2020 criteria pollution factors come from U.S. EPA MOVES model

21 Average criteria pollution factors come from U.S. DOT (2018).

22 Expenditure shares are created by the RFF Incidence Model using data from U.S. Bureau of Labor Statistics (2010-2016).

23 The sticker prices of new buses are from Johnson et al. (2020).

    - Criteria pollution factor is for a new 2020 vehicle of each type.[24] This factor does not change over time.

- Rail and bus transit fare subsidies (RailFare + BusFare)

    - Fare subsidies are distributed to states proportional to the state share of transit fare revenue and are applied to a state average fare.
    - The transit trip elasticity of demand with respect to transit fares is assumed to be –0.3 for buses and –0.1 for trains.[25]
    - Additional passenger trips caused by fare reduction do not cause an increase in emissions from transit vehicles.
    - We assume that 35 percent of additional passenger trips taken on buses and that 42 percent of additional passenger trips taken on trains as a result of fare reduction would previously have been taken by personal vehicle, and that 12 percent of additional bus trips and 18 percent of additional train trips would not otherwise have been taken at all.[26]
    - The criteria pollution factors for the personal vehicle miles that are reduced because people have switched to buses are the average criteria pollution factors for light-duty trucks and autos.[27] This factor does not change over time.
    - Fare subsidies are distributed to households based on their share of public transit expenditures.[28]

- Land-use density Incentive[29] (LandUse)

    - Using the analysis done by Cambridge Systematics in its investment tool, we assume it costs $3,000 in incentives to a municipality to create an additional unit of dense housing.
    - Each additional unit of dense housing automatically moves a household from one of five density regions to the next most dense region.
    - The household's VMT are reduced from the average VMT in the original region of residence to the average VMT in the new region of residence.
    - The central case uses the VMT change between Cambridge Systematics's Suburban and Medium Urban density regions.

24 2020 criteria pollution factors come from U.S. EPA MOVES model.
25 Transit use elasticities come from Litman (2019).
26 Diversion factors come from Dunkerley et al. (2018).
27 Average criteria pollution factors come from U.S. DOT (2018).
28 Expenditure shares are created by the RFF Incidence Model using data from U.S. Bureau of Labor Statistics (2010-2016).
29 We use simplified results from the analysis performed by Cambridge Systematics as part of its investment tool for all aspects of our land-use pathway, except for the four-year time lag. A full description of its land use pathway is available in Cambridge Systematics (2015).

- Uncertainty cases involve VMT change between the Rural and Suburban density regions (higher emissions reduction case) and the Medium Urban and High Urban density regions (lower emissions reduction case).
- There is a four-year lag between when subsidies are disbursed and when a household moves to the new unit.

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