Transportation Sustainability Tracking Tool

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1 INTRODUCTION

This report describes the development of the Transportation Sustainability Tracking Tool for the Chittenden County Regional Planning Commission (CCRPC). The University of Vermont Transportation Research Center (TRC) was contracted by CCRPC to create an interactive, web-based tool that enables municipalities and planning agencies in Chittenden County to evaluate if the needle is moving in the right direction to meet their transportation and climate policy goals.

Development of the tool took place during FY 2024 using the free, open-source R-package "shiny". The TRC currently hosts the tool on a UVM web server. The tool can be accessed at ccrpctranspstats.uvm.edu. On this website, visitors can explore transportation performance metrics across Chittenden County at varying spatial and temporal scales, including emissions, mileage, and fuel consumed by vehicles registered within the county. The data comes from an enhanced version of the Vermont Department of Motor Vehicles registration and inspection records. The TRC updates and maintains this longitudinal vehicle travel data set for Vermont as an ongoing project. The TRC will update the data in the Transportation Sustainability Tracking Tool annually to track changes over time.

While the data in this tool is observed from actual travel data derived from Vermont registration and inspection records (nearly 60,000 vehicles in each year of data), there are some important limitations. For one, it does not include every vehicle registered in the county due to missing and incomplete records what were removed through our data cleaning process. Furthermore, only light-duty, personal vehicles are included. The tool does not include data about medium-duty, heavy-duty or commercial vehicles, vehicles owned by companies or government agencies, or transit vehicles. Additionally, the values in the tool should not be interpreted as exact values. They are estimates, and as such are most useful as relative values to track changes over time and across communities. Finally, the data represents the vehicle mileage and emissions generated from the residents of a community, not the total travel or emissions occurring within a community which also comes from trips made from people traveling to or through the community. This is useful for understanding the impact of policies and plans that affect the decisions that households and individuals make about the vehicles they own or lease and how much they drive them. The data do not provide information about the total amount of vehicle travel, energy use or emissions occurring in communities.

The following sections discuss the sourcing, cleaning, and aggregation of the underlying data as well as a detailed overview of the tool, including appropriate and inappropriate uses of the data.

2 UNDERLYING DATA

The data in the tool comes from the Vermont Department of Motor Vehicle (DMV) registration and inspection records. The DMV provides these data to the University of Vermont Transportation Research Center (TRC) on an annual basis for use in various research projects to improve transportation decision making and policy analysis. These data include vehicles registered in Vermont and the odometer readings from all vehicles receiving a state safety inspection.

There are three main elements of the vehicle data: the odometer readings from the inspection records, the mailing addresses from the registration records, and the vehicle identification numbers (VINs) contained in each record. From the odometer readings, we can calculate vehicle mileage. From the mailing addresses, we can link each vehicle to a point in space. Then, using the VINs within each data set, we can merge these records together. After extensive data cleaning, the final product is a disaggregated, longitudinal data set containing vehicle information for all registered vehicles in Chittenden County, Vermont. A summary of the key attributes of the data, their sourcing and uses, and the calculated attributes can be found in **Appendix A**.

2.1 Estimating Vehicle Miles Travelled

Vehicle odometer readings are recorded at an annual vehicle safety inspection required for all vehicles registered in Vermont. Vehicle miles travelled (VMT) can be calculated by looking at odometer readings from subsequent inspections. First, we calculate the difference in odometer readings, normalized by the number of days between those inspections. We then remove records with implausible or erroneous values by excluding vehicles with VMT per day exceeding 273 miles (equivalent to over 100,000 miles per year) or with negative mileage values.

From the retained VMT per day estimates, we extrapolate this value to a calendar year of travel by multiplying by 365 days. If there are multiple VMT per day estimates for a single calendar year, we weight the estimates by the number of days they overlap with the year, as shown in **Figure 1**. Ultimately, we get an estimate of the miles travelled per calendar year per vehicle.

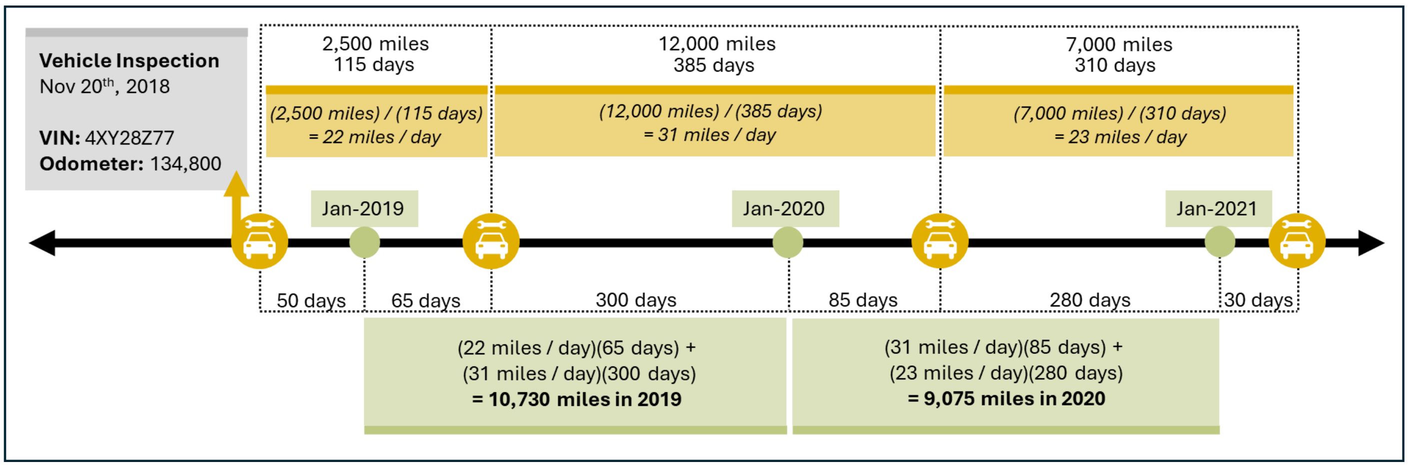

FIGURE 1 VMT per calendar year per vehicle estimation

2.2 Getting Vehicle Location

Vehicle registration records contain the mailing address for vehicles registered in Vermont. These addresses can vary considerably for the same address, such as misspellings in town names, discrepancies in street names, or small variations in referring to the same address such as "Road" versus "Rd". The TRC iteratively cleans the address data to fix these issues, so across the years addresses are relatively consistent. After the data cleaning, these addresses are converted into geospatial coordinates (i.e., geocoded) by feeding a locater created using the Enhanced 911 (E-911) addresses for Vermont[1] into the geocoding software provided by ArcGIS. The address data contain unit numbers which allows us to separate vehicles in multi-unit residential structures. This allows us to link vehicles to a location in space and perform spatial analyses, such as visualizing transportation performance metrics on maps at any desired spatial scale.

The Vermont E-911 address list contains information on the type of address site. We include this variable when linking each address to geospatial coordinates so we can identify which addresses are residential. There are 129 unique site type distinctions[2]. We define an address as residential if it is in the following list of site types: single family dwelling, multi-family dwelling, mobile home, condominium, other residential home, commercial with residence, seasonal home, nursing home / long term care unit, and residential farm.

2.3 Getting Vehicle Fuel Economy Information

Vehicle fuel economies are obtained from a database maintained by the U.S. Environmental Protection Agency (US EPA). To look up the fuel economy of each vehicle, we first need to obtain detailed information about each vehicle

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[1] Enhanced 911 Site Locations: https://geodata.vermont.gov/datasets/VCGI::vt-data-e911-site-locations-address-points-1/about

[2] Enhanced 911 Metadata: https://maps.vcgi.vermont.gov/gisdata/metadata/EmergencyE911_ESITE.htm

which is encoded in the VIN. Each VIN is decoded using a VIN decoder maintained by the National Highway Traffic Safety Administration (NHTSA) to get the unique attributes of each vehicle, such as the make, model, gross vehicle weight, fuel type, engine displacement, number of axles, etc. These attributes are then matched to information from the US EPA fuel economy database[3]. Note that the database only contains fuel economy estimates for light-duty vehicles, and there are multiple fuel economy values offered. We use the combined highway and city fuel economy estimate for each vehicle expressed in miles per gallon. Fuel economy estimates for plug-in hybrid electric vehicles (PHEVs) that use both internal combustion and electric motors include a utility factor that adjusts for the estimated proportion of time that these vehicles operate using their internal combustion engines (charge sustaining mode) and the time that they use their electric motors (charge depleting mode). The energy efficiency of PHEVs and battery-electric vehicles (BEVs) are estimated using the US EPAs' combined highway and city estimates expressed as kilowatt-hours of electricity consumption per 100 miles. The vehicle fuel economy matching is performed using computer programming scripts developed by the TRC and manually checked to ensure reliability and improve matching rates.

2.4 Vehicles Included and Not Included in the Final Data

The final data used in the tool does not include all vehicles registered in Chittenden County, since the vehicle registration and inspection records from the DMV require extensive data cleaning.

First, we ensure each vehicle has a reliable VMT estimate. Vehicles were filtered to only include those with VMT estimates between 0 miles and 100,000 miles per year. Calendar year VMT estimates less than 0 miles occur when the odometer reading from an inspection was entered as a lower number than the previous inspection. Calendar year VMT estimates greater than 100,000 miles occur when an odometer reading is considerably higher than the previous inspection. After internal deliberation, we decided both were suggestive of errors in the inspection data and removed these records.

Next, we ensure the vehicles in the data are used for personal travel by households which was the focus of our project[4]. We filter the data to only include light-duty vehicles: passenger cars, vans, SUVs / MPVs, and pickup trucks with a gross-vehicle weight less than 14,000 lbs. We also filter the data to only include vehicles registered at residential addresses. We exclude vehicles that are unable to be matched with an address from the Vermont E-911 data and vehicles that are registered at a mailing address with a commercial site type. We also exclude vehicles that list post-office boxes as their mailing address on their registration form (approximately 8% of all addresses in Chittenden County, Vermont) since we have no information where the people who use these vehicles live.

Finally, we filter the data to only include vehicles registered with a mailing address in Chittenden County. This means the final dataset describes the vehicle travel generated by people living in Chittenden County which have registered their vehicles in Vermont. It does not display vehicle travel through Chittenden County[5] and does not account for vehicles registered in other states or countries[6].

[3] EPA fuel economy database: https://www.fueleconomy.gov/feg/download.shtml

[4] While the DMV data does contain inspections and registrations for all registered vehicles, the EPA fuel economy database only contains light-duty fuel economy estimates, so we would be unable to calculate fuel consumption for most commercial vehicles. Furthermore, commercial and government vehicles may be registered at addresses far from where they are stored and used.

[5] Information on through-traffic is outside of the scope of this project. For those interested, this type of data is available from the Federal Highway Administrations' Highway Performance Monitoring System (HPMS) using their annual average daily traffic counts for roadway links.

[6] We use estimation methods that account for these missing vehicles in constructing the metrics displayed by the tool.

2.5 Performance Metrics

Four key performance metrics are calculated from the underlying data: vehicle miles travelled (VMT), tailpipe greenhouse gas (GHG) emissions, fuel consumed, and electricity consumed. Each performance metric is calculated per vehicle, per household, and per capita for each calendar year at varying spatial scales.

2.5.1 VMT per Vehicle

VMT per vehicle is taken from the calendar year VMT estimate, as described in the "Estimating Vehicle Miles Travelled" section above.

2.5.2 Tailpipe GHG Emissions per Vehicle

Tailpipe GHG emissions per vehicle are calculated using VMT estimates and per mile emissions factors. We use the EPA's Motor Vehicle Emissions Simulator (MOVES) to generate estimates of emissions factors for Chittenden County by vehicle type (i.e., motorcycle, passenger car, passenger truck, and other), fuel type (i.e., gasoline, diesel, CNG, E-85, and electricity) and model year (i.e., 1994 to current year). We then match each vehicle from the DMV data with an emission factor by vehicle type, fuel type, and model year. Tailpipe emissions are calculated by multiplying the emissions factor (kilograms of CO_2 equivalents per mile) by the VMT estimates (miles per calendar year) to get kilograms of CO_2 equivalents per calendar year per vehicle.

2.5.3 Fuel Consumed per Vehicle

Fuel consumed per vehicle is calculated using vehicle mileage and fuel economy. The calculation for vehicle mileage is detailed in the "Estimating Vehicle Miles Travelled" section. Fuel economy is estimated from the EPA Fuel Economy database, as described in the "Getting Vehicle Fuel Economy" section. For every gasoline consuming vehicle, we calculate gasoline consumed per vehicle as each vehicle's calendar year vehicle miles travelled estimate divided by it's EPA-matched fuel economy. Vehicles that do not consume gasoline, such as battery electric vehicles, have a gasoline consumption of zero. Similarly, we calculate diesel consumed per vehicle for diesel consuming vehicles as each vehicle's calendar year vehicle miles travelled divided by it's EPA-matched fuel economy. The fuel economy estimates from the EPA for PHEVs include a utility factor that assumes the ratio of fuel-consuming driving to total driving. Therefore, no adjustments were made to the fuel economy estimates for PHEVs in the calculation of fuel consumption. The fuel consumed by BEVs is assumed to be zero.

2.5.4 Electricity Consumed per Vehicle

Electricity consumed per vehicle is calculated using vehicle mileage and energy efficiency estimates. The calculation for vehicle mileage is detailed in the "Estimating Vehicle Miles Travelled" section, 2.1. Energy efficiency estimates are obtained from the EPA Fuel Economy database, as described in the "Getting Vehicle Fuel Economy" section, 2.3. Electricity consumption is calculated as the vehicle mileage multiplied by the energy efficiency (kilowatt hours per 100 miles) to get electricity consumed per calendar year. The electricity consumption is only calculated for PHEVs and BEVs. The electricity consumption for all other vehicles is assumed to be zero.

2.5.5 Percentage of Vehicles

Percentage of vehicle metrics are calculated by summing the number of vehicles within a vehicle type and fuel type across a geography and dividing by the total number of vehicles across that geography. These ratios are then converted into percentages. For example, the percentage of SUVs in Burlington in 2020 is calculated as the number of SUVs of any fuel type registered in Burlington in 2020 divided by the total number of vehicles registered in Burlington in 2020.

2.5.6 Per Household Estimation

Per household metrics are calculated by summing the metric of all vehicles registered at the same address. For example, household VMT is calculated as the sum of the VMT from all vehicles registered at the same address. Similarly, household gasoline consumption is calculated as the sum of all gasoline consumed from all vehicles registered at the same address.

2.5.7 Per Capita Estimation

Per capita estimates are made by dividing per household estimates by the average household size of households in the Census block group where the household is located. The tool reports the average of these values for different geographic areas.

Average household size is taken from the U.S. Census Bureau's American Community Survey. The average household size variable (Code: B25010_001) is pulled at the block group geography for all years of data (e.g., 2018, 2019, 2020, etc.). The data is then spatially joined to the household addresses, so each address is assigned the year-specific average household size for their corresponding block group[7].

2.5.8 Municipal Totals

While the registration data in the tool includes most vehicles in Chittenden County, it does not include all of them (e.g., vehicles registered to PO boxes). Therefore, to estimate total values for each metric for each municipality we first multiplied each per household metric by the total number of households in each municipality using estimates from the U.S. Census Bureau. Since not all households own a vehicle, we also applied an adjustment factor to account for carless households.

Total household counts for each municipality are obtained from the U.S. Census Bureau's American Community Survey. The total household count (Code: B08201_001) is pulled at the county subdivision (i.e., municipal) geography for each year of vehicle data in the tool (e.g., 2018, 2019, 2020, etc.). We also obtained the margin of error for each estimate to calculate a 95% confidence interval for estimated totals using the following equations:

$$Lower\ Bound = Estimate - (1.96\ x\ Margin\ of\ Error)$$

$$Upper\ Bound = Estimate + (1.96\ x\ Margin\ of\ Error)$$

$$95\%\ Confidence\ Interval = (Lower\ Bound, Upper\ Bound)$$

The proportion of carless households is also obtained from the U.S. Census Bureau's American Community Survey (ACS) for each municipality. The number of households with no vehicle available (Code: B08201_002) is pulled at the county subdivision (i.e., municipal) geography for each year of vehicle data in the tool (e.g., 2018, 2019, 2020, etc.) and divided by the estimated number of households in each municipality to get the proportion of car-less households in each municipality.

Finally, we calculate metric totals for each municipality using the following equation:

$$Total\ Metric_i = \overline{M}_i^{hh} \cdot n_i^{acs} \cdot (1 - p_i)$$

Where;

$\overline{M}_i^{hh}$ is an average per household metric for municipality, *i*

n_i^{acs} is the number of households in in each municipality, *i,* from the ACS

p_i is the proportion of carless households in each municipality, *i*

So, for example, the total number of vehicles per municipality is calculated as the average number of vehicles per household in that municipality, multiplied by the proportion of households in the municipality with cars, multiplied by the total number of households in the municipality according to the ACS. This is more reliable than summing the number of vehicles in our data, since not all registered vehicles are included in the final data set.

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[7] In 2020 the U.S. Census Bureau changed some block group GEOIDs and spatial boundaries, so block groups before and after 2020 will vary minimally.

In the tool, we calculate the lower bound for a total count (e.g., total households = lower bound of total households), the most likely total count (i.e., total households = estimate), and the upper bound for a total count (i.e., total households = upper bound). Therefore, we can be 95% confident that the true total count of vehicles is between the upper bound and the lower bound.

2.6 *Data Validation*

The metrics contained in the tool are unique and among the most comprehensive and spatially detailed household level vehicle use data available anywhere. Therefore, there are limited options available to compare our estimates against to validate our methods and the robustness of the underlying data we received from the Vermont DMV. Data from the National Household Travel Survey are the only publicly available data set known to the researchers that contains estimates of household level VMT from personal travel that covers the Vermont region. Comparing our VMT estimates with those estimated using data from the NHTS shows that our VMT estimates fall within the same range as the survey-based data, providing some level of assurance that our estimates are reliable indicators of VMT and the vehicle emissions, fuel consumption and energy consumption estimates estimated from the mileage estimates. Details of the validation methods and results can be found in **Appendix B.**

2.7 Annual Data Updates

The tool will be updated annually (and possibly semiannually) as the TRC receives new vehicle registration and inspection records from the DMV. However, the estimates in the tool will always lag one to two years behind the current calendar year because it takes at least a full calendar year of current registration and inspection records to reliably estimate the prior year's VMT. Additional time is required to process the data, query additional databases, and check the data for errors.

3 TOOL OVERVIEW

The tool is run on an R-shiny dashboard hosted on a UVM web server and features seven tabs, two of which contain information for the user, and four of which contain opportunities to visualize the data spatially and temporally with real-time data querying.

3.1 Development and Hosting

The tool was developed using the R-package "shiny". R is a free, open-source programming language geared towards statistical analysis. Shiny is an R-package used to create interactive, web-based applications that can display data processed using R[8].

The tool is hosted on a TRC web server that is owned and operated by UVM[9]. The tool uses mamba as a package manager, Node.js as the runtime environment and "pm2" as the process manager.

3.2 Tool Features

The tool offers two unique features: information (see the About and Data Dictionary tabs) and data exploration (see the Vehicle Travel, Household Travel, Per Capita Travel, and Total Travel). Visit the tool at ccrpctranspstats.uvm.edu.

[8] Information on R shiny and examples of other applications can be found here: https://shiny.posit.co/.

[9] As of April 2025, CCRPC does not pay for this server. Web hosting and the virtual machine are complementary services provided to the Transportation Research Center by the University of Vermont. This may change in future years.

3.2.1 Informational Pages

The About tab is the landing page for the tool and includes important background information such as the project purpose and funding sources. The Data Dictionary provides definitions and explanations of key terms and abbreviations used throughout the tool. A copy of these definitions can be found in **Appendix C**.

3.2.2 Data Exploration Pages

Using the side panel on any of these pages, the user can select a performance metric to visualize (e.g., VMT, tailpipe emissions, fuel consumption, or electricity consumption), and explore how this metric varies across time and space in Chittenden County. The side panel chooses the metric and filters the data for the entire page. More options are available on the subtabs so users can create custom visualizations of the data using maps, graphs, and summary tables.

Using the maps, users can look at a metric in any given year across one of five pre-set spatial scales: county, municipalities, block groups, 1-kilometer square grid cells, and the CCRPC future planning areas. The map then displays the average or median metric. On the Vehicle Travel tab, users can also explore the percentage of vehicles at any spatial scale that fall within the selected vehicle type and fuels.

On the graph subtab, users can compare trends in metrics between municipalities or the CCRPC future planning areas. These two comparisons were requested by the CCRPC. Users can change the municipalities and years displayed on the graph and add a line to view county-wide trends. These changes can be made by either clicking on the graph's legend or using the dropdowns.

On the summary table subtab, a table is displayed comparing the metric across all years of data for either municipalities or the CCRPC future planning areas, including a row for the county-wide metric. Users can search, filter, and download the data in a .csv or .xlsx format. It also includes a warning, signified by an exclamation point in the "Info" column, when a municipality or future planning area has a very small sample size. Small sample sizes make summary statistics like medians and averages less reliable. Typically, statisticians define a small sample size as any grouping with less than 50 data points.

While the Vehicle Travel, Household Travel, and Per Capita Travel pages are laid out in the exact same way, the Total Travel page is different. It takes per household estimates of the performance metrics and extrapolates them to the municipal level. Remember that the totals only account for light-duty vehicles used by households and are not estimates of the total amount of vehicle use, emissions or energy consumption in each municipality.

3.3 Real-Time Data Querying

Rather than any of the performance metrics being pre-calculated for the county, municipalities, or other spatial scales for every given year, shiny allows users of the tool to create custom data queries that are executed in real time. This allows us to limit the pre-processing of the data and prevents us from having to predict the querying needs of the user. This also provides greater flexibility for adding new metrics and tabulations in updates to the tool.

This process is best explored through an example. Say a user wants to visualize vehicle tailpipe emissions from SUVs in 2022 across municipalities in Chittenden County. On the Vehicle Travel tab, the user inputs the following:

- ➔ Select a metric: Kilograms of Tailpipe CO2 Emissions
- ➔ Select vehicle types: SUV / MPV
- ➔ Select vehicle fuels: All (Gasoline, HEV, Diesel, FFV, PHEV, E-85, BEV)

So far, the user has selected the information about vehicle tailpipe emissions and filtered the underlying data to only include SUVs / MPVs with any fuel type. Then, the user goes to the map subtab and inputs the following:

- ➔ Select a spatial boundary: Municipalities
- ➔ Select year(s) of data: 2022

Now, the data is queried again. First, the data about tailpipe emissions for SUVs is filtered to only include vehicle registrations active in Chittenden County in 2022. Then, the data is grouped by municipality, and the code calculates the average tailpipe emissions for all vehicles with active registrations for each municipality. Similarly, the user can change the summary function to "median", so the code calculates the median tailpipe emissions for all vehicles with active registrations for each municipality.

This process works the same way regardless of the metric, vehicle filters, spatial scale, or year(s) of data selected by the user. Each time, the data is filtered and queried in real time.

3.4 Appropriate Uses

The data in this tool represents the vehicle use and travel generated by light-duty vehicles registered at residential addresses in Chittenden County. It would be appropriate to use the data to explore the following questions:

- ➔ **How has the total number of BEVs changed in Burlington since 2020?**
  Use the total number of vehicles in Burlington estimate from the "Total Travel" page, multiplied by the proportion of BEVs in Burlington from the "Vehicle Travel" page for 2020, 2021, and 2022. Compare the values.
- ➔ **How have vehicle tailpipe emissions from light-duty SUVs changed in Shelburne, VT since 2019?**
  Use the average or median tailpipe emissions from Shelburne, VT on the "Vehicle Travel" tab for 2019, 2020, 2021, and 2022, filtering to only include SUVs.
- ➔ **How has the COVID-19 pandemic shifted light-duty vehicle gasoline consumption across Chittenden County?**
  Use the average or median gasoline consumption from Chittenden County on the "Vehicle Travel" tab, "Household Travel" tab, or the "Per Capita Travel" tab. Alternatively, use the total gasoline consumption from Chittenden County on the "Totals Tab".
- ➔ **What are the average gallons of gasoline consumed per household in Burlington, VT?**
  Use the average gallons of gasoline consumed per household in Burlington, VT in any given year from the "Household Travel" tab.

3.5 Inappropriate Uses

The data in this tool does not depict the total travel within or through Chittenden County or within or through municipalities. It also does not contain information on medium duty or heavy-duty vehicle travel. It would be inappropriate to use the data to explore the following questions:

- ➔ **How much has traffic congestion changed in Chittenden County?**
  We cannot answer this question using the data in the tool for several reasons. The tool does not include travel from all vehicles in Chittenden County. There is no truck data or data on municipal fleets and there is no data on trips to or through the county that originated elsewhere. Furthermore, there is no information about when or where trips occur or the routes they take which are required to estimate traffic speed and congestion levels.
- ➔ **What light-duty vehicle-related emissions are residents of South Burlington, VT exposed to?**
  While this question is correct in using the tool to investigate light-duty vehicles, we cannot make statements about emissions exposure since we do not know where vehicles are traveling. Furthermore, we have not included criteria and toxic air pollution emission estimates.
- ➔ **Is Burlington contributing its fair share to Vermont's GHG emission reduction targets?**
  While the tool is designed to evaluate progress towards sustainable transportation and climate goals, it is not designed as a substitute for GHG emission inventories used to estimate the state's emission reduction targets. The GHG emission estimates in the tool only account for emissions generated by household vehicle travel. The tool does not include travel that occurs for other purposes or for travel occurring in Burlington (or Vermont) that originates outside the city (or state). The tool is designed to provide a spatially

detailed set of key sustainability metrics that can be used as performance measures to track change over time and across communities. The tool is designed to show where progress is being made and the rate of change.

4 ACKNOWLEDGMENTS

The development of the Transportation Sustainability Tracking Tool was supported with funding from the Chittenden County Regional Planning Commission (CCRPC). Additional funding from the National Science Foundation (Award #2228667) contributed to developing the underlying dataset and the National Center for Sustainable Transportation (Award #69A3552344814) contributed to developing the methods to host the tool on the web.

The Transportation Sustainability Tracking Tool was developed by Clare Nelson and Dr. Greg Rowangould at the University of Vermont Transportation Research Center. Additional technical support in setting up the server technology and creating the underlying dataset was provided by Narges Ahmadnia, Avi Chawla, Owen Palcsik, Sarah Lindberg, Brooke Lundigran and Dr. Dana Rowangould with the University of Vermont Transportation Research Center.

APPENDIX A. KEY DATA ATTRIBUTES

VARIABLE	DESCRIPTION
VIN	Vehicle identification number, unique to each vehicle
Location	
Record Year	The year associated with the vehicle's VMT and its active registration at the mailing address.
Street	The street from the mailing address, checked for typos and uniformity across all records and corrected if necessary (e.g., "River Rd", "River Road" → "River Road")
City	The city from the mailing address, checked for typos and uniformity across all records and corrected if necessary (e.g., "S Burlington", "South Burlington" → "South Burlington")
County	The county from the mailing address, checked for typos and uniformity across all records and corrected if necessary (e.g., "Chittenden", "Chittnden" → "Chittenden")
Zip Code	The zip code from the mailing address.
Unit	The unit number from the mailing address, checked for typos and uniformity across all records and corrected if necessary (e.g., "Apt A", "Unit A" , "A" → "A")
2010 Block Group GEOID	Block group GEOID associated with the mailing address based on the 2010 U.S. Decennial Census boundaries.
2020 Block Group GEOID	Block group GEOID associated with the mailing address based on the 2020 U.S. Decennial Census boundaries.
X Coordinate	X-coordinates for the mailing address obtained from an ArcGIS geocoding process using Vermont E-911 address data. These coordinates correspond to parcel center points.
Y Coordinate	Y-coordinates for the mailing address obtained from an ArcGIS geocoding process using Vermont E-911 address data. These coordinates correspond to parcel center points.
Address Site Type	Site type is provided in the Vermont E-911 address data. Addresses from the mailing address were matched to addresses from the Vermont E-911 data to combine these data sets.
Vehicle Characteristics	
Vehicle Type	
Vehicle Fuel	

Fuel Economy	Gallons of fuel consumed per mile travelled of city and highway combined driving from the EPA's fuel economy database.
Electrical Efficiency	Kilowatt hours of electricity consumed per 100 miles of undepleted city and highway combined driving from the EPA's fuel economy database.
Vehicle Year	
Make	
Model	
Gross Vehicle Weight	

Calculated Fields	
Residential Address	Site type included in….
Light-duty Vehicle	Passenger cars, SUVs / MPVs, and trucks with a gross vehicle weight less than 14,000 lbs.
VMT	Vehicles miles travelled per calendar year based on the difference between subsequent inspection records, normalized by the number of days between inspections, and extrapolated to a 365 days of travel per calendar year by weighting each per day estimate proportional to the number of days it overlaps with that calendar year.
Emissions Factors	Kilograms of CO2 equivalents per vehicle mile travelled from Chittenden County, Vermont run specifications from EPA MOVES. Matched to vehicles based on vehicle type, fuel type, and model year.
Tailpipe Emissions	Kilograms of CO2 equivalents produced per calendar year per vehicle. Calculated as (VMT) x (Emissions Factor)
Gasoline Consumed	Gallons of gasoline consumed per calendar year per vehicle. Calculated for gasoline vehicles and PHEVs as (VMT) / (Fuel Economy).
Diesel Consumed	Gallons of diesel consumed per calendar year per vehicle. Calculated for diesel vehicles as (VMT) / (Fuel Economy).
Electricity Consumed	Kilowatt hours of electricity consumed per calendar year per vehicle. Calculated for PHEVs and BEVs as (VMT) x (Electrical Efficiency).

APPENDIX B. DATA VERIFICATION MEMO

To: Jason Charest, Melanie Needle, Eleni Churchill at CCRPC
From: Clare Nelson and Gregory Rowangould
Date: June 20th, 2024
Memo: VT Inspection Data Vehicle Miles Travelled Verification

We use Vermont vehicle inspections to calculate VMT estimates for all registered light-duty, personal vehicles in Chittenden County. Below, we compare these VMT estimates to three VMT estimates from the National Household Travel Survey (NHTS)[10] across four geographic scales.

VT VEHICLE INSPECTION DATA

Odometer readings are recorded at required, annual vehicle inspections in Vermont.

1. **Annual VMT for each vehicle:** The difference between odometer readings from subsequent inspections, normalized by the number of days between inspections to get an estimate of daily VMT, and multiplied by 365 to get an estimate of annual VMT.
2. **Annual VMT for each household:** The sum of VMT from all vehicles registered at the same address. Addresses include unit numbers to separate households in multi-unit buildings.

NHTS DATA

The National Household Travel Survey, conducted by the FHWA, gathers responses from a nationally representative sample of United States citizens. Respondents record all trips taken within a 24-hour period including details about each trip, the person taking the trip, any vehicles used, and their household. There are three mileage estimates in the data: (1) the mileage of each trip taken on the travel day, (2) a self-reported estimate of annual vehicle miles travelled for each vehicle owned by the household, and (3) an adjusted self-reported estimate developed by the FHWA. A full description of variables used in this memo can be found in **Table A5**.

Geographic Samples

The most recent NHTS data is from 2017 and 2022. In 2017, the smallest available geography is at the state level (e.g., “Vermont”). In 2022, due to a smaller sample, the smallest available geography is the “Census Division-MSA Status-Presence of Rail” category (e.g., New England not in an MSA, New England MSA of less than 1 million, etc.).

The VMT estimates were summarized across four different geographic samples. The 2017 NHTS sample from Vermont serves as a direct comparison to the VMT estimates from Vermont inspections. The 2017 and 2022 New England (No MSA or MSA < 1 million), New England (MSA > 1 million) and New England samples were included due to their larger sample size, which allows for more statistical confidence in the estimated VMT means and medians.

Mileage Estimate #1. Trip Day VMT

The vehicle miles travelled (VMT) for each trip taken on the travel day is recorded. This estimate only includes miles driven in a privately owned vehicle where the survey respondent was the primary driver. While this presents the actual VMT from a single day of travel, it may not reflect all travel done by the household when extrapolated to an annual mileage estimate (e.g., road trips, work commutes if the travel diary was filled out on a weekend, mileage from other vehicles in the household). The following steps were used to calculate an annual mileage estimate:

1. **Merge**: Merge the household, trip, and vehicle data using the household and vehicle identifiers.

[10] We chose not to use the Federal Highway Administration (FHWA) statistics since they do not separate commercial and personal VMT estimates.

2. **Clean**: Filter the data to only include households with at least one vehicle, even if they did not drive on the travel day[11]. Filter the data to only keep the sample from the desired geography (e.g., Vermont, New England, etc.).
3. **Calculate daily VMT for each vehicle**: Sum personal VMT for all unique household-vehicle identifiers.
4. **Calculate daily VMT for each household**: Sum personal VMT for all unique household identifiers.
5. **Calculate annual VMT**: Multiply daily VMT by 365 days.

Mileage Estimate #2. Self-Reported VMT

Respondents are asked to estimate annual VMT for each vehicle owned by the household. While this includes respondent-specific knowledge about travel done outside of the travel day, the literature has found respondents may not be able to reliably report their annual VMT from memory[12].

1. **Annual VMT for each vehicle:** Equivalent to the self-reported estimate.
2. **Annual VMT for each household**: The sum of self-reported VMT estimates for all vehicles at the same household.

Mileage Estimate #3. FHWA-Adjusted VMT

The 2017 NHTS includes a third mileage estimate called "Best Mile"[13]. This is calculated by adjusting the self-reported mileage estimate using a combination of odometer readings, self-reported mileage estimates, and information on the primary driver of the vehicle. *Think about listing pros and cons of this estimate here....*

1. **Annual VMT for each vehicle:** Equivalent to the FHWA-adjusted VMT estimate.
2. **Annual VMT for each household**: The sum of FHWA-adjusted VMT estimates for all vehicles at the same household.

Applying Household Weights

Applying the NHTS weights is necessary to correct for sampling biases, such as demographic and geographic oversampling and nonresponse. We apply the household weights to both the household VMT estimates and the vehicle VMT estimates, since a vehicle is considered a household attribute[14]. Weighted means and standard deviations were calculated for each VMT estimate at each geography using the following formulas:

$$MEAN(VMT) = \frac{\sum_{i=1}^{N}(VMT)(W)}{N}$$

$$SD(VMT) = \frac{\sum_{i=1}^{N}(VMT)(W)}{N}$$

Where,

N is the total number of vehicles (or households) in the data
VMT is the annual VMT estimate
W is the NHTS household weight

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[11] In accordance with the 2017 NHTS User Guide, removing vehicles that did not travel on the travel day will result in inflated (i.e., inaccurately higher) VMT estimates.

[12] Some sources here.....

[13] Documentation for how "Best Mile" is calculated can be found here: https://nhts.ornl.gov/assets/2017BESTMILE_Documentation.pdf

[14] As stated in the NHTS 2017 User Guide. Source: https://nhts.ornl.gov/assets/2017UsersGuide.pdf

Weighted medians were calculated by creating a lengthened vector of VMT estimates, with each VMT value repeated the number of times equal to its weight (e.g., if the VMT estimate is 10,000 miles and the weight is 4, the lengthened vector of VMT estimates would repeat 10,000 four times). We took the median of this lengthened vector.

RESULTS

Summary of annual vehicle and household VMT estimates from the NHTS trip day, NHTS self-reported, NHTS adjusted self-reported, and VT vehicle inspections can be found in **Table A1** and **Table A2**.

We see the expected trends in the Vermont vehicle inspection data. For one, VMT is decreasing. The Vermont vehicle inspection record data suggests VMT has declined since 2018 on a per vehicle and per household basis. Median VMT for households in Chittenden County decreased from 13,700 miles a year to 11,800 miles a year between 2018 and 2022. Across the same timeline, median VMT for households across Vermont also decreased from 15,600 miles per year to 13,400 miles per year (**Table A3**). The NHTS trip day estimates support this trend of decreasing VMT between 2017 and 2022. Furthermore, we see the expected variation in VMT across municipalities in Chittenden County, with more centrally located, downtown areas having lower VMT than less centrally located, more sprawling areas. Based on **Figure A1**, the municipalities with the lowest average and median VMT estimates per vehicle are consistently South Burlington, Essex Junction Village, Burlington, and Winooski. Household median VMT estimates also show lower median VMT in these four municipalities.

We then compared the NHTS mileage estimates to the Vermont vehicle inspection mileage estimates using median values and found the Vermont vehicle inspections have slightly higher mileage estimates. Median values are a better measure of center because the data is skewed, as evidenced by the average values being higher than the median values. We find Vermont households travelled a median of 15,600 miles in 2018, which is higher than the 2017 NHTS mileage estimates for Vermont (10,500 miles based on trip day data and 14,600 miles based on adjusted self-reported data). In 2022, Vermont households travelled a median of 13,400 miles, which is also higher than the 2022 NHTS mileage estimates for New England (5,800 miles based on trip day data and 10,000 miles based on self-reported data) (**Table A3**).

Finally, we assessed the statistical significance of the differences between the NHTS mileage estimates and the Vermont vehicle inspection mileage estimates and found they are comparable. Using an unequal variance t-test, we find no statistically significant differences between the means of the household-level VMT estimates between the DMV data and the NHTS data (**Table A4**). Using the same tests, we also find there is no significant difference between the vehicle-level 2018 DMV data and the 2017 Vermont NHTS Trip-Day estimates (**Table A2**). Overall, we would expect the Vermont-to-Vermont 2017 comparison to be more accurate than the Vermont-to-New England 2022 comparison due to larger sample sizes and the better overlap in geographies.

CONCLUSIONS

Validating the VMT estimates from the Vermont vehicle inspection data is challenged by the lack of personal vehicle mileage data sets available for Vermont. We believe the NHTS is the best comparison. Based on this analysis, the NHTS shows comparable mileage estimates. We feel confident moving forward with the Vermont vehicle inspection data as a representation of personal vehicle mileage in Chittenden County.

TABLE A1 Vehicle Annual Vehicle Miles Travelled

				Annual Vehicle VMT [in 1000s of miles]	
Year	**Geography**	**N**	**Average**	**Median**	**St. Dev**
NHTS Trip Day					
2017	New England *All*	2,128	11.9	7.4	22.7
2017	New England *MSA > 1 million*	838	11.6	7.8	14.5
2017	New England *No MSA or MSA < 1 million*	1,290	12.2	7.1	28.6
2017	Vermont	407	14.6	6.9	71.1
2022	New England *All*	211	11.1	5.6	14.9
2022	New England *MSA > 1 million*	104	12.9	6.8	17.6
2022	New England *No MSA or MSA < 1 million*	107	9.6	5.2	12.2
NHTS Self-Reported VMT					
2017	New England *All*	1,526	11.9	10	12.4
2017	New England *MSA > 1 million*	580	11.9	10	11.5
2017	New England *No MSA or MSA < 1 million*	946	12	10	13.2
2017	Vermont	297	12.2	11	7.9
2022	New England *All*	198	12.8	10	17
2022	New England *MSA > 1 million*	96	11.2	10	14.2
2022	New England *No MSA or MSA < 1 million*	102	14	10	18.9
NHTS FHWA-Adjusted VMT					
2017	New England *All*	1,978	12.2	10.2	11.2
2017	New England *MSA > 1 million*	785	12.3	10.4	9.6
2017	New England *No MSA or MSA < 1 million*	1,193	12.1	10.1	12.5
2017	Vermont	366	12.8	10.7	16
VT Vehicle Inspection					
2018	Chittenden County	61,425	10.7	9.8	6.6
2018	Vermont	233,523	11.7	10.6	7.5
2019	Chittenden County	65,438	10.2	9.3	6.4
2019	Vermont	249,434	11.2	10.1	7.4
2020	Chittenden County	65,698	9	8.1	6.1
2020	Vermont	249,142	10	9	6.9
2021	Chittenden County	66,837	9.4	8.5	6.4
2021	Vermont	254,445	10.4	9.4	7.1
2022	Chittenden County	57,759	9.7	8.8	6.4
2022	Vermont	216,749	10.6	9.6	7.1

TABLE A2 Statistical Difference Tests for Vehicle VMT

VT Vehicle Inspection	NHTS	P-value	Interpretation[1]
2018 Chittenden County	2017 Vermont Trip Day	0.135	No Statistical Difference
	2017 Vermont Self-Reported VMT	0.001	Statistical Difference
	2017 Vermont FHWA-Adjusted VMT	0.006	Statistical Difference
2018 Vermont	2017 Vermont Trip Day	0.206	No Statistical Difference
	2017 Vermont Self-Reported VMT	0.138	No Statistical Difference
	2017 Vermont FHWA-Adjusted VMT	0.095	No Statistical Difference
2022 Chittenden County	2022 New England Trip Day	0.087	No Statistical Difference
	2022 New England Self-Reported VMT	0.006	Statistical Difference
2022 Vermont	2022 New England Trip Day	0.313	No Statistical Difference
	2022 New England Self-Reported VMT	0.035	Statistical Difference

[1] Statistical Difference: P-value < 0.05; No Statistical Difference: P-value >= 0.05

TABLE A3 Household Annual Vehicle Miles Travelled

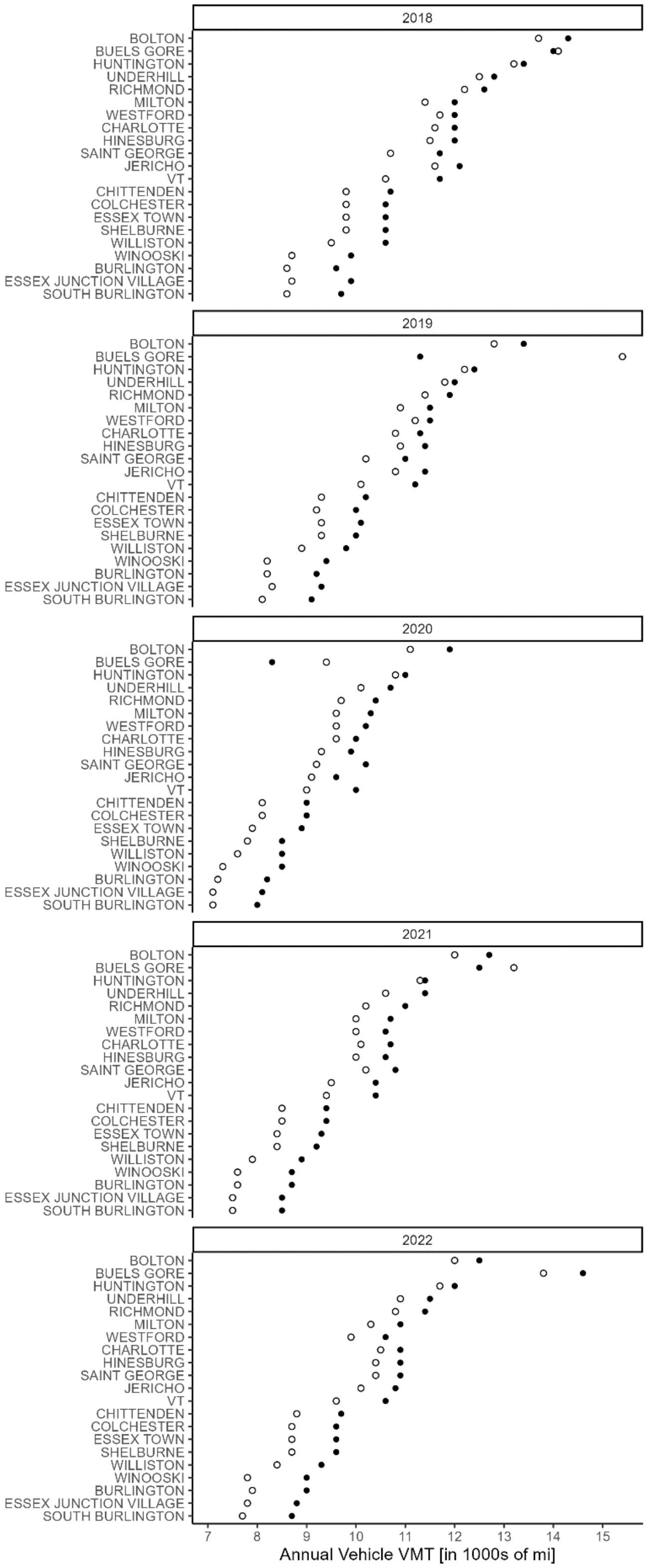
			Annual Household VMT [in 1000s of miles]		
Year	**Geography**	**N**	**Average**	**Median**	**St. Dev**
NHTS Trip Day					
2017	New England *All*	1,524	17.3	10.8	28.6
2017	New England *MSA > 1 million*	595	16.8	10.9	18.6
2017	New England *No MSA or MSA < 1 million*	929	17.8	10.8	35.8
2017	Vermont	296	21.6	10.5	86.4
2022	New England *All*	168	13.8	5.8	17.7
2022	New England *MSA > 1 million*	84	15.5	7.1	20.4
2022	New England *No MSA or MSA < 1 million*	84	12.3	5.2	14.9
NHTS Self-Reported VMT					
2017	New England *All*	1,188	15.6	12	16.1
2017	New England *MSA > 1 million*	459	14.9	12	14.1
2017	New England *No MSA or MSA < 1 million*	729	16.1	12	17.7
2017	Vermont	234	16.4	12	12
2022	New England *All*	164	14.8	10	18.6
2022	New England *MSA > 1 million*	80	12.8	10	15.2
2022	New England *No MSA or MSA < 1 million*	84	16.5	12	20.8
NHTS FHWA-Adjusted VMT					
2017	New England *All*	1,486	16.8	13.1	15.5
2017	New England *MSA > 1 million*	584	16.9	12.9	14
2017	New England *No MSA or MSA < 1 million*	902	16.7	13.6	16.7
2017	Vermont	284	17.4	14.6	19.7
VT Vehicle Inspection					
2018	Chittenden County	38,966	16.9	13.7	13.3
2018	Vermont	142,944	19.1	15.6	14.6
2019	Chittenden County	40,693	16.3	13.1	13
2019	Vermont	149,317	18.7	15.2	14.6
2020	Chittenden County	41,200	14.3	11.3	11.8
2020	Vermont	150,665	16.6	13.3	13.5
2021	Chittenden County	41,872	15.1	12	12.7
2021	Vermont	153,848	17.3	13.9	14
2022	Chittenden County	38,475	14.6	11.8	12
2022	Vermont	140,821	16.4	13.4	12.8

TABLE A4 Statistical Difference Tests for Household VMT

VT Vehicle Inspection	**NHTS**	**P-value**	**Interpretation[1]**
2018 Chittenden County	2017 Vermont Trip Day	0.175	No Statistical Difference
	2017 Vermont Self-Reported VMT	0.737	No Statistical Difference
	2017 Vermont FHWA-Adjusted VMT	0.335	No Statistical Difference
2018 Vermont	2017 Vermont Trip Day	0.309	No Statistical Difference
	2017 Vermont Self-Reported VMT	1.000	No Statistical Difference
	2017 Vermont FHWA-Adjusted VMT	0.926	No Statistical Difference
2022 Chittenden County	2022 New England Trip Day	0.720	No Statistical Difference

	2022 New England Self-Reported VMT	0.445	No Statistical Difference
2022 Vermont	2022 New England Trip Day	0.971	No Statistical Difference
	2022 New England Self-Reported VMT	0.864	No Statistical Difference

[1] Statistical Difference: P-value < 0.05; No Statistical Difference: P-value >= 0.05


2018
2019
2020
2021
2022
BOLTON
BUELS GORE
HUNTINGTON
UNDERHILL
RICHMOND
MILTON
WESTFORD
CHARLOTTE
HINESBURG
SAINT GEORGE
JERICHO
VT
CHITTENDEN
COLCHESTER
ESSEX TOWN
SHELBURNE
WILLISTON
WINOOSKI
BURLINGTON
ESSEX JUNCTION VILLAGE
SOUTH BURLINGTON
7
8
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15
Annual Vehicle VMT [in 1000s of mi]

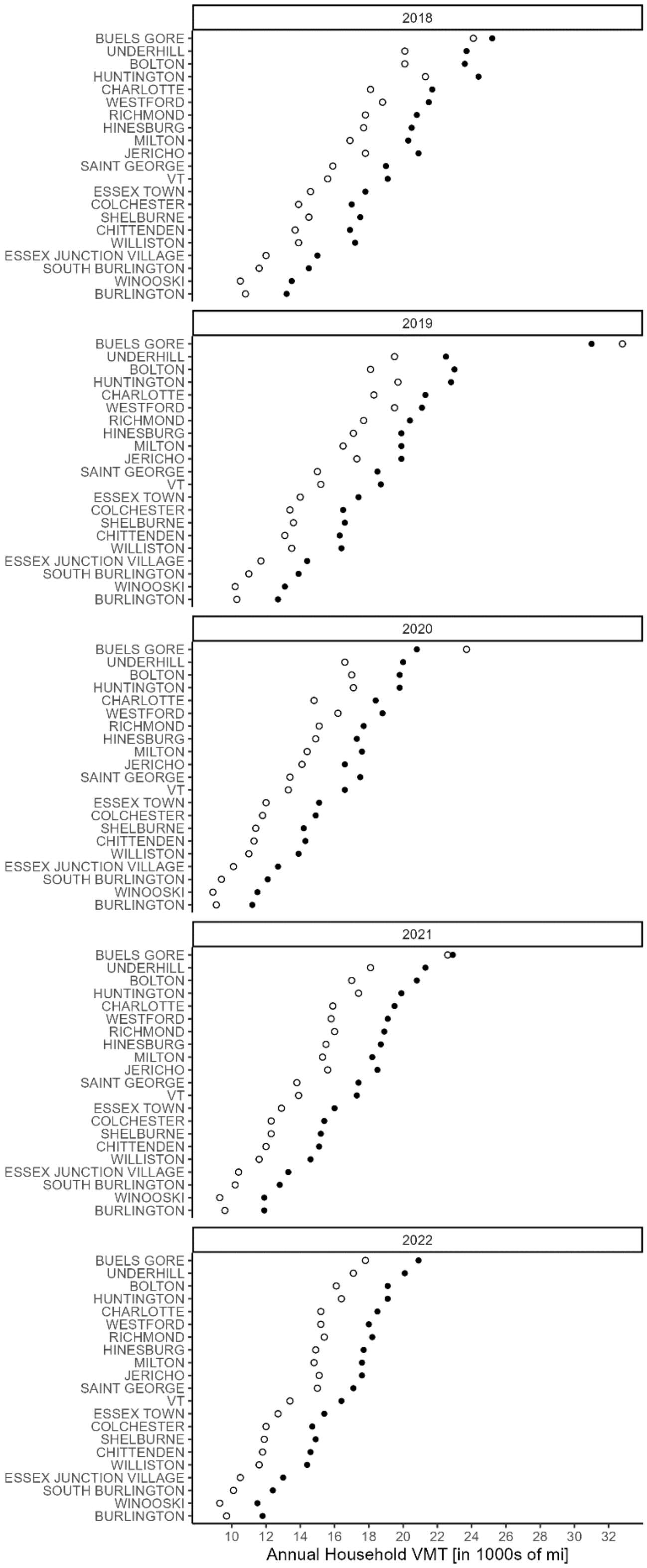

FIGURE A1 VT Vehicle Inspection Annual Vehicle and Household Vehicle Miles Travelled from 2017 to 2022, with mean values represented with black dots and median values represented with white dots

TABLE A5 National Household Travel Survey Variables

Dataset	Variable	Description	Levels
House	HOUSEID[3]	Household identifier	[30000007, 50515573] = 2017 Responses [9000013002, 9000218040] = 2022 Responses
	WTHHFIN	Final household weight	[7.0766987086, 22155.068296] = 2017 Responses [103.58613435, 308074.69884] = 2022 Responses
	CDIVMSAR	Grouping of household by combination of Census division, MSA status, and presence of rail	11 = New England (MSA or CMSA of 1 million or more with heavy rail) 12 = New England (MSA or CMSA of 1 million or more without heavy rail) 13 = New England (MSA less than 1 million) 14 = New England (not in MSA) …
	HHSTATE[1]	Household state	*All 50 U.S. State abbreviations (e.g., "VT")*
	HHVEHCNT	Count of household vehicles	[0, 12] = 2017 Responses [0, 17] = 2022 Responses
Trip	HOUSEID[3]	Household identifier	[30000007, 50515573] = 2017 Responses [9000013002, 9000218040] = 2022 Responses
	VEHID[3]	Household Vehicle Identifier Used on Trip	-9 = Not ascertained [01, 12] = 2017 Responses [01, 17] = 2022 Responses
	VMT_MILE	Trip distance in miles for personally driven vehicle trips	-9 = Not ascertained -1 = Appropriate skip [0, 5,441.489] = 2017 Responses [0, 1,682.699] = 2022 Responses
Vehicle	HOUSEID[3]	Household identifier	[30000007, 50515573] = 2017 Responses [9000013002, 9000218040] = 2022 Responses
	VEHID[3]	Household Vehicle Identifier Used on Trip	-9 = Not ascertained [01, 12] = 2017 Responses [01, 17] = 2022 Responses
	ANNMILES	Self-reported annual mile estimate for the vehicle	-9 = Not ascertained [0 – 200,000] = Responses
	BESTMILE[1]	Best estimate of annual miles	-9 = Not ascertained [0 – 200,000] = Responses

[1] Only available in the 2017 NHTS
[2] Only available in the 2022 NHTS
[3] Responses vary between 2017 NHTS and 2022 NHTS

APPENDIX C. DATA DICTIONARY

VARIABLE	DESCRIPTION
Vehicle Miles Travelled (VMT)	The difference between odometer readings from subsequent vehicle inspections, normalized by the number of days between inspections to get an estimate of daily VMT, and multiplied by 365 to get an estimate of annual VMT.
Kilograms of Tailpipe CO2 Emissions	Vehicle miles travelled multiplied by a CO2 equivalent emissions rate. Emissions rates were calculated by vehicle age, vehicle type, and fuel type using MOVES for Chittenden County.
Gallons of Gasoline Consumed by Vehicles	Vehicle miles travelled from gasoline-consuming vehicles divided by fuel economy
Gallons of Diesel Consumed by Vehicles	Vehicle miles travelled from diesel-consuming vehicles divided by fuel economy
Kilowatt-hours of Electricity Consumed by Vehicles	Kilowatt-hours per 100 miles multiplied by vehicle miles travelled from electricity-consuming vehicles
Passenger Car	Passenger cars
SUV	Sports utility vehicles
MPV	Multi-purpose Vehicle
Light-duty Truck	Trucks with gross vehicle weight less than 14,000 lbs
Motorcycle	Motorcycles
HEV	Hybrid-electric vehicles, which have a combustion engine and an electric motor that charges with regenerative braking
PHEV	Plug-in hybrid electric vehicles, which have a combustion engine and an electric motor can charge with regenerative braking and/or by plugging into an external battery
BEV	Battery electric vehicles, also known as all-electric vehicles, which have a battery that provides electricity to power the vehicle
FFV	Flexible fuel vehicle consuming ethanol-blend fuels up to 85%
E-85	Flexible fuel vehicle consuming ethanol-blends over 85%