



EVALUATION OF GREENHOUSE GAS EMISSIONS REDUCTIONS DUE TO VERMONT'S CLEAN TRANSPORTATION INCENTIVE PROGRAMS

Hallie Hinchman

Parsa Pezeshknejad

Narges Ahmadnia

Dana Rowangould, PhD

Gregory Rowangould, PhD

University of Vermont Transportation Research Center

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16. Abstract This study evaluates four of Vermont's recent clean transportation incentive programs in terms of emissions reductions, cost effectiveness, and equity. We evaluate the New PEV, Replace Your Ride, MileageSmart, and eBike programs overall and for variations in the types of vehicles incentivized. The four programs evaluated achieved GHG emission reductions between 27,400 and 81,900 metric tons CO ₂ in total when accounting for the likelihood of free riders, reflecting average emissions reductions of 4.1 to 12.4 metric tons CO ₂ per incentive. In terms of cost effectiveness, all programs combined had per incentive costs that were slightly higher than the value of estimated emissions reductions. Two subgroups of incentives exhibited estimated benefits that exceeded program costs when evaluating using more optimistic assumptions: incentives from the more recent version of the New PEV program and New PEV incentives used to acquire a battery-electric vehicle. The estimated value of the emissions reduction benefits of the other programs and program subgroups were either inconclusive or did not exceed program costs. The shares of incentive funds distributed to recipients living in multi-family housing and rural areas were similar to the distribution of registered vehicles in Vermont, indicating a relatively even distribution of incentives along these dimensions. Low-income households received most of the incentives from each program, particularly for Replace Your Ride and MileageSmart, reflecting the equity objective of the programs' design.			
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Hallie Hinchman

Parsa Pezeshknejad

Narges Ahmadnia

Dana Rowangould, PhD

Gregory Rowangould, PhD



University of Vermont
Transportation Research Center

Prepared for the Vermont Agency of Transportation:

Project Champion:

Ari Lattanzi

Technical Advisory Committee:

Emily Parkany

Ashlie Mercado

Philip Cecchini, Capstone

Pierce Cheney (CSE)

Hilary DelRoss

Patrick Murphy

Alexander Newman (VT DEC)

David Roberts (VEIC)

Collin Smythe

Andrea Wright

About the Transportation Research Center

The Transportation Research Center at the University of Vermont (UVM TRC) conducts research that advances the science of understanding how we travel, the design of resilient transportation systems, and the impact of transportation on the environment, our health and wellbeing, and the economic prosperity of diverse communities. The UVM TRC has a unique focus on understanding the transportation challenges of people and businesses in small municipalities and rural communities to provide local and state government decision makers with practical, research-informed insights to support more sustainable, equitable, and resilient transportation systems that serve the needs of all individuals and communities.

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EXECUTIVE SUMMARY

The purpose of this study is to evaluate Vermont's recent clean transportation incentive programs to understand the extent to which they achieved greenhouse gas (GHG) emissions reductions efficiently, equitably, and effectively. Vermont's Global Warming Solutions Act requires greenhouse gas emissions reductions of 26% below 2005 levels by 2025 for all sectors, ramping up to 80% below 1990 levels by 2050. Transportation greenhouse gas emissions account for 40% of Vermont's emissions. Achieving greenhouse gas emissions reductions from transportation in Vermont's largely rural context is particularly challenging because of the more limited transportation options in rural settings and the long distances between where people live and their essential destinations.

A central focus of Vermont's transportation decarbonization effort has been the provision of five clean transportation incentive programs:

- New Plug-in Electric (New PEV),
- MileageSmart,
- Replace Your Ride
- eBike, and
- Electrify Your Fleet.

The Replace Your Ride and MileageSmart programs could be stacked with the New PEV program when applicable to increase the incentive amount. These programs provided incentive funds to consumers to encourage a shift to new and used battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), used high-efficiency conventional hybrid vehicles (HEVs or hybrids), and electric bicycles (e-bikes.) These five programs targeted clean transportation for Vermont's commercial and public fleets as well as personal vehicles. State funding for the New PEV, MileageSmart, and Replace Your Ride incentive programs ended in 2024 and funds for the eBike and Electrify Your Fleet programs ended in 2025.

Informing future efforts to reduce greenhouse gas emissions by increasing vehicle electrification requires information about how the state's incentive programs have affected emissions. While the effects of clean transportation incentive programs on fuel intensity, vehicle miles traveled, and greenhouse gas emissions have been evaluated in urban and suburban contexts in California and elsewhere, little is known about their effects in rural or northern contexts like Vermont. It is important to better understand the effects of clean transportation incentives in these areas because their residents have distinct travel behaviors and transportation needs.

This project uses information about Vermont's incentives and their recipients as well as detailed vehicle data to evaluate the performance of Vermont's clean transportation incentive programs in terms of greenhouse gas emissions, cost effectiveness, and equity. Determining the effectiveness of clean transportation incentive programs in the Vermont context is important to inform clean vehicle incentive programs in the future should funding return.

This analysis evaluates the New PEV, Replace Your Ride, MileageSmart, and eBike programs. The Electrify Your Fleet program was omitted due to the relatively small number of incentives provided

at the time of the analysis. To provide additional insights about effective program design, we also sought to evaluate program-specific reductions and reductions for subgroups of program incentives where sufficient data were available. These subgroups include:

- standard versus enhanced incentive levels, which tie greater incentive amounts to lower income consumers,
- incentive program updates, reflecting changes to the New PEV program implemented after July 2023,
- incentivized vehicle type, including BEV versus PHEV,
- leased versus owned incentivized vehicles, and
- used versus new incentivized vehicles.

Results are summarized in Table E1. The range of estimates shown reflects uncertainty in two assumptions: 1) the share of free riders, or incentive recipients that are assumed to be people who would acquire a clean vehicle even without the incentive and 2) how long incentivized vehicles are expected to last. In some cases programs or program subgroups had insufficient or inconclusive data. We report results for programs and program subgroups with robust estimates. We do not report results for the overall New PEV program and additional New PEV program subgroups because results were inconclusive. There was insufficient data to conclusively estimate emissions changes associated with the eBike incentive program, the Replace Your Ride program stacked with MileageSmart, the standalone Replace Your Ride program, and additional Replace Your Ride and MileageSmart program subgroups.

Table E1 shows that overall the four clean vehicle incentive programs evaluated achieved GHG emission reduction benefits of between 27,400 and 81,900 metric tons CO₂ in total, even when accounting for the likelihood of free riders, reflecting average emissions reductions of 4.1 to 12.4 metric tons CO₂ per incentive. The program-specific analysis indicates that the highest savings were achieved through the New PEV program incentives, particularly for those distributed to consumers acquiring a BEV, those distributed under the second version of the program implemented after July 2023 (which increased income limits and the incentive amount for low income BEVs), and those issued as stacked incentives combined with a Replace Your Ride program incentive.

For clean vehicle programs and program subgroups with conclusive emissions reductions estimates, we also estimate costs and benefits of each incentive. We estimate the value of emissions avoided based on the marginal damages of each additional ton of CO₂ emitted, the incentive costs based on the incentive amounts provided to consumers, and overall cost effectiveness measured as the cost per metric ton of CO₂ avoided. As shown in Table E1, for all programs combined the per incentive costs are slightly higher than the estimated range of emissions reduction benefits. There were two subgroups of incentives with an estimated value of the benefits that the potential to exceed the program costs when using more optimistic assumptions: incentives issued through the second version of the New PEV program and New PEV incentives issued to consumers acquiring a BEV. The other programs and program subgroups

evaluated were less cost effective and the estimated value of their emissions reduction benefits did not exceed program costs.

Table E1 Summary of GHG reductions, costs, and benefits of clean vehicle incentive programs

Program and subgroup¹	Program reach	GHG emissions saved by each incentive	Total GHG emissions saved by the program	Incentive benefits (value of GHG emissions reductions)	Incentive cost (purchase incentive amount)	Cost effectiveness
	# vehicles	avg metric tons CO ₂ / incentive	metric tons CO ₂	avg 2024 \$ / incentive	avg 2024 \$ / incentive	2024 \$ per metric ton CO ₂ averted
New PEV only						
Enhanced	2,286	4.8 – 14.6	11,000 – 33,400	\$1,300 - \$4,100	\$4,440	\$300 - \$930
Version 2 ²	2,202	5.8 – 16.9	12,800 – 37,200	\$1,600 - \$4,800	\$3,610	\$210 - \$620
BEV acquisition	3,172	4.8 – 16.2	11,000 – 51,400	\$1,300 - \$4,500	\$3,770	\$230 - \$790
New PEV + RYR						
All	264	6.3 – 17.8	1,700 – 4,700	\$1,700 - \$5,100	\$8,690	\$490 - \$1,390
MileageSmart only						
All	1,136	2.0 – 6.8	2,300 – 7,800	\$500 - \$1,900	\$4,720	\$690 - \$2,320
BEV acquisition	347	3.6 – 12.5	1,200 – 4,300	\$900 - \$3,400	\$4,900	\$390 - \$1,360
All PV programs³						
BEV acquisition	3,868	4.7 – 15.9	18,200 – 61,500	\$1,300 - \$4,400	\$4,270	\$270 - \$900
Leased	2,317	4.8 – 15.1	11,100 – 35,000	\$1,300 - \$4,200	\$4,040	\$270 - \$850
Used	1,298	2.0 – 6.6	2,600 – 8,600	\$500 - \$1,800	\$5,120	\$770 - \$2,570
All programs⁴						
All	6,489	4.1 - 12.4	27,400 – 81,900	\$1,100 - \$3,500	\$3,700	\$300 - \$890

¹ Programs and program subgroups with inconclusive results are not shown.

² The second version of the New PEV program, implemented on 7/1/23, increased raised low- and moderate-income eligibility tiers and low-income BEV incentive amounts.

³ All passenger vehicle programs including RYR, New PEV, and MileageSmart; excludes eBikes.

⁴ Includes all programs evaluated: RYR, New PEV, MileageSmart, and eBikes; excludes Electrify Your Fleet.

At the same time, the clean transportation incentive programs were designed with the dual purpose of achieving CO₂ reductions and expanding the affordability of the transition to a clean transportation system for low-income Vermonters, so they should not be evaluated solely based on their CO₂ reductions. These dual objectives were particularly important in the design of Replace Your Ride and MileageSmart. Table E2 shows that the shares of incentive funds distributed to recipients living in multi-family housing and rural areas were similar to where Vermont vehicles are located, indicating a relatively even distribution of incentives along these dimensions. These results also show that low-income households received the majority of the incentives from each program, particularly for Replace Your Ride and MileageSmart, which is an outcome largely dictated by the design of the programs.

Table E2 Clean vehicle incentives distributed to multifamily, rural, and low-income households

Program	Multifamily housing incentives (#)	Multifamily housing incentive funds (\$)	Rural incentives (#)	Rural incentive funds (\$)	Low income incentives (#)	Low income funds (\$)
New PEV	16%	16%	38%	61%	54%	69%
MileageSmart	25%	25%	40%	60%	100%	100%
RYR	16%	15%	35%	66%	85%	92%
eBike	17%	19%	56%	56%	79%	88%
Vermont (% vehicles)	20%	20%	63%	63%	NA	NA

Overall, the purpose of Vermont’s clean vehicle incentive programs is to reduce GHG emissions from the transportation sector and help the state achieve its GHG emission reduction targets, while also ensuring that the transition to clean transportation is accessible to all Vermonters. The most desirable programs will be both cost effective and equitable and can be implemented at a scale that meaningfully contributes to overall emission reductions. The New PEV program BEV acquisitions and the post-July 2023 version of the New PEV incentive program showed potential for achieving GHG reductions benefits that exceeded program costs under the most optimistic assumptions, while other programs evaluated did not. All clean incentive programs reached a relatively high share of low-income Vermonters, and the clean incentive programs with more restrictive income requirements achieved higher rates of low-income uptake, likely expanding the reach of the clean incentive programs. Prior research also indicates that lower income incentive recipients are also less likely to be free riders, making incentives that target lower-income Vermonters a more cost-effective strategy for achieving GHG reductions. Vermont’s clean incentive programs reflected this more effective design strategy by targeting lower-income consumers.

This study accounts for an unprecedented level of detail in terms of changes in household vehicles and their vehicle use. However, it also has several limitations. The value of GHG emission reductions used in the benefit cost assessment are consistent with those recommended by the Vermont Climate Council, but these estimates are uncertain and higher or lower values have been used in other analyses. Additionally, while we use a range of free rider estimates based on the best available evidence, the rates of free riders in the Vermont programs may differ. Our analysis has also not accounted for possible co-benefits including public health benefits attributable to improved air quality or cost savings to households from the potential for lower operating and maintenance costs. At the same time, this study does not include the administrative costs of implementing the clean vehicle incentive program, nor does it consider the convergent effects of layering state incentives with federal and utility incentives. Additionally, we consider each incentive’s effects on one household in isolation. It is possible that incentives play a role in advancing clean vehicles beyond recipients’ actions, prompting more people to perceive them as a viable option, prompting more dealers to carry them, or increasing the viability of charger

investments, which could have ripple effects on other vehicle consumers who may decide to purchase clean vehicles without an incentive. Importantly, this evaluation reflects a snapshot of the effect of policies implemented from 2019 to 2025. Past research has indicated that GHG incentive effectiveness has improved over time, perhaps due to complementary changes such as the increasing range of vehicle options, lower vehicle costs, expanding charging infrastructure, or shifts in consumer attitudes. However, as of this writing, federal incentives for vehicles and charging infrastructure are ending and vehicle standards are being rolled back, so the trajectory of electric vehicle adoption and rates of free riders is uncertain.

Finally, while the focus of this assessment is the performance of clean transportation incentives, decision makers in Vermont may also consider how these programs compare to other GHG emission reduction strategies available in the transportation sector and the broader economy. The cost effectiveness values estimated in this study can be used when considering clean transportation incentive programs alongside other GHG mitigation strategies in the future, such as strategies that seek to expand access to electric vehicle charging, expand access to non-auto travel options, or reduce emissions from non-transportation sectors. When cost effectiveness estimates are available for many possible strategies, strategies can be prioritized in terms of their cost effectiveness and the scale of the reductions they achieve to ensure that emissions reductions are sufficient and low cost. However, as demonstrated in the description of limitations of this study it can also be difficult to precisely evaluate the cost effectiveness of many GHG mitigation strategies. In the absence of full knowledge of each GHG mitigation strategy's costs and benefits, decision makers may also consider market-based GHG mitigation strategies such as carbon taxes or a cap-and-trade (or cap-and-invest or cap-and-dividend) program. These market-based programs create financial incentives that cover a broader range of activities than incentives tied to high efficiency and electric vehicle purchases, offering greater flexibility in how a household or business chooses to reduce GHG emissions. Market-based policies also generate revenue that can be used to address equity concerns by offsetting program costs for low income households by distributing funds to households through a dividend or reduced income tax or by funding targeted vehicle incentive programs like those considered in this study. When carefully designed with mechanisms to address equity and affordability, market-based GHG reduction programs have the potential to achieve GHG reductions at a lower overall cost while addressing equity concerns. They may also be implemented in combination with investments in specific programs (such as vehicle incentives) where merited.

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1. INTRODUCTION

As Vermont seeks to reduce greenhouse gas (GHG) emissions from transportation, it is important to evaluate policies and programs to inform the state's ongoing efforts to ensure that they are effective, efficient and equitable. Vermont's Global Warming Solutions Act requires steadily decreasing GHG emissions, mandating GHG reductions of 26% below 2005 levels by 2025 and reductions of 80% below 1990 levels by 2050 (Vermont Global Warming Solutions Act of 2020, 2020). Approximately 40% of the state's emissions are attributed to the transportation sector (ANR, 2025). Decarbonizing Vermont's transportation is a necessary step toward meeting mandated GHG reductions. Reducing transportation emissions in Vermont's rural context is challenging, with fewer transportation options and long distances between destinations in many Vermont communities.

Reducing transportation GHGs can be achieved using a range of strategies designed to affect how much people drive and the emissions intensity of their travel. One critical strategy is shifting from internal combustion engine (ICE) vehicles to electric vehicles (EVs), which generate fewer emissions while providing the mobility and flexibility benefits of personal vehicles. Vermont's Comprehensive Energy Plan calls for all new light-duty vehicles to be zero emission by 2035 (Vermont Department of Public Service, 2022).

An important part of Vermont's strategy for achieving this goal was the implementation of four clean transportation incentive programs that encouraged Vermonters to adopt clean vehicles, including:

- new and used battery-electric vehicles (BEVs),
- new and used plug-in hybrid electric vehicles (PHEVs),
- used high-efficiency vehicles including hybrid electric vehicles (HEVs),
- and new electric bicycles (eBikes).

Vermont's clean transportation incentive programs, which exhausted their funding by 2025, were an important component of the state's ongoing transportation GHG reduction efforts. Incentive amounts amongst the programs ranged from \$400 to \$6,000 depending on income eligibility as well as the price and fuel type of the clean vehicle (*State of Vermont Incentives - Drive Electric Vermont*, 2024). The incentive programs were a complement to Vermont's adoption of California's Advanced Clean Cars II program, which mandates a growing share of clean vehicles in the new vehicle market. As of October 2024, the majority of funding for the programs was exhausted. In 2024, BEVs and PHEVs made up 8.2% of vehicles registered for the first time in Vermont¹, and as of March 2025, BEVs and PHEVs comprised 2% and 1% of the state's registered light-duty vehicles, respectively².

¹ According to <https://atlaspolicy.com/evaluatevt/>

² Estimated using the TRC vehicle database, which is built using Vermont DMV registration and inspection records. At the time of this report the TRC vehicle database uses registration data from March 2025

If Vermont is to consider additional investments in clean transportation incentive programs to increase adoption of EVs in the future, it is important to ensure that the programs effectively and equitably reduce GHG emissions to ensure the most valuable use of the state's funds. Evaluating the strengths and weaknesses of Vermont's clean transportation incentive programs can inform the design and promotion of future GHG reduction initiatives in Vermont.

This report addresses the need for Vermont-specific program evaluation. We used detailed Vermont vehicle data and incentive data to evaluate the greenhouse gas emissions reductions, cost-effectiveness, and equity of Vermont's clean transportation incentive programs.

2. BACKGROUND

Transportation GHG emissions are a function of 1) the amount of vehicle travel, 2) the carbon intensity of vehicle fuel, and 3) vehicle efficiency (Kay et al., 2014; Lutsey & Sperling, 2009; McCollum & Yang, 2009). The GHG benefits of an electric vehicle acquisition depend on the efficiency of the vehicle purchased (Thorne & Hughes, 2019), whether and which vehicles are replaced (Thorne & Hughes, 2019), changes in travel behavior that accompany a change in vehicle (Hamamoto, 2019; Jia & Chen, 2022), charging behavior for plug-in hybrid vehicles (Hardman et al., 2018; Pagany et al., 2019), the amount that each vehicle is used (Jensen & Mabit, 2017), and the GHG intensity of electricity used to charge electric vehicles (Thorne & Hughes, 2019). In practice, the GHG benefits of electric vehicle acquisition can be overestimated when using overly simplistic assumptions about people's electric vehicle use and charging behavior (Hamamoto, 2019).

The effectiveness of financial incentives for acquiring a clean vehicle also depends on the vehicles (or other mobility options) that would be purchased (or not) without the incentive (Chen et al., 2021; Xing et al., 2021). The effectiveness of incentives is diminished when consumers that receive an incentive are "free riders" that would have made the same choice without the incentive. Prior research indicates that the majority of incentive recipients are in fact free riders (Hardman et al., 2017; Jenn et al., 2020). Incentive effectiveness varies with incentive and recipient attributes, for example their effectiveness varies across regions (Azarafshar & Vermeulen, 2020). They are also more likely to change people's vehicle choices when consumers purchase lower end vehicles (Hardman et al., 2017), when they are offered closer to the point of sale (e.g. during or right after purchase) (Hardman et al., 2017), and for consumers with a lower income (DeShazo et al., 2017; Sheldon & Dua, 2019). The effectiveness of incentives has also increased over time as the EV market has matured (Jenn et al., 2020; Sheldon & Dua, 2024). One study evaluates the cost effectiveness of vehicle incentive programs across nations while accounting for free riders and typical vehicle usage, estimating that incentives are relatively expensive, with an estimated cost of \$700 to \$4,000 per metric ton of carbon dioxide reduced (Sheldon & Dua, 2024).

Incentive effectiveness for PHEVs versus BEVs depends on both incentive design and electric miles driven. State-level BEV incentives have been found to be more effective when compared with PHEV incentives in terms of their effect on market share (Wee et al., 2018), although a study in Canada found that the effect of PHEV versus BEV incentives on the market share of vehicles was not

significantly different (Azarafshar & Vermeulen, 2020). However, the Canadian study also accounted for the emissions intensity of travel, finding that BEVs were more cost effective than PHEVs with savings of C\$500 to C\$900 per tonne of carbon saved versus C\$600 to C\$1100 per tonne, respectively (Azarafshar & Vermeulen, 2020). A third study that accounted for electric miles driven found that PHEV incentives are more effective than BEV incentives, although this depends on incentivized vehicles' electric range (Hardman et al., 2017).

Most prior studies that evaluate incentive effectiveness focus on the number of vehicles affected, and the share of recipients that are free riders, assuming typical vehicle usage. However, the GHG reductions that result from incentives can also be shaped by household-level transportation behavior with and without incentives. Importantly, the GHG reductions from electric vehicle acquisition can be overestimated when using simplistic assumptions about people's clean vehicle use and charging behavior (Hamamoto, 2019).

Additionally, while clean transportation incentive programs have been evaluated in urban areas, little is known about their effectiveness in rural contexts, which differ in terms of how vehicles perform and are used. When compared with their urban counterparts, rural communities typically have fewer transportation options and more dispersed land uses. Not surprisingly, rural households take less frequent but longer trips than urban households, resulting in higher overall VMT per person (Millward & Spinney, 2011; Pucher & Renne, 2005; Ralph et al., 2016, 2017; Schukei & Rowangould, 2025; Voulgaris et al., 2017).

When seeking to evaluate the effects of incentives in the Vermont context, it is important to draw from data and analysis that accounts for the unique conditions experienced by Vermont residents. For example, the share of a household's miles that are electric (e.g. from vehicle use in multivehicle households and charging behavior for plug-in hybrid vehicles) relates to battery range and distances traveled (Jensen & Mabit, 2017; Thorne & Hughes, 2019). Considering winter conditions, which diminish EV range, and the long distances between charging opportunities in rural contexts, Vermonters in rural areas who adopt EVs may be more likely to choose larger and more powerful vehicles with larger batteries, which may affect both efficiency and usage. At the same time, rural travelers may be traveling longer distances than nonrural travelers, so multivehicle households may be more likely to use gasoline powered vehicles for longer trips. On the other hand, recent research in Vermont suggests that the fuel efficiency "rebound effect" (the gains in VMT that accompany improvements in fuel economy when a household acquires a more efficient vehicle) are larger among households living in more rural areas (Ahmadnia & Rowangould, 2024).

This report evaluates the effectiveness of four of Vermont's clean transportation incentive programs implemented between December 2019 and May 2025 (Table 1). We use Vermont-specific vehicle data to evaluate program effectiveness in terms of GHG emissions reductions, equity, and cost effectiveness.

Table 1: Vermont clean transportation incentive programs

Program ³	Eligible Vermont entities ⁴	Eligible purchases	Amount ⁵	Program period	Incentives as of May 2025
New PEV	Residents Standard: moderate income Enhanced: low income	New BEV and PHEVs subject to eligibility: MSRP ≤ \$52,500 PHEV electric range ≥ 30 miles	Standard: BEV: \$2,500 PHEV: \$1,500 Enhanced: BEV: \$5,000 PHEV: \$3,000	12/2019 – 10/2024	Standard: 2,105 Enhanced: 2,495
MileageSmart	Residents Low income	Early program: Used high efficiency vehicle (40+ mpg) Later program: Used PHEV or BEV (40+ mpg), HEV for SNAP recipients only	≤\$5,000	8/2020 – 10/2024	1,277
Replace Your Ride⁶	Residents Standard: moderate income Enhanced: low income	Scrap a functional 10+ year old internal combustion vehicle and replace with a new or used electric vehicle or credit toward other clean mobility options	Standard: ≤\$2,500 Enhanced: ≤\$5,000	10/2022 – 10/2024	Standard: 103 Enhanced: 348
eBike	Residents Low income Moderate income (round 1 only)	New eBikes (standard, cargo, adaptive) subject to MSRP and power limits	Standard eBike: ≤\$400 Cargo or adaptive: \$800	5/2022 – 6/2025	Standard: 124 Enhanced: 463

³ The state’s Electrify Your Fleet program provided incentives to commercial, municipal, and nonprofit fleet owners to replace fleet vehicles through August 31 2025, is excluded from this analysis because only 44 incentives were awarded during the analysis period.

⁴ Initial eligibility for the New PEV program set low- and moderate-income tiers ranging from ≤\$50k to ≤\$75k and ≤\$100k to ≤\$125k, respectively, depending on tax filing status. The second version of the New PEV program began on 7/1/23, adjusting low- and moderate-income tiers to ≤\$60k to ≤\$90k and ≤\$100k to ≤\$150k, respectively, depending on tax filing status. Replace Your Ride income eligibility corresponds to New PEV program eligibility. Eligibility for MileageSmart was based on SNAP recipient status or income at 80% of the state median income. The eBike program set low- and moderate-income tiers ranging from ≤\$50k to ≤\$90k and ≤\$100k to ≤\$150k, respectively, depending on tax filing status and the incentive round.

⁵ New PEV incentives for BEVs were adjusted from \$4K to \$5K on 7/1/23. On 7/1/23 Replace Your Ride incentive amounts changed from \$3k (low income only) to \$5k and \$2.5k for low and moderate income, respectively. On 6/1/24 MileageSmart incentives were adjusted from ≤\$5k to ≤\$2.5k. EBike incentives were adjusted in rounds 2 and 3 to include cargo and adaptive eBikes and to remove moderate income eligibility.

⁶ New PEV and MileageSmart can be stacked with a Replace Your Ride incentive if scrapping an internal combustion vehicle that is at least 10 years old.

3. STUDY OBJECTIVE

The objective of this report is to evaluate the Vermont clean vehicle incentive programs' GHG emissions reductions, cost effectiveness, and equity to inform potential future clean vehicle incentive program design and investment in Vermont.

3.1 GHG emissions reductions

What are the effects of each clean vehicle incentive program on recipients' GHG emissions?

Acquiring an EV has the potential to lower a household's GHGs, but the change in GHGs depends on the household's vehicles' fuel intensity, efficiency, and use. Understanding the GHG reductions from clean vehicle incentive programs therefore requires answering three questions. First, what is the net effect of acquiring a clean vehicle on a household's GHG emissions from all vehicles, accounting for their fuel emissions intensity, efficiency, and use? Second, are the GHG changes associated with a clean vehicle acquisition different for recipients of different types of incentives, and for those acquiring a vehicle without an incentive? Finally, to what extent does the incentive cause people to acquire an EV (versus subsidizing a shift that would have occurred anyway)?

3.2 Cost effectiveness

What is the cost effectiveness of each incentive type and level?

The cost effectiveness of clean transportation incentives can be evaluated based on the value of GHG reduction benefits and the financial costs of GHG reductions caused by each incentive. We can evaluate the costs and benefits of each incentive summarized by incentive type and level to determine whether benefits outweigh costs for each program.

3.3 Equity

What types of entities receive each incentive type and level?

Understanding the characteristics of incentive recipients can provide an indication of the equity of the incentive program. Available data allow us to evaluate variation in where incentive recipients live (town, single vs multifamily resident) as well as the income level of incentive recipients.

4. METHODS

4.1 Overview

To evaluate the GHG impact of each incentive program we evaluate the change in emissions that can be attributed to the incentives. We estimate this change by evaluating the emissions in the year before and after an incentive was acquired for incentive recipients as well as emissions changes for households that acquired a vehicle without an incentive or did not acquire any vehicle. This analysis relies primarily on an evaluation of a household sample that includes households for which we have complete before and after GHG data.

Because this sample may not be representative of all Vermont households, we use machine learning to extrapolate GHG outcomes to a larger sample of incentivized households for which have partial data to ensure that bias in the household sample is corrected. To adjust these estimates to account for household emissions that would have occurred without the incentive program (e.g. free riders), we use the machine learning model results and apply insights from literature and surveys of incentive recipients. We then project emissions savings for the lifetime of incentivized vehicles to assess total GHG savings that occur due to the incentive program.

To calculate the cost effectiveness of each program, we estimate the dollars spent per metric ton of GHG emissions reduced. We also estimate the dollar value of benefits of GHG reductions using the social cost of carbon, or the cost of damages caused by a ton of GHG emissions. We then compare costs of clean transportation incentive programs with the benefits of the GHG reductions that they achieve to determine whether the GHG benefits of each incentive program outweigh the costs.

To examine the equity of the clean transportation incentive program, we use incentive data to evaluate the geographic distribution of incentives across Vermont, the share of incentive recipients that live in multifamily housing, the share of incentive recipients that live in rural areas, and the share of incentive recipients that qualify for low-income incentives.

4.2 Data

We use a detailed longitudinal household-level vehicle dataset to evaluate the incentive emissions reductions, cost effectiveness, and equity. This analysis uses Vermont's Clean Transportation Incentive Data acquired from the Vermont Agency of Transportation (Vermont Agency of Transportation, 2025). We also use data from the Transportation Research Center's Vermont Vehicle Database (TRC Vehicle Data), which merges Vermont Department of Motor Vehicles (DMV) registration and inspection records and supplements them with additional information from other sources. Incentives are first matched to TRC Vehicle Data. Vehicle level data is then aggregated to assemble household-level data for two samples: i) households that have complete before and after GHG data for whom we can directly estimate changes in greenhouse gas emissions, and ii) a larger sample of incentivized vehicles for which we have partial data that we can simulate emissions for to reduce sampling bias.

Clean vehicle incentive data ("Incentives")

To identify incentivized vehicles, we use vehicle incentive data from the Vermont Agency of Transportation (Vermont Agency of Transportation, 2025). The data provides information about the incentive program, incentive level (enhanced or standard), dollar amount, and whether incentive recipients are low-income. The incentive data also includes information that can be matched with TRC Vehicle Data, such as the incentivized vehicle's unique Vehicle Identification Number (VIN), date of purchase, and the address of the incentive recipient. When the incentive includes a trade-in vehicle, the trade-in's VIN is also included. The incentive data is filtered to include relevant entries as shown in Table 2.

Table 2: Clean vehicle incentive data filtering

Filter applied	# incentives remaining after filter (% of original 7,029 incentives)
1. Remove duplicate application records	6,990 (99%)
2. Remove unverified and fraudulent incentives	6,962 (99%)
3. Remove Electrify Your Fleet and Clean Transportation Debit Card incentives ⁷	6,894 (98%)

Vermont vehicle data

The TRC Vehicle Data is a comprehensive Vermont vehicle-level dataset. It integrates two Vermont DMV sources: vehicle registration records and annual vehicle inspection records, both obtained from 2017 to 2025⁸. Each annual inspection record includes the VIN, inspection date, and odometer reading. This allows vehicle odometers to be tracked over time to estimate annual mileage. Vehicle registration records provide information on VIN, make, model, model year, and registered address. Addresses are geocoded to ascertain vehicle locations. The VIN can be used to connect registration and inspection records and to extract additional vehicle attributes such as vehicle and fuel type from the National Highway Traffic Safety Administration (NHTSA) VIN Decoder (NHTSA, 2025). These vehicle characteristics are supplemented with fuel efficiency and range estimates from the U.S. Environmental Protection Agency (EPA) Fuel Economy Data (U.S. Department of Energy, 2025). The final merged TRC Vehicle Dataset contains detailed information on estimated annual mileage, vehicle attributes, and residential location for vehicles registered in Vermont from 2018 to 2025. Because we have information from consecutive years, we can also observe the change in vehicles at registration addresses within a given year or over a period of several years, for example when one vehicle is replaced by another at the same address, or when a vehicle moves to another address.

Linked vehicle data

To link vehicle incentives with the TRC Vehicle Data, we used incentive dates and VINs (using fuzzy matching to resolve erroneous entries⁹), linking entries to corresponding registration records that

⁷ Electrify Your Fleet incentives were not included in the GHG analysis due to insufficient sample size, and Clean Transportation Debit Card incentives were not included because of insufficient information about how they were used and the GHG implications of their use. However, these incentives are included in the incentive recipient maps used in the equity analysis.

⁸ At the time of this analysis the 2025 data were incomplete because the registration and inspection data were provided in March 2025 and June 2025, respectively, so it did not reflect the full year of data. Additionally, the March 2025 registration data was missing a small portion of entries. Because the analysis uses statistics to extrapolate patterns rather than relying on a complete census of data, these data gaps did not materially impact the analysis.

⁹ Of the 5,722 vehicles that were acquired with a clean vehicle incentive, 1,212 had VINs that did not match that of any vehicle registered in the state of Vermont. We performed fuzzy matching on the unmatched VINs using Levenshtein string distances to identify similar VINs. VINs were determined to match if their string

were within 5 months before through 7 months after the incentive was issued. This time window was used to accommodate late vehicle registrations, particularly during the Covid-19 pandemic. Although eBikes cannot be linked directly to vehicle records using a VIN, we linked incentivized eBikes to vehicle records based on the address and purchase date provided in the incentive data.

Table 3 presents the number of incentives issued under each program and the number that were linked to TRC Vehicle data. Of the programs evaluated in this report, the New PEV program accounts for the highest number of incentives, while the Replace Your Ride program has the fewest. When merging the incentive data with the vehicle registration records, not all incentives could be included in the analysis as some were not registered with Vermont’s DMV within the temporal matching window, if at all.

Table 3 Incentive linkage to vehicle data

Incentive program	Incentives data entries	Incentives in scope after filtering incentive data (Table 2)	Incentives matched to TRC Vehicle Data	Incentives after filtering vehicle data (Table 4)
New PEV	4,669 (100%)	4,602 (99%)	3,403 (73%)	3,344 (72%)
MileageSmart	1,277 (100%)	1,277 (100%)	1,135 (89%)	1,085 (85%)
Replace Your Ride	451 (100%)	428 (95%)	265 (59%)	257 (57%)
Ebike	588 (100%)	587 (>99%)	464 (79%)	464 (79%)
Electrify Your Fleet	44 (100%)	0 (0%)	0 (0%)	0 (0%)
Total	7,029 (100%)	6,894 (98%)	5,267 (75%)	5,150 (73%)

After linking incentive data to TRC vehicle data we then applied the following filters to ensure that the analysis includes only incentives that were linked to suitable vehicle data, as summarized in Table 4:

- Only cars and trucks were included, removing inapplicable vehicle types,
- Vehicles registered to the government were excluded,
- Only light-duty vehicles with a gross vehicle weight rating (GVWR) of less than 14,000 pounds were included, removing medium and heavy-duty vehicles,
- Only vehicles registered at Vermont addresses were retained, and
- Overlapping vehicle registrations due to transfer of ownership or moving addresses were consolidated to one active registration per vehicle at any given time.

The final count of incentives linked to suitable vehicle data is shown in the final row of Table 4. The final column Table 3 shows the final same count broken down by incentive type.

distance was less than 6, the incentive address matched the registration address, and the vehicle was registered the same or subsequent year as the incentive. Fourteen fuzzy matches were obtained.

Table 4 Linked vehicle data filtering

Filter applied	Share of TRC Vehicle Data records remaining after filter	Incentives remaining after filter
0. All vehicles in TRC data	100%	5,267 (75%)
1. Remove trailers, motorcycles, snowmobiles, motorboats, and buses	92%	5,267 (75%)
2. Remove government vehicles	89%	5,267 (75%)
3. Remove medium- and heavy-duty vehicles	82%	5,264 (75%)
4. Remove vehicles registered to addresses outside of Vermont	78%	5,256 (75%)
5. Keep one active registration at a time for each vehicle ¹⁰	62%	5,150 (73%)

Assembling vehicles into households

To track GHG emissions from each household’s vehicles before and after they acquire an incentive, it is necessary to first assemble the Vermont vehicle records into household records. Because the TRC Vehicle Data does not include the name of the person who registered each vehicle, we cannot identify households directly. In lieu of names, we identify Vermont households as groups of one or more vehicles that are registered to the same street address in each year of the analysis¹¹. Note that the households we identify in this process are those that arise using the entire Vermont vehicle dataset, not just those that received an incentive. Households that did not receive an incentive are included in the analysis to provide counterfactual information about how GHGs change among households that did not receive an incentive, which is required for the free-rider adjustment.

Once we assemble the households at each address for each year of the analysis, we create two different data tables: a table of Vermont households with complete before and after GHG data, and a table of incentivized vehicles with partial data, each described below.

Vermont households with complete before and after GHG data (“Households”)

The first data table we create from the assembly of households is a table that allows us to directly observe GHG changes over time. Since vehicle incentives occur at various times throughout the year and across multiple years, we track households over six overlapping three-year intervals between 2018 and 2025: 2018–2020, 2019–2021, 2020–2022, 2021–2023, 2022–2024, and 2023–2025. Each three-year period is used to evaluate the change in emissions relative to the second

¹⁰ This step involves selecting the most “current” record from TRC DMV vehicle records in each year of the data, which includes all records including past records when a registration is updated. A relatively small share of incentives were cut from the analysis because they were linked to an earlier record in the same year, indicating that the household moved or sold the vehicle within the year.

¹¹ We exclude households with 10 or more vehicles because they are likely to be multifamily residences that were mischaracterized as single family residences.

year in the period. For example, the change in emissions for a household that acquired an incentivized vehicle in 2019 is evaluated based on the differences in that household's emissions in 2020 versus 2018. We also evaluate the change in emissions for households that do not acquire an incentivized vehicle over the same period.

Because moving itself may affect household travel and this will confound the estimates of GHGs, our analysis of each three-year interval excludes households that move to a new address during the interval. We identify households that stay in place during each three-year period in two ways. For households with multiple vehicles, we include households as non-movers when at least one vehicle stays at the same address from year 1 to 2 and from year 2 to 3. We also retain single-vehicle households that replace their vehicle (shed one vehicle and gain another) during the three-year interval as well as in single-vehicle incentive households where the prior VIN¹² was registered during the year before the incentive. The latter approach is the best available estimate of single car incentive households, but it is imperfect because it may erroneously include single vehicle households that move away and are replaced by a new single vehicle household.

To isolate the effect of each incentive, we also remove households that received an incentive for multiple fuel types and households that received incentives from multiple programs in the same year (except for stacked incentives, which are retained in the analysis). We cannot predict GHG changes for specific vehicles from multi-program households because their effects are combined, and we cannot predict GHG changes households that got incentivized vehicles of multiple fuel types because the free rider adjustments (described further below) are specific to the fuel type of the vehicle.

Within this household-level sample, we then identify whether households changed their vehicle ownership during the second year of each three-year interval (the "vehicle change year"), such as adding or removing vehicles from their household fleet. We also distinguished vehicle acquisitions that were incentivized through Vermont's clean vehicle incentive programs from acquisitions that were not linked to an incentive and from households that did not acquire a vehicle.

Using this household-level data, we assemble two types of variables that are used for two purposes:

- 1) **Variables for GHG before/after estimation:** These variables are needed to estimate the change in GHGs for households that do not move over the three-year period. These include estimates of household vehicle attributes during the first and third year of the three-year period, including the household's vehicle-specific VMT, emissions rates, and the utility-specific emissions factor. For PHEVs, we assume typical charging behavior to estimate vehicle energy emissions rates, as represented in EPA emissions factor assumptions. Once

¹² Prior VINs refer to scrapped vehicles that receive a Replace Your Ride incentive as well as some other incentive program recipients' vehicle that they indicate that they intend to replace. Not all incentive data includes entries for prior VINs.

we estimate the GHG emissions for each vehicle in the household in years 1 and 3 we then estimate the change in household-level GHGs from year 1 to 3.

- 2) **Variables for GHG extrapolation:** These variables are more readily available and are used in a machine learning model to tie this household data to a sample of incentivized vehicles with partial data in order to extrapolate GHG emissions changes to a larger population of incentivized vehicles. This set of variables is based on household-level data in the year an incentive is acquired (the second year of the three-year period) and includes incentive program and level, vehicle gain versus replacement, the fuel type of acquired vehicles, and baseline household vehicle counts (counts of BEVs, HEVs, PHEVs, and ICEs before acquiring the incentive vehicle). This list of variables excludes year 1 and year 3 variables that require a household to stay in place as well as VMT, which is not available for all households.

The final cleaned and filtered household-level dataset includes only those households with complete information from passenger vehicles owned by households that did not move over the three-year analysis period. The resulting sample contains 961 incentive households that acquired 853 incentivized vehicles and 131 incentivized eBikes.

The household sample filtering steps and their effect on the data included in our analysis (including all households in the Vermont vehicle data as well as incentivized households) are shown in Table 5.

Table 5 Filtering of sample households¹³ with complete before and after GHG data

Filter applied	All households in Vermont vehicle data remaining after filter: % of households in Vermont vehicle data	Incentivized households remaining after filter: Number (%) of linked incentive households
0. All households in TRC data	100%	4,707 (100%)
1. Keep only households that stay at their address over the 3-year interval	60%	3,530 (75%)
2. Remove households that received incentives from multiple programs (excluding stacking) or with incentives with different fuel types in the same year	60%	3,493 (74%)
3. Remove households with at least one vehicle with missing or anomalous annual VMT (< 5 miles or > 100,000 miles)	28%	1,077 (23%)
4. Keep households with complete information	25%	961 (21%)

¹³ Note that Table 5 shows households (not incentives.) The number of households shown do not match the number of incentives shown in Tables 3, 4, 6, and 7 because some households receive more than one incentive.

Incentivized vehicles with partial data (“Vehicles”)

The second data table we create using vehicle records that have been aggregated into households is a table that includes vehicles for which we have a subset of key vehicle- and household-level variables in any given analysis year. This table includes all vehicles that have the variables that we use as predictors in the machine learning model of GHG emissions change (described further below). The majority of these vehicles do not include enough information to directly observe the change in GHGs.

Variables included in this table are the same as variables described above that are used for GHG extrapolation in the table of households with complete before and after GHG data. These variables are based on household-level data in the year an incentive is acquired and include incentive program and level, vehicle gain versus replacement, the fuel type of acquired vehicles, and baseline household vehicle counts (counts of BEVs, HEVs, PHEVs, and ICEs).

As with the table of households with complete before and after GHG data, we also removed any incentivized vehicles and eBikes whose household acquired vehicles from multiple different incentive programs or incentive levels or acquired multiple incentivized vehicles of different fuel types because we do not have sufficient information to evaluate their GHGs (n = 173 incentives in 37 households).

Summary of data cleaning steps and three data tables

The filters and cleaning described above result in three data tables that are used in this analysis, with the number of incentivized households included at each step summarized in Table 6. The first table includes all valid incentives (referred to as “Incentives”.) The second table includes a sample of Vermont households for which we have sufficient data to observe the change in GHGs directly (referred to as “Households”.) The third table includes a sample of a larger number of incentivized vehicles that we can use to extrapolate GHGs to reduce bias in the second table’s sample (referred to as “Vehicles”.)

Table 6 Incentive sample size through data cleaning process

Data cleaning step	Incentives remaining after step: number (%)
1. Original incentive data table	7,029 (100%)
2. Remove invalid and out of scope incentives (Table 2) (“Incentives”)	6,894 (98%)
3. Link incentive and vehicle data (Table 3)	5,267 (75%)
4. Filter linked vehicle data (Table 4)	5,150 (73%)
5a. Create table of observed household-level GHG changes in 961 households with complete before and after GHG data (Table 5) (“Households”)	1,005 (14%)
5b. Create a larger incentivized vehicle dataset to simulate GHGs based on incentivized vehicles with partial data (“Vehicles”)	4,393 (62%)

Sample representativeness

To assess potential bias in the incentivized households included in the “Households” table, we compare their attributes to attributes of the “Incentives” and “Vehicles” tables (Table 7). Most attributes are relatively similar for households that are in versus outside of the household-level sample. Focusing on differences, the proportion of incentive recipients that are low-income, enhanced incentive recipients, leased, and BEVs are modestly lower in the household table when compared with the incentive and vehicle tables. We also report the attributes of incentives in the three tables split by incentive type in Appendix C, with visualizations of uncorrected data shown in Appendix F. The differences observed point to the need to reduce bias using statistical methods, as described further below.

Electricity emissions data

Emissions of electricity used by BEV and PHEV vehicles are estimated based on the electric utility that serves the vehicle’s registered address. We estimate the emissions intensity (quantity of CO₂ per MWh) of each Vermont utility based on the composition of the utility’s energy sources in 2024 (A. Jacobs, personal communication, October 17, 2024) and the emissions intensity of New England residual mix (*NEPOOL Generation Information System: Residual Mix Report, 2023 Q1 to Q4, 2025*), accounting for Renewable Energy Credits trading and distribution losses. The method we used is consistent with the Vermont Department of Public Service’s method for estimating the electricity emissions intensity for the Vermont statewide GHG inventory. We use 2024 utility-specific emissions factors for all date ranges evaluated as we expect any error introduced by this simplification to be minimal because electricity emissions factors in Vermont are small relative to the emissions factors for gasoline. See Appendix A for additional information.

4.3 Analysis methods

We first evaluate the GHG changes associated with receiving an incentive. We then build on this analysis to evaluate incentives’ cost effectiveness. Finally, we evaluate the equity of incentives received.

GHG effects

Overview

As described above, the Households table includes estimated changes in GHGs from the year before the incentive to the year after the incentive, for households that did and did not receive an incentive. To fully evaluate the GHG effects of the incentive program, we use this information to 1) create a statistical model to extrapolate emissions changes in the Household sample to the larger Vehicle sample to address potential sample bias, 2) adjust these estimates to account for what incentive recipients would have done if there were no incentive program, and 3) estimate the total emissions changes that result from each incentive over the incentivized vehicle’s lifetime.

Table 7 Attributes of incentives reflected in incentive, vehicle, and incentivized household tables

	Incentives	Vehicles	Households
Table description	All valid incentives	Incentives for vehicles with partial data	Incentives for households with complete data
Number of records	6,894	4,393	1,005
Incentive Characteristics	% of incentives	% of incentives	% of incentives
Program and level			
Program			
New PEV	67%	68%	71%
MileageSmart	19%	21%	16%
Replace Your Ride	6%	10%	4%
eBike	9%	8%	13%
Enhanced	48%	45%	40%
Incentivized vehicles			
Fuel Type			
BEV	61%	58%	53%
PHEV	23%	24%	27%
HEV	8%	10%	8%
eBike	9%	8%	13%
New	79%	76%	72%
Purchased	64%	70%	77%
Additional Vehicle Acquisition	NA	60%	48%
Incentive recipients			
Low-Income	67%	59%	56%
Housing Type			
Multi-Family	NA	17%	16%
Single Family	NA	70%	72%
Other	NA	3%	2%
NA	NA	10%	10%
Urban/Rural			
Urban	NA	36%	37%
Rural	NA	53%	53%
NA (not geolocated)	NA	12%	10%
Incentivized household travel¹⁴	Mean (st dev)	Mean (st dev)	Mean (st dev)
Vehicle count (number)	NA	1.8 (1.2)	1.8 (0.8)
Emissions intensity (kg CO ₂ /mile) ¹⁵	NA	0.29 (0.15)	0.32 (0.12)
Annual VMT (miles/year)	NA	NA	19,100 (11,800)
Annual GHG emissions (kg CO ₂) ¹⁶	NA	NA	6,200 (4,500)

¹⁴ Vehicle count and emissions intensity are from the household at the beginning of the year of the incentive. Annual VMT and GHG emissions are from the household the year before the incentive was received.

¹⁵ Emissions intensity is the average kg CO₂/mile for all vehicles in the household (not weighted by VMT.)

¹⁶ Annual GHG emissions is weighted by each vehicle's VMT.

Step 1: Create a statistical model of GHG emissions changes using the Household sample and extrapolate to the Vehicle sample

We use statistical modeling to tie the change in GHGs observed in Vermont households to more widely available attributes using data from the Household table. The statistical model is a predictive random forest machine learning algorithm that predicts the absolute change in household GHGs (kg CO₂) from the first to third year of each three-year period evaluated (2019 – 2021, 2020 – 2022, etc). For households that received an incentive in the second year of the three-year period, this represents the change in GHGs in the year after the incentive was received relative to the year before it was received. For households that did not receive an incentive, this represents the change in GHGs over the same period, serving as a point of comparison that is used in subsequent steps to understand the impact of the incentive.

We chose a random forest because of the method's ability to capture nonlinear effects and interactions automatically. It also allows the use of continuous and categorical predictor variables without preprocessing. Predictor variables included the year (second year of the period), household attributes such as the number of vehicles by fuel type, acquisition of a new or used vehicle, average emissions intensity, and receipt of an incentive from the clean transportation programs.

The statistical model is not designed as an explanatory or causal model but is instead designed to extrapolate estimates from the smaller Household sample to the larger Vehicle sample using variables that are available in both samples. This modeling process reduces potential bias in the estimate of incentive effectiveness. Before extrapolation, we apply proximity-based weighting to weigh incentivized vehicles more heavily in the model training.

We evaluate the accuracy of our model by comparing the mean predicted household GHG change to the mean observed household GHG change. We perform this comparison on subgroups of the incentive Households to determine which results are robust enough to report (Table 8). A subgroup's results are reported if its mean predicted household GHG change is within 10% of its mean observed household GHG change. Model checks and variable attributes are detailed in Appendix D.

Once the statistical model is finalized, we use the statistical model derived from the Household table to predict GHG changes for incentive recipients that are in the Vehicle table, which has the same set of variables that was used as predictors in the statistical model. This allows us to use the observed GHG changes from the Household sample to predict GHG changes in the larger Vehicle sample, thereby reducing the sample bias in the estimates. The results of this sample bias evaluation and correction are in Appendix D7.

Table 8 Subgroups evaluated for model performance

Program	Category	Reportable results
New PEV only	All	No
	Enhanced	Yes
	Standard	No
	Version 1 (pre-July 2023)	No
	Version 2 (post-July 2023)	Yes
	BEV	Yes
	PHEV	No
New PEV + Replace Your Ride	All	Yes
MileageSmart only	All	Yes
	BEV	Yes
	PHEV	No
	HEV	No
MileageSmart + Replace Your Ride	All	No
eBike	All	No
	Enhanced	No
	Standard	No
All passenger vehicle programs evaluated ¹⁷	BEV	Yes
	PHEV	No
	HEV	No
	New	No
	Used	Yes
	Purchase	No
	Lease	Yes
All programs evaluated ¹⁸	All	Yes

Step 2: Adjust estimated GHG changes to account for a no-incentive counterfactual

To evaluate GHG changes that would occur if there were no incentive program, we adjust the estimates from Step 1 based on expectations of what incentive recipients would have done if the incentive had not been offered.

The primary goal of this step is to adjust for “free riders,” or incentive recipients who would have purchased the same type of vehicle without an incentive. Based on prior literature and surveys of Vermont incentive recipients, we assume that incentive recipients would have made one of the following choices if there were not an incentive program: i) acquire a clean vehicle anyway, ii) acquire an internal combustion engine (ICEV) or hybrid electric vehicle (HEV) vehicle, or iii) not acquire a vehicle. In the review of prior literature, we prioritized studies that evaluated programs similar to those implemented in Vermont in terms of vehicle and recipient eligibility. We also

¹⁷ Includes New PEV, RYR, and MileageSmart; excludes eBikes and Electrify Your Fleet.

¹⁸ Excludes Electrify Your Fleet.

prioritized estimates that reflect the effect of incentives at the person-level rather than the market-level since the incentives may not be offered to everyone if they include vehicle or person eligibility or if there is a cap on the total funds available. Where applicable, we used multiple estimates reflecting the range of estimated effects.

The specific assumptions used for each program are shown in Table 9. The table shows the “without incentive” counterfactual assumptions for each incentive program and for each type of incentivized vehicle acquired, as applicable. In some cases the analysis uses two sets of assumptions, one that assumes that the program has a lower effect and one that assumes it has a higher effect. For example, for the RYR program and the RYR + New PEV program, the lower effect assumptions assume that 51% of incentive recipients who purchase a BEV would have acquired a BEV without the program, 24.5% would have acquired an ICEV/HEV without the program, and 24.5% would not have acquired a vehicle without the program. The higher effect assumptions assume that without the program 28% would have acquired a BEV, 36% would have acquired an ICEV/HEV, and 36% would not have acquired a vehicle.

We adjust each incentivized vehicle’s household attributes to represent three versions of a possible choice that capture each of the three choices reflected in the free rider assumptions. Next, we use the estimated relationships from the statistical model from Step 1 to simulate the emissions changes that would have occurred for each of the three choices. We then weight each outcome by the odds of each choice to estimate the GHG changes that would result if there were no incentive program. Finally, we estimate the change in GHG emissions that occur due to the incentive program as the difference between the change in GHGs with the incentive program minus the change in GHGs that would have occurred without the incentive program.

Because this modeling is based on the difference in GHG emissions before and after an incentive was acquired, the estimate represents the household-level GHG emissions changes in the first year after the incentive was received. These estimates are generated for all incentive recipients in the Vehicle sample. The resulting estimate corrects for bias in the household sample and is adjusted to account for the choices incentive recipients would have made without the incentive program.

Step 3: Estimate total emissions changes over the incentivized vehicle’s lifetime

Once we have these estimates of GHG changes in the first year after the incentive was received, we estimate total emissions that occur over each incentivized vehicle’s lifetime. We use several assumptions to estimate a range of lifetime emissions:

- **Vehicle lifetime:** Emissions from all household vehicles are estimated for each year in a vehicle’s lifetime to calculate lifetime emissions. We use a range of vehicle estimates. The short estimate of the lifetime of newly acquired cars and trucks is assumed to be eight years, consistent with the eight year or 80,000 mile warranty on emissions control devices and electric vehicle batteries mandated by federal law (*40 CFR 85.2103 -- Emission Warranty.*, n.d.). For eBikes, we assume a shorter vehicle lifetime of 2 years. The long lifetime estimate for new cars and trucks is 15 years, based on EPA’s median lifetime for light-duty vehicles (USEPA, 2016). For eBikes, we assume a longer vehicle lifetime of 5 years.

Table 9 Free rider assumptions used to adjust estimated GHG reductions from incentives

Program	Would acquire same type of vehicle without incentive	Would acquire ICEV/HEV without incentive	Would not acquire vehicle without incentive ¹⁹	Reasoning
RYR or RYR + New PEV	Lower effect: BEVs: 51% PHEVs: 61% HEV: 30% Higher effect: All: 28%	Lower effect: BEVs: 24.5% PHEVs: 19.5% HEV: 35% Higher effect: All: 36%	Lower effect: BEVs: 24.5% PHEVs: 19.5% HEV: 35% Higher effect: All: 36%	The low effect estimate of acquiring the same type of vehicle is based on an evaluation of the California RYR program, which had similar incentive levels and eligibility (Sheldon & Dua, 2019). The split of remaining recipients acquiring an ICEV/HEV versus not acquiring a vehicle is based on an unweighted survey of VT RYR recipients (Center for Sustainable Energy, Undated). The high effect is based on an unweighted survey of VT RYR recipients (Center for Sustainable Energy, Undated).
MileageSmart	Same as RYR	Same as RYR	Same as RYR	In the absence of relevant studies, we apply the same assumptions as the RYR program because it is similar.
New PEV	Lower effect: BEVs: 75% PHEVs: 68% Higher effect: All: 53%	Lower effect: BEVs: 14% PHEVs: 23% Higher effect: All: 30%	Lower effect: BEVs: 11% PHEVs: 9% Higher effect: All: 17%	The lower effect is estimated from a California survey ²⁰ (Jenn et al., 2020), which yields estimates that are consistent with prior literature (Hardman et al., 2017). The high effect is based on an unweighted survey of VT New PEV recipients (Center for Sustainable Energy, Undated) and is similar to responses to the federal income tax credit described in a California survey (Hoogland et al., 2025).
eBike	All: 48%	Not applicable.	All: 52%	Based on unweighted responses to the Vermont eBike Incentive Recipient Survey (Center for Sustainable Energy, 2024).

¹⁹ To estimate the effects of not acquiring a vehicle, if the incentivized vehicle was a replacement, we use the vehicles present at the beginning of the incentive year and remove the incentivized vehicle. If the incentivized vehicle was additional or an eBike, we use the vehicles present at the end of the incentive year and remove the incentivized vehicle.

²⁰ The California survey estimate is based on federal income tax credit incentives without income limits (rather than point of sale with income limits), which may make this estimate conservative. On the other hand, these incentives were also rated more important than state incentives, likely due to the higher amount offered, which may make this estimate optimistic.

- **VMT trends:** Based on VMT in Vermont from 2000-2019²¹ from the Vermont 2021 Transportation Energy Profile (Dowds & Rowangould, 2022) (shown in Appendix B), we assume that household VMT stays the same as in the year after the incentive was received. We also assume that each vehicle's share of household VMT also remains the same as in the year after the incentive.
- **Emissions intensity:** Based on analysis of the TRC vehicle data from 2017-2023, the average emissions intensity (kg CO₂ per mile) of ICEVs and HEVs in the Vermont fleet improves by 0.79% each year (Appendix B). We assume that this trend holds in future years.

To estimate lifetime emissions, we start with the estimated change in household GHGs established in the first year after an incentive is acquired for the Vehicle sample in step 2. We then estimate the changes in GHGs for the remainder of the incentivized vehicles' lifetime by adjusting the emissions each year based on the -0.79% change in vehicle emissions intensity.

While additional inter- and intra-household travel and vehicle changes might occur, these assumptions represent an expectation of the magnitude and direction of changes that may occur when aggregated across the state. For example, many households will likely replace vehicles and therefore improve their fuel economy over a period of eight years. Rather than evaluating household-level fleet turnover, we assume steady improvement in emissions intensity in the aggregate, consistent with recent trends. Implicitly, this assumes that if some incentivized households replace their EVs they largely remain in the state of VT. It also assumes that any changes to the VMT share of the incentivized vehicle within a household are minimal when aggregated across all households.

Note that the adjustment in emissions intensity is derived based on ICEV/HEVs and is applied to all household vehicles, including EVs that are acquired. We do not include EVs in the derived rate to avoid double counting reductions in emissions intensity caused by EVs. Because EVs are a small share of overall vehicles and the typical emissions from EVs are orders of magnitude lower than emissions of HEVs and ICEVs, the error introduced by applying this change to EVs is minimal. Additionally, adjusting separately based on EVs versus other vehicles is not possible because of the limited variables available in the vehicle-level sample.

Our final step is to extrapolate these emissions changes to all incentives granted given that our Vehicle sample captures just a portion of incentives. The estimates above are derived for all vehicles in the Vehicle sample. We then assume that the per-incentive GHG savings are applicable to all incentivized vehicles for each incentive program and level.

²¹ Due to VMT fluctuations during the Covid-19 pandemic we did not use TRC Vehicle Data from 2018-2024 to project future VMT trends.

Cost effectiveness

Present value of benefits

For each incentive, we first estimate the present value of emissions benefits in 2020 dollars based on the social cost of CO₂ assuming a discount rate of 2%, following the values in Appendix A5 of the November 2023 US EPA Report on Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances (USEPA, 2023). These estimates represent the marginal cost of damages from GHGs emitted in each year, with damages assessed through the year 2300. The use of these values and a discount rate of 2% is consistent with guidance from the Science and Data Subcommittee of the Vermont Climate Council (Duval et al., 2024). However, there are a range of discount rates that are considered reasonable in the scientific community. We also explore the sensitivity of our results by performing estimates using the 1.5% and 2.5% discount rates (Appendix E.)

We apply year-specific values for social cost of carbon to each year's free-rider adjusted emissions savings, estimated based on the year the incentive occurred and the vehicle's estimated lifetime, and changes in emissions each year over the vehicle lifetime, as described above. We then sum the total benefits over the vehicle's lifetime to arrive at the present value of benefits of emissions averted. Finally, we convert these estimates to 2024 dollars using the Consumer Price Index (US Bureau of Labor Statistics, 2025).

Present value of costs

We estimate the present value of the costs of each incentive in 2024 dollars by adjusting the actual expenditure (amount received by the incentive recipient from incentive data) using the Consumer Price Index (US Bureau of Labor Statistics, 2025).

Equity

We evaluate the equity of the incentive program in terms of where incentives are received (dollars and number of incentives in communities across Vermont) and the share of incentives that require low-income eligibility. Location and eligibility of recipients are summarized using all valid incentive data, only excluding incentives that were duplicates, unverified, or were ineligible. We also evaluate the share of incentives received for residents of single and multi-family residences as well as urban and rural census blocks (as defined by the 2020 US Census) using data from the household-level sample that is also geolocated, which include sufficient location data to determine residence type. Additional vehicle attributes of incentive recipients are visualized in Appendix G.

5. RESULTS

5.1 Greenhouse gas emissions

Estimated vehicle emissions reductions by clean vehicle incentive program

Most clean vehicle incentive programs showed a reduction in GHG emissions when compared to what would happen without the incentive program. This holds even when accounting for free riders who would have purchased clean vehicles without the incentive.

As shown in Table 10, the New PEV program achieved GHG savings with 4.8 to 16.9 metric tons CO₂ mitigated per incentive. Stacking a Replace Your Ride incentive with the New PEV incentive achieved greater emissions reductions with 6.3 to 17.5 metric tons CO₂ mitigated per stacked incentive. The MileageSmart incentive program achieved smaller GHG savings ranging from 2 to 6.8 tons CO₂ per incentive although larger savings of 3.6 to 12.5 metric tons CO₂ were achieved when a BEV was acquired through the MileageSmart program.

The eBike program, Replace Your Ride program and Replace Your Ride program stacked with MileageSmart are not shown in Table 10 because there was not enough data to produce reliable GHG savings estimates. This does not mean that these programs did not change emissions – it means that we have insufficient information to draw conclusions. The Replace Your Ride program made up only 6% of incentives given. Furthermore, the relatively small amount of ICEV driving that an e-bike is expected to replace makes it difficult to detect with the annual vehicle mileage data used in this study.

GHG savings from incentives of each program type are visualized in Appendix H.

Table 10: Vehicle lifetime GHG savings²² from clean vehicle incentive programs

Program	Category	Low estimate of GHG savings: average metric tons CO₂ per incentive	High estimate of GHG savings: average metric tons CO₂ per incentive
New PEV only	Enhanced incentive	4.8	14.6
	Version 2 (post-July 2023)	5.8	16.9
	BEV acquisition	4.8	16.2
New PEV + RYR	All	6.3	17.8
MileageSmart only	All	2.0	6.8
	BEV acquisition	3.6	12.5
All vehicle programs evaluated ²³	BEV acquisition	4.7	15.9
	Leased	4.8	15.1
	Used	2.0	6.6
All programs evaluated ²⁴	All	4.1	12.4

²² Estimates account for free riders and emissions over the lifetime of the incentivized vehicle. Estimated GHG savings are derived using vehicle and household samples sizes as follows:

Program	Category	Vehicles	Households
New PEV only	Enhanced incentive	1325	295
	Version 2 (post-July 2023)	1023	148
	BEV acquisition	1945	481
New PEV + RYR	All	133	17
MileageSmart only	All	864	156
	BEV acquisition	247	43
All passenger vehicle programs evaluated	BEV acquisition	2366	542
	Leased	1241	248
	Used	953	161
All programs evaluated	All	4178	961

²³ Includes New PEV, RYR, and MileageSmart; excludes eBike

²⁴ Excludes Electrify Your Fleet.

Estimated total emission reductions by clean vehicle emission program

To estimate the total emissions savings of each program shown in Table 11, we multiplied the estimated GHG savings per incentive from Table 10 by the total number of clean transportation incentives provided by each program. The estimated emissions savings for all of the incentive programs combined is between 27,400 and 81,900 metric tons (MT). The low and high estimates represent two different vehicle lifetimes and two different free rider assumptions based on prior literature and surveys of Vermont incentive recipients' data, as described in Table 9.

Table 11: Estimated total GHG emissions savings²⁵ for all clean transportation incentives

Program	Category	Total emissions savings: metric tons CO₂	# of incentivized vehicles and eBikes
New PEV only	Enhanced incentive	11,000 – 33,400	2,286
	Version 2 (post-July 2023)	12,800 – 37,200	2,202
	BEV acquisition	11,000 – 51,400	3,172
New PEV + RYR	All	1,700 – 4,700	264
MileageSmart only	All	2,300 – 7,800	1,136
	BEV acquisition	1,200 – 4,300	347
All vehicle programs evaluated ²⁶	BEV acquisition	18,200 – 61,500	3,868
	Leased	11,100 – 35,000	2,317
	Used	2,600 – 8,600	1,298
All programs evaluated ²⁷	All	27,400 – 81,900	6,489

5.2 Cost and benefit assessment

Program costs and benefits

The monetized benefits and costs of each incentive program are summarized in Table 12. These estimates account for the emissions savings over the lifetime of each vehicle and are adjusted for free riders. The low and high estimates represent two different vehicle lifetimes and two different free rider assumptions based on prior literature and surveys of Vermont incentive recipients' data, as described in Table 13.

Generally, the cost benefit assessment finds that the estimated costs of each incentive program exceeded the estimated value of the GHG emission reduction benefits. There are two exceptions. The high estimate of the benefits achieved by the New PEV program under Version 2 of the program and for recipients who acquired a BEV programs exceed program costs by up to \$1,190 and \$730,

²⁵ Estimates account for free riders and emissions over the lifetime of the incentivized vehicle.

²⁶ Includes New PEV, RYR, and MileageSmart; excludes eBike.

²⁷ Excludes Electrify Your Fleet.

respectively. These estimates represent free rider and vehicle lifetime assumptions that are more optimistic. The low end estimates for both of these versions of the New PEV program, which represent a less optimistic view of free rider behavior and vehicle lifetimes, indicate that costs exceeded benefits. The MileageSmart and stacked New PEV + Replace Your Ride programs had the largest gap between program costs and GHG reduction benefits. The cost of the MileageSmart program was nearly 2.5 times greater than its GHG reduction benefits while the cost of the stacked New PEV + Replace Your Program was 1.7 times greater than its GHG reduction benefits.

Cost effectiveness

We also estimate the cost effectiveness of each clean vehicle incentive program by summing up the total amount paid to incentive recipients and dividing by the estimated total GHG savings. The cost of avoiding a metric ton of CO₂ using the New PEV program ranged between \$230 and \$930, making it the most cost effective incentive program. Version 2 of the New PEV program was the most cost effective (\$210 to \$620 per metric ton CO₂) followed by BEV recipients (\$230 to \$790 per metric ton CO₂). The other programs were less cost effective and with mitigation costs exceeding the social cost of carbon.

The lowest end of the cost effectiveness estimates for the New PEV program compare favorably with the social cost of carbon for the approximate period of the programs' GHG emissions benefits, which increase over time from \$231 to \$319²⁸. Statewide, incentivized BEVs and leased vehicles also exhibit favorable cost effectiveness at the low end of their estimates of \$270 to \$900 and \$270 to \$850, respectively. Cost effectiveness estimates for other programs exceed the range of estimates of the social cost of carbon.

5.3 Equity

Program equity was evaluated by considering the share of incentives received by people living in urban and rural areas, single family and multi-family housing, and those with lower incomes as shown in Table 13. The share of incentives received by recipients living in single and multi-family homes generally aligned with the distribution of registered vehicles among these two housing types. Mileage Smart recipients were somewhat more likely to live in a multi-family homes than the average Vermont vehicle owner while New PEV, Replace Your Ride, and eBike incentive recipients were somewhat less likely to live in multi-family housing.

²⁸ Estimated in 2024 dollars based on historic Consumer Price Index data (US Bureau of Labor Statistics, 2025) and values for the social cost of carbon from 2020 to 2040 in in Appendix A5 of the November 2023 US EPA Report on Social Cost of Greenhouse Gases: Estimates Incorporating Recent Scientific Advances (USEPA, 2023), assuming a 2% discount rate.

Table 12: Value of GHG benefits and costs per incentive for each incentive program²⁹

Program	Category	Value of GHG reduction benefits: avg 2024 \$ / incentive	Incentive cost: avg 2024 \$ / incentive	Cost effectiveness: 2024 \$ / metric ton CO ₂ averted
New PEV only	Enhanced	\$1,300 - \$4,100	\$4,440	\$300 - \$930
	Version 2	\$1,600 - \$4,800	\$3,610	\$210 - \$620
	BEV	\$1,300 - \$4,500	\$3,770	\$230 - \$790
New PEV + RYR	All	\$1,700 - \$5,100	\$8,690	\$490 - \$1,390
MileageSmart only	All	\$500 - \$1,900	\$4,720	\$690 - \$2,320
	BEV	\$900 - \$3,400	\$4,900	\$390 - \$1,360
All vehicle programs evaluated ³⁰	BEV	\$1,300 - \$4,400	\$4,270	\$270 - \$900
	Leased	\$1,300 - \$4,200	\$4,040	\$270 - \$850
	Used	\$500 - \$1,800	\$5,120	\$770 - \$2,570
All programs evaluated ³¹	All	\$1,100 - \$3,500	\$3,700	\$300 - \$890

Table 13 Clean vehicle incentive recipient characteristics

Program	Multi-family housing: Share of incentives, dollars	Rural Share of incentives, dollars	Low income Share of incentives, dollars
New PEV	16%, 16%	38%, 61%	54%, 69%
MileageSmart	25%, 25%	40%, 60%	100%, 100%
Replace Your Ride	16%, 15%	35%, 66%	85%, 92%
eBike	17%, 19%	56%, 56%	79%, 88%
Vermont (% vehicles)	20%	63%	NA

Rural – urban equity was more complex. While fewer incentives were distributed to rural areas than would be expected based on the distribution of vehicles registered to rural households, the dollar value of the incentives distributed to rural areas was closely aligned with the distribution vehicles registered to rural households. That is, rural households were less likely to receive clean vehicle incentives, but when they did the value of the incentive was on average larger than those received by urban households.

We only had household income information from households that received incentives. We had no information about the income of other vehicle owners, so it was not possible to conduct a complete equity analysis based on income level. However, the data we have shows that a majority

²⁹ Estimates account for free riders and emissions over the lifetime of the incentivized vehicle.

³⁰ Includes New PEV, RYR, and MileageSmart; excludes eBike

³¹ Excludes Electrify Your Fleet.

of clean vehicle incentives went to low-income recipients. This is particularly true for the MileageSmart and Replace Your Ride programs which have the strictest income requirements.

We also mapped the number and value of clean vehicle program incentives by municipality as shown in Figure 1. Most of the incentives went to recipients in Burlington and surrounding communities, which is not surprising given the concentration of Vermont's population in this region. When we adjust these values to reflect the size of the population in each municipality – showing the incentives and their value per capita - the incentives are found to be more evenly distributed across the state's communities. The very high and low per capita distribution in some rural municipalities shown in these maps is largely the result of very small populations which results in noisier data. Additional information about recipient locations for specific incentive programs is provided in Appendix G.3.

5.4 Summary of results

Overall the four clean vehicle incentive programs evaluated (all except Electrify Your Fleet) achieved GHG emission reduction benefits of between 27,400 and 81,900 metric tons CO₂ in total, even when accounting for the likelihood of free riders, reflecting an average emissions reductions of 4.1 to 12.4 metric tons CO₂ per incentive.

The program-specific analysis indicates that the New PEV program, which was the largest incentive program, exhibited reductions ranging from 4.8 to 16.9 metric tons CO₂ per incentive for three subgroups: the enhanced New PEV incentives (which provides a higher incentive amount to consumers with lower incomes), the second version of the New PEV program (implemented after July 2023 with higher income limits and a higher incentive level for low-income BEV recipients), and for New PEV recipients who acquire a battery electric vehicle (BEV). Additional reductions were achieved when the New PEV program incentives were stacked with Replace Your Ride incentives (6.3 to 17.8 metric tons CO₂ per incentive) and through the MileageSmart program (2 to 6.8 metric tons CO₂ reductions per incentive overall and 3.6 to 12.5 metric tons CO₂ per incentive applied to a BEV vehicle acquisition.) We do not report results for the overall New PEV program and additional subgroups because the results were inconclusive. There was insufficient data to estimate emissions changes associated with the eBike incentive program, the Replace Your Ride program stacked with MileageSmart, the standalone Replace Your Ride program, and additional Replace Your Ride and MileageSmart program subgroups.

While all of the incentive programs with conclusive results were found to reduce GHG emissions, cost effectiveness measured as the cost per metric tons CO₂ avoided varied widely. Of the clean vehicle programs and program subgroups with conclusive emissions reductions estimates, the three subgroups of the New PEV program were the most cost effective. The post-July 2023 New PEV incentives and New PEV incentives used for BEV acquisitions were the only groups of incentives with an estimated dollar value of the benefits from CO₂ reductions had the potential to exceed the program costs when using more optimistic assumptions. The other programs and program subgroups that were evaluated were less cost effective and the estimated value of their emissions reduction benefits did not exceed program costs.

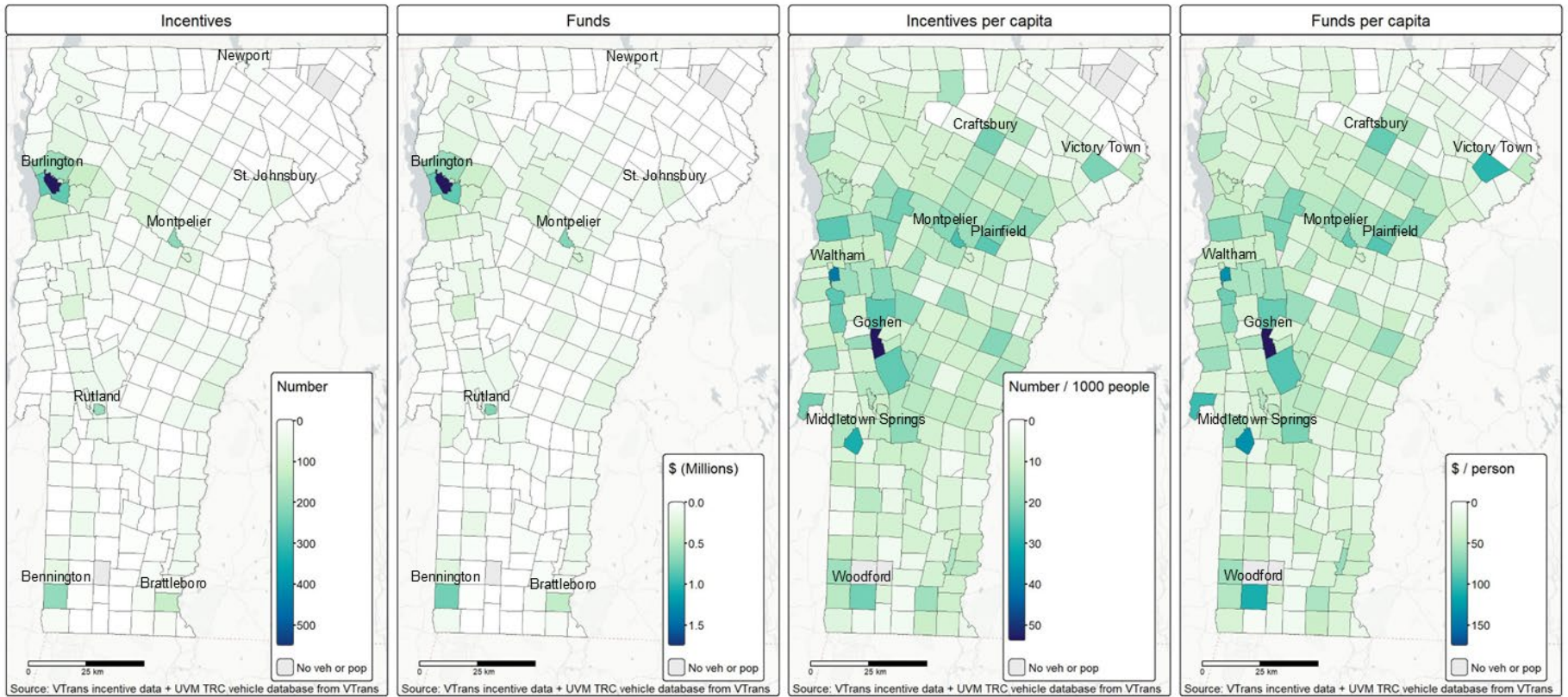


Figure 1: Clean vehicle incentive recipients and funds in Vermont's municipalities.

The distribution of incentive funds across recipients living in single and multi-family housing and urban and rural areas was similar to where Vermonters with vehicles live, indicating a relatively even distribution of incentives across the state's households with vehicles along these dimensions. While the value of incentive funds distributed to rural households was similar to those received by urban households, rural households were somewhat less likely to receive an incentive. Low-income households received the majority of the incentives from each program, which is an outcome largely dictated by the design of the programs.

6. DISCUSSION AND LIMITATIONS

The purpose of Vermont's clean vehicle incentive programs is to reduce GHG emissions from the transportation sector and help the state achieve its GHG emission reduction targets. The most desirable programs will be both cost effective and equitable and can be implemented at a scale that meaningfully contributes to overall emission reductions. The New PEV program BEV acquisitions and the post-July 2023 version of the New PEV incentive program (which increased income limits and raised the BEV incentive amount for low-income recipients) showed potential for achieving GHG reductions benefits that exceeded program costs under the most optimistic assumptions, while other programs evaluated did not. All clean incentive programs reached a relatively high share of low-income Vermonters, and the clean incentive programs with more restrictive income requirements achieved higher rates of low-income uptake, likely expanding the reach of the clean incentive programs. Prior research also indicates that lower income incentive recipients are also less likely to be free riders, making incentives that target lower-income Vermonters a more cost-effective strategy for achieving GHG reductions. Vermont's clean incentive programs reflected this more effective design strategy by targeting lower-income consumers.

This study accounts for an unprecedented level of detail in terms of changes in household vehicles and their vehicle use. However, it also has several limitations. For example, this study assumes that PHEV owners charge their vehicles at the rate assumed by USEPA, which may differ in the Vermont context. Similarly, assumptions about the length of each vehicle's lifetime in the state are unknown, particularly because we do not have a sufficient record of the current cohort of EVs to determine how long these vehicles remain in use in Vermont and also given that vehicle technology changes rapidly which may affect the longevity of batteries.

There are also uncertainties about the value of GHG emission reductions used in the benefit cost assessment. We use values of the social cost of carbon that are consistent with those recommended by the Vermont Climate Council, but higher or lower values are possible and have been used in other analysis. Additionally, there are uncertainties about the prevalence of free-riders – people who would have purchased a clean vehicle without the incentive they received. While we use the best available evidence and a range of values to account for free riders in our analysis, some uncertainty is inherently unaccounted for. Our analysis has also not accounted for possible co-benefits including public health benefits attributable to improved air quality or cost savings to households from the potential for lower operating and maintenance costs. At the same time, this study does not include the administrative costs of implementing the clean vehicle incentive

program, nor does it consider the convergent effects of layering state incentives with federal and utility incentives.

Additionally, we consider each incentive's effects on one household in isolation. It is possible that incentives play a role in advancing clean vehicles beyond recipients' actions, prompting more people to perceive them as a viable option, prompting more dealers to carry them, or increasing the viability of charger investments, which could have ripple effects on other vehicle consumers who may decide to purchase clean vehicles without an incentive.

Additionally, these policies have been considered in isolation and for the period from 2019 to 2025. Past research has indicated that GHG incentive effectiveness has improved over time, perhaps due to complementary changes such as the increasing range of vehicle options, lower vehicle costs, expanding charging infrastructure, or shifts in consumer attitudes. However, as of this writing, federal incentives for vehicles and charging infrastructure are ending and vehicle standards are being rolled back, so the trajectory of electric vehicle adoption is uncertain.

Finally, while the focus of this assessment is the performance of clean transportation incentives, decision makers in Vermont may also consider how these programs compare to other GHG emission reduction strategies available in the transportation sector and the broader economy. The cost effectiveness values estimated in this study can be used when considering clean transportation incentive programs alongside other GHG mitigation strategies in the future. Other transportation GHG gas mitigation strategies can include efforts to expand access to public and home electric vehicle charging, investments in expanding non-auto travel options such as public transit, walking, and biking, and efforts to plan land use to enable reduced vehicle travel, among others. Other strategies can also include efforts to reduce emissions from other sectors such as residential and industrial energy use or agriculture.

When cost effectiveness estimates are available for many possible strategies, strategies can be prioritized in terms of their cost effectiveness and the scale of the reductions they achieve to ensure that emissions reductions are sufficient and low cost. However, as noted in the description of limitations of this study it can also be difficult to precisely evaluate the cost effectiveness of GHG mitigation strategies. In the absence of full knowledge of each GHG mitigation strategy's costs and benefits, decision makers may also consider market-based GHG mitigation strategies such as carbon taxes or a cap-and-trade (or cap-and-invest or cap-and-dividend) programs. In principle, these market-based programs create financial incentives that cover a broader range of activities than incentives tied to high efficiency and electric vehicle purchases, offering greater flexibility in how a household or business chooses to reduce GHG emissions. For example, a broadly applied carbon tax could incentivize a household to drive less, car-pool or use public transit more often, purchase a more efficient vehicle, or invest in home energy efficiency improvements – or some combination of all these options. Market-based policies also generate revenue that can be used to address equity concerns by off-setting program costs for low income households by distributing funds to households through a dividend or reduced income tax or by funding targeted vehicle incentive programs like those considered in this study. When carefully designed with mechanisms to address equity and affordability, market-based GHG reduction programs have the potential to

achieve GHG reductions at a lower overall cost while addressing equity concerns. They may also be implemented in combination with investments in specific programs (such as vehicle incentives) where merited. For additional discussion of market and non-market measures in Vermont, see a study by Resources for the Future previously conducted for the Vermont legislature (Hafstead et al., 2019) and the *2025 Assessment of a Cap-and-Invest Program for Vermont*, prepared for the Vermont Agency of Natural Resources and the Vermont Agency of Transportation (Cambridge Systematics et al., 2025).

7. CONCLUSIONS

This study evaluates the effectiveness of Vermont’s clean vehicle program using detailed vehicle data for households across the state to determine the extent to which these programs are cost effective and equitable. The New PEV program BEV acquisitions and the post-July 2023 version of the New PEV incentive program showed potential for achieving GHG reductions benefits that exceeded program costs under the most optimistic assumptions. All clean incentive programs reached a relatively high share of low-income Vermonters, and the clean incentive programs with more restrictive income requirements achieved higher rates of low-income uptake, likely expanding the reach of the clean incentive programs. Insights from this research will be a valuable resource for the Vermont Agency of Transportation and the Vermont State Legislature as they continue to consider strategies for reducing GHG emissions from transportation in Vermont.

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APPENDICES