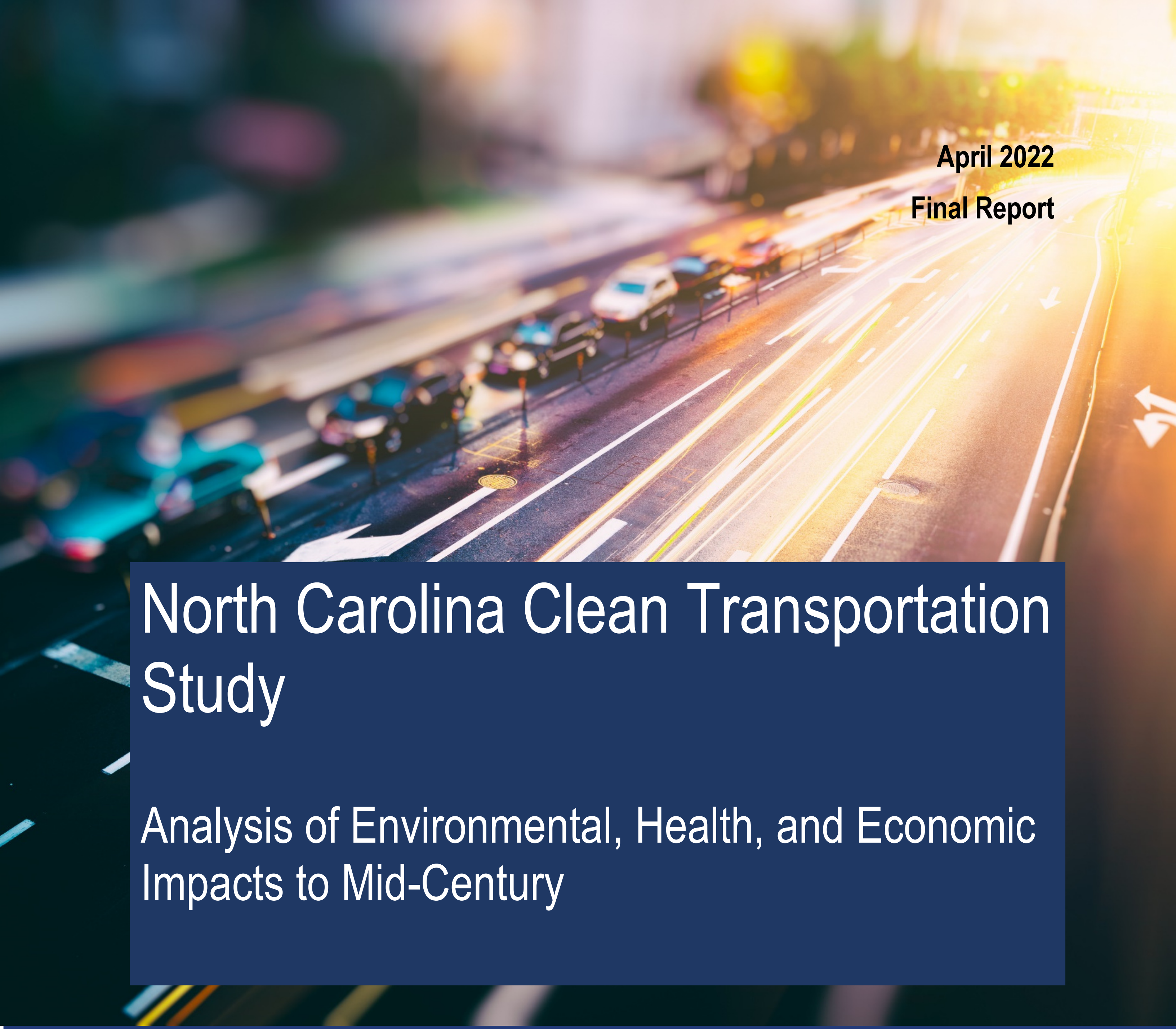


April 2022

Final Report

North Carolina Clean Transportation Study

Analysis of Environmental, Health, and Economic Impacts to Mid-Century

Prepared by

Jeffrey Petrusa
Ben Fein-Smolinski
Elizabeth Brown
Sara Nienow
RTI International
3040 E Cornwallis Road
Research Triangle Park NC 27709

RTI Project Number 0218290

RTI INTERNATIONAL

Acknowledgments

The RTI research team would like to thank the Environmental Defense Fund (EDF) for its generous support of this research. We appreciated the technical feedback over the course of the study and their time providing comments on the final report.

Table of Abbreviations

ACC	Advanced Clean Cars
ACT	Advanced Clean Trucks
AEO	Annual Energy Outlook
BAU	Business as usual
BEV	Battery Electric Vehicle
CARB	California Air Resources Board
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
COBRA	Co-Benefits Risk Assessment
DEF	Diesel exhaust fluid
DIEM	Dynamic Integrated Economy/Energy/Emissions Model
DMV	Department of Motor Vehicles
EMFAC	EMission FACtor
EPA	U.S. Environmental Protection Agency
EWIR	Emissions Warranty Information and Reporting
GHG	Greenhouse gas
GREET	Gases, Regulated Emissions, and Energy Use in Technologies
HDO	Heavy-Duty Omnibus
ICE	Internal combustion engines
LD	Light-duty
LEV	Low emissions vehicle
MHDV	Medium- and heavy-duty vehicles
MOVES3	MOtor Vehicle Emission Simulator 3
NCDEQ	North Carolina Department of Environmental Quality
NRDC	National Resource Defense Council
NOX	Nitrous oxide
OSBM	Office of State Budget and Management
PM	Particulate matter
PTW	Pump to wheel
SAFE	Safer Affordable Fuel-Efficient
SCR	Selective catalytic reduction
SELC	Southern Environmental Law Center
SRIA	Standardized Regulatory Impact Assessment
VMT	Vehicle miles traveled
VMTY	Vehicle miles traveled per year
VPOP	Vehicle population
WTP	Well to pump
WTW	Well to wheel
ZEV	Zero emission vehicle

Table of Contents

List of Tables

List of Figures

Executive Summary

As scientific evidence of how climate change is impacting our world becomes more apparent each year, the focus on advancing mitigation and adaptation measures have risen as a top priority in North Carolina. A heightened sense of urgency is building as North Carolinians bear witness to extreme weather hitting our state in the form of increased flooding due to more frequent and intense rainfall and tropical storms, plus droughts and wildfires. As a result, rapid, large-scale efforts are being undertaken to transform our energy systems and transportation services to low-carbon, renewable, and energy efficient sources and technologies which are essential to achieving the deep reductions in greenhouse gas (GHG) emissions required to avoid even more severe impacts of climate change.

North Carolina, along with several other states, are already undertaking energy transitions to make dramatic reductions in carbon intensity. Similar transformation of the transportation sector remains uncertain in our state, despite the transportation sector leading the energy sector as the largest source of GHG emissions in North Carolina, as indicated in the state's most recent emissions inventory (NCDEQ, 2022). The state has a significant opportunity to reduce emissions and meet its carbon goals, all while improving air quality and health by electrifying the transportation sector and shifting to low-NO_x-emitting vehicles.

This study analyzes the impacts of North Carolina adopting the Advanced Clean Trucks (ACT) and Heavy-Duty Omnibus (HDO) clean transportation policies[1]. These policies apply to medium- and heavy-duty trucks (MHDVs) that California adopted under section 177 of the Clean Air Act. ACT sets manufacturers' sales targets for MHD ZEVs; HDO sets increased emissions standards for newly manufactured MHD vehicles powered by ICEs.

Our analysis was conducted over a 5-month period starting in October 2021 and ending in February 2022. Over the study period, several new developments occurred that impacted our study. First, in October 2021, NC Governor Roy Cooper signed into law HB951: Energy Solutions for North Carolina, which mandates that in-state electricity generation achieve a 70% reduction in carbon emissions from 2005 levels by 2030 and be carbon neutral by 2050. If achieved, this would be a major transformation in the energy system. Second, in January 2022 the Federal government finalized the GHG emissions standards for light-duty (LD) vehicles with model years 2023 through 2026[2], referred to as the SAFE2 standard throughout this remainder of this report. These new light-duty vehicle emissions standards represent a significant increase in stringency over previous federal GHG emissions standards (SAFE).

If fully implemented, HB951 effectively changes the trajectory of CO_2 and non-GHG pollutant emissions in NC's electricity sector. The decarbonization of the electricity sector means that transportation electrification would provide even greater GHG reductions. For this reason, we present "business as usual" (BAU) and HB951 grid mix scenarios. The BAU scenario was the baseline model created as a reference case during the development of the state's Clean Energy Plan. Under both scenarios, the

[1] The recent passage of new more stringent Federal emissions standards on passenger cars and light-duty trucks renders the analysis of Advanced Clear Cars 1 (ACC1) largely moot. For this reason, the report only presents the analysis and findings for ACT and HDO policies. The analysis of ACC1 has been move to the appendix.
[2] US EPA. 2022. *Final Rule to Revise Existing National GHG Emissions Standards for Passenger Cars and Light Trucks through Model Year 2026*. Available at: https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-revise-existing-national-ghg-emissions

carbon intensity of the power sector is falling over time, however, the HB951 scenario falls to net-zero by 2050, while the BAU grid mix still includes some fossil fuel combustion in the energy mix at that time.

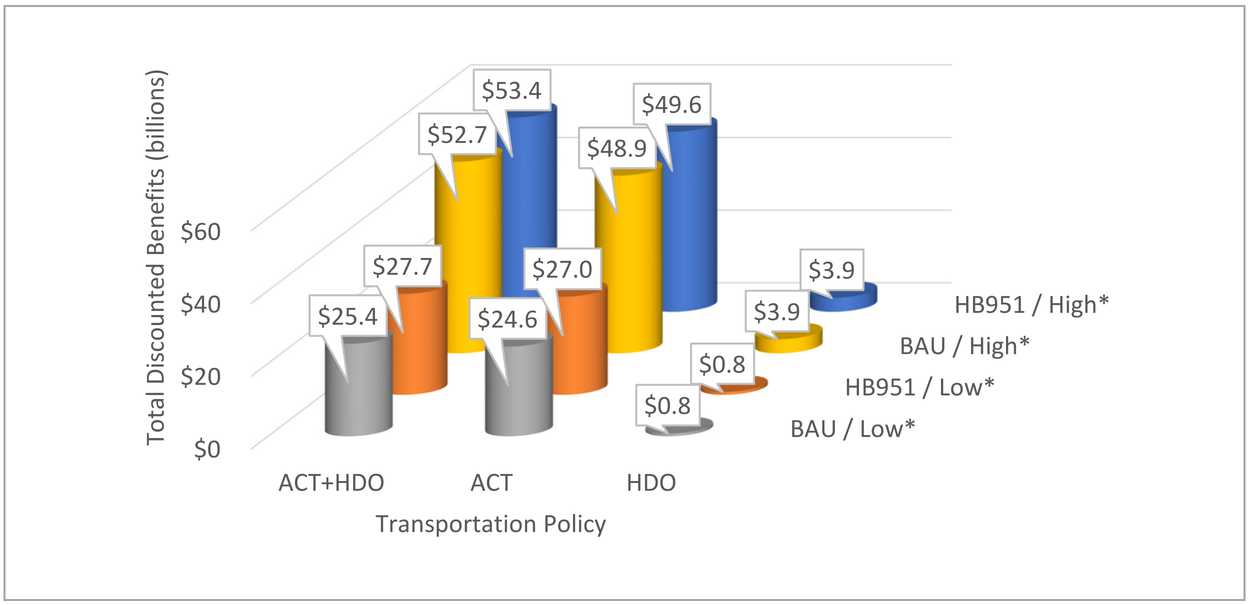
Under SAFE2, baseline emissions from light-duty vehicles starting in 2026 will exceed the emission reductions achievable under California's Advanced Clean Cars 1 (ACC1) rule. As a result, we have moved the presentation of our modeled ACC1 results to the appendix[3].

Although there remains substantial uncertainty in how NC policy for clean energy and transportation will evolve over the next 25 years, this study quantifies the potential impacts to the state's overall public health, the corresponding change in emissions of criteria pollutants and GHGs, and the economic impacts of adopting ACT and ACT + HDO for the state.

Our analysis assumes that the ACT and HDO rules take effect in 2026 and include the corresponding sales targets and emissions standards defined under the California rules. We modeled ZEV adoption and implementation of the emissions standards on ICE vehicles in North Carolina to 2050.

Our team found that both ACT and HDO have the potential to provide positive total net benefits to North Carolina. Combined, these policies offer total discounted net benefits between $53 billion and $25 billion in economic impacts (present value terms, 2026, 7% discount rate) accruing to North Carolina between 2026 and 2050. The total net benefits are the combination of health savings, owner net costs/savings, and monetized climate benefits of GHG emission reductions. Figure ES-1 shows the annual net social benefits in select years.

Figure ES-1. Summary of Total Discounted Benefits of ACT + HDO in North Carolina



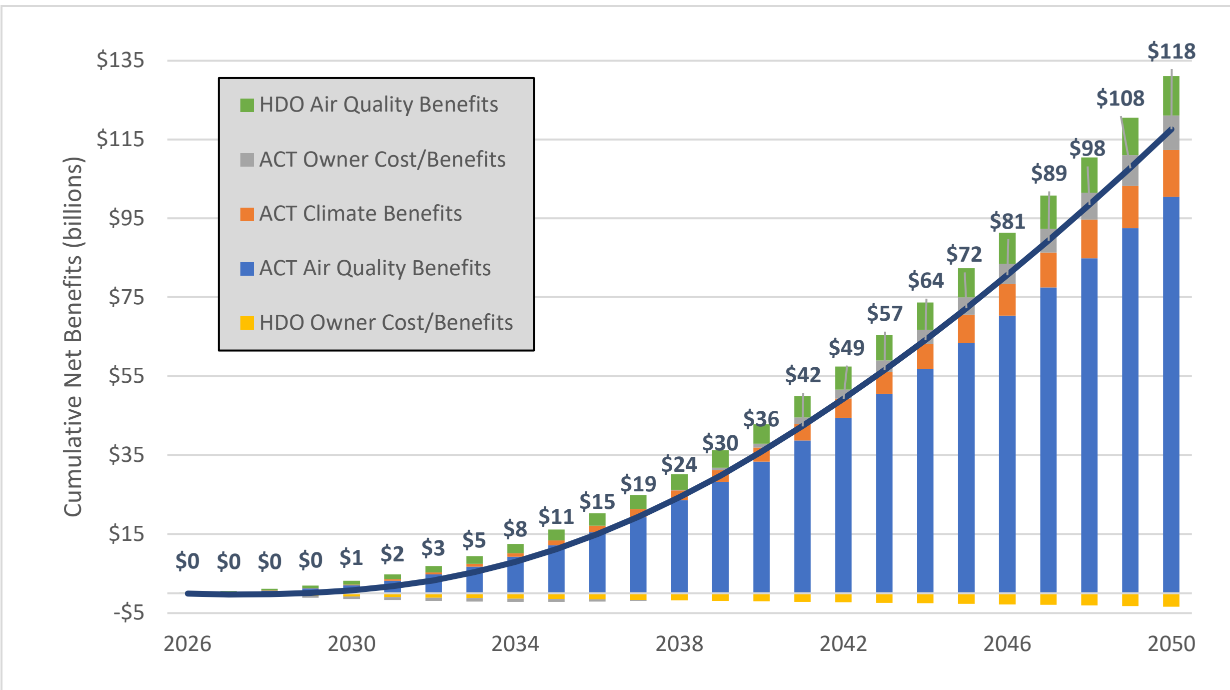
Note: *Low = low health savings; High = high health savings estimates from COBRA. BAU and HB951 two different grid mix scenarios.

[3] California is currently developing ACC2 regulations which would be an build upon ACC1. ACC2 was not evaluated in this report because it has not yet been finalized.

There are overwhelmingly positive net social benefits to adopting both ACT and HDO. Significant reductions in NO_X and $PM_{2.5}$ create sizeable savings from the quantifiable improvements in public health over the next 25 years, accounting for the largest share of the overall benefits associated with these policies. The monetized climate benefits of these policies are also significant. Alone, ACT provide immediate net savings starting in 2027. HDO has a net economic cost through 2050, but ACT + HDO provide positive economic, health and climate benefits as well.

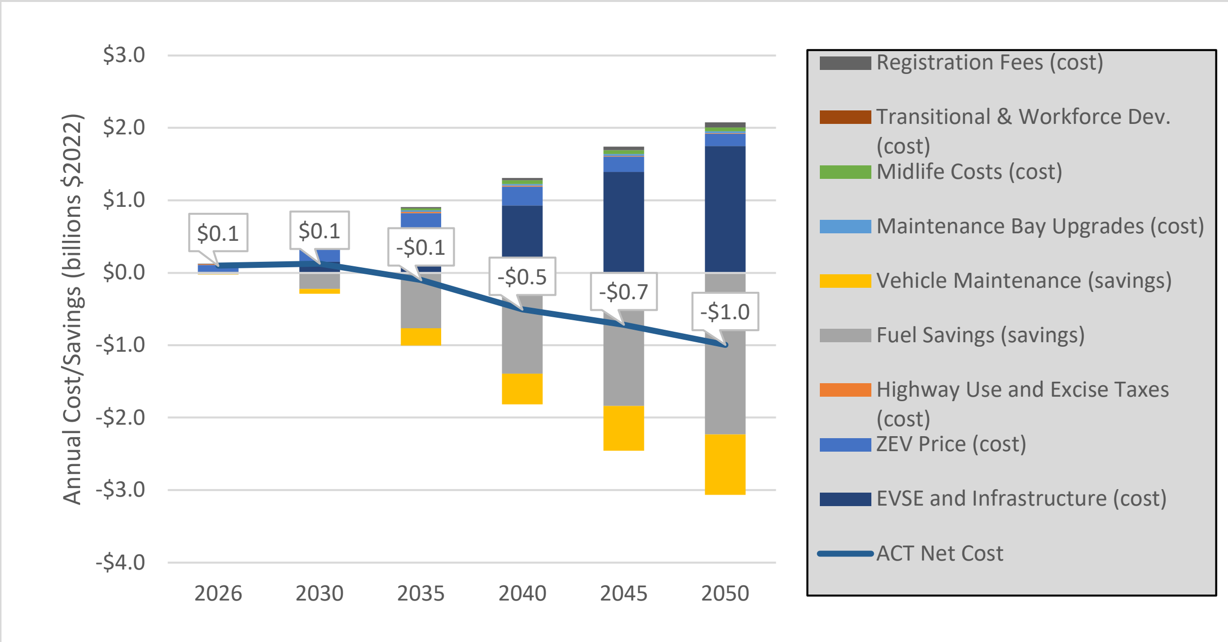
Figure ES-2 shows the resulting cumulative net benefits estimated in this study. By 2050, the cumulative net benefits are expected to grow to over $118 billion. Average public health savings due to improved air quality over the 25-year period is approximately $110 billion. Climate benefits associated with reductions of GHG emissions provides an additional $12 billion. Cumulative economic cost savings of $5.3 billion are also achieved over the same period driven largely by the incremental savings in fuel and annual maintenance of ZEV trucks compared with ICE trucks.

Figure ES-2. Cumulative Net Benefits of ACT and HDO



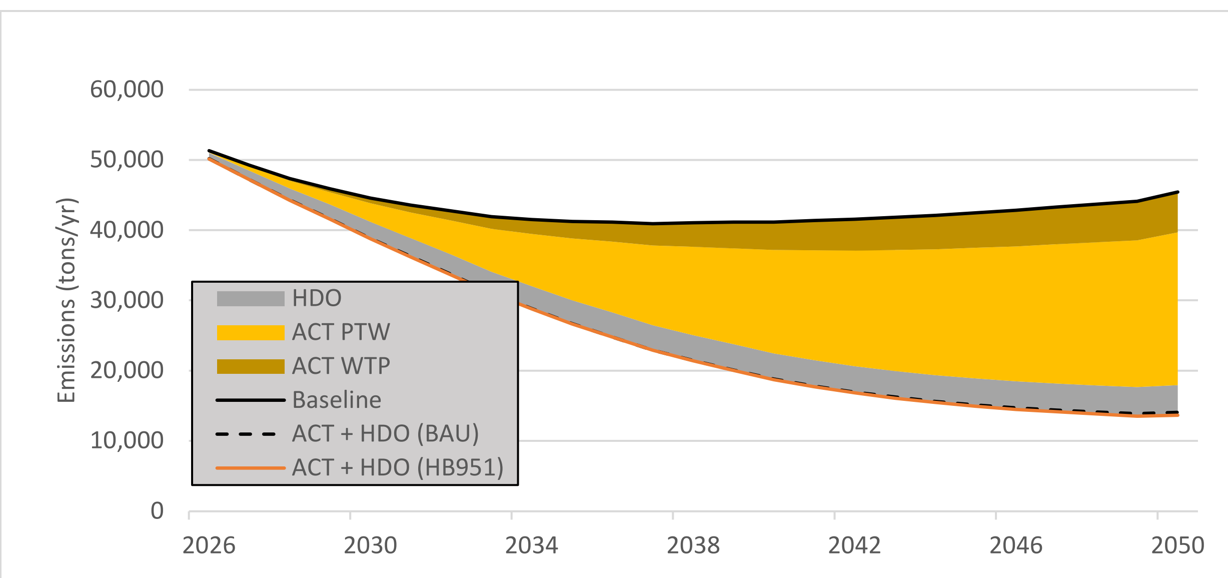
We found that avoided tailpipe emissions due to electrification of new trucks under ACT represents the largest share of health benefits starting in 2027, while the HDO emissions standards continue to offer significant heath savings over the 25-year period. Figure ES-3 shows more detail on the components of our economic cost estimates. Vehicle maintenance and fuel cost savings associated with ACT offset the incremental additional costs of both ACT and ACT + HDO.

Figure ES-3. Summary of MHDV User Costs and Savings for Select Years



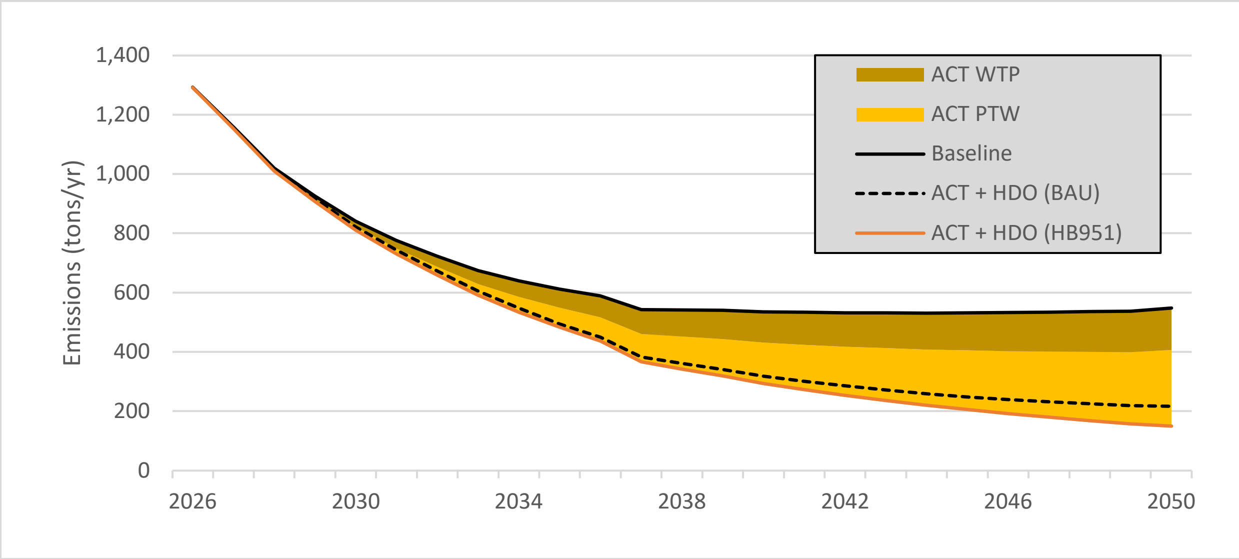
The significant improvements in public health are a direct result of improvements in local air quality via emission reductions in criteria pollutants NO_X and $PM_{2.5}$. This study found that the adoption of ACT + HDO in North Carolina would lead to a cumulative reduction of 370,116 and 2,811 tons of NO_X and $PM_{2.5}$ respectively. Figure ES-4 and Figure ES-5 show the annual reductions in NO_X and $PM_{2.5}$ over the modeled period and the contributions to the reductions from ACT and HDO.

Figure ES-4. NO_x Emissions Reductions: 2026–2050



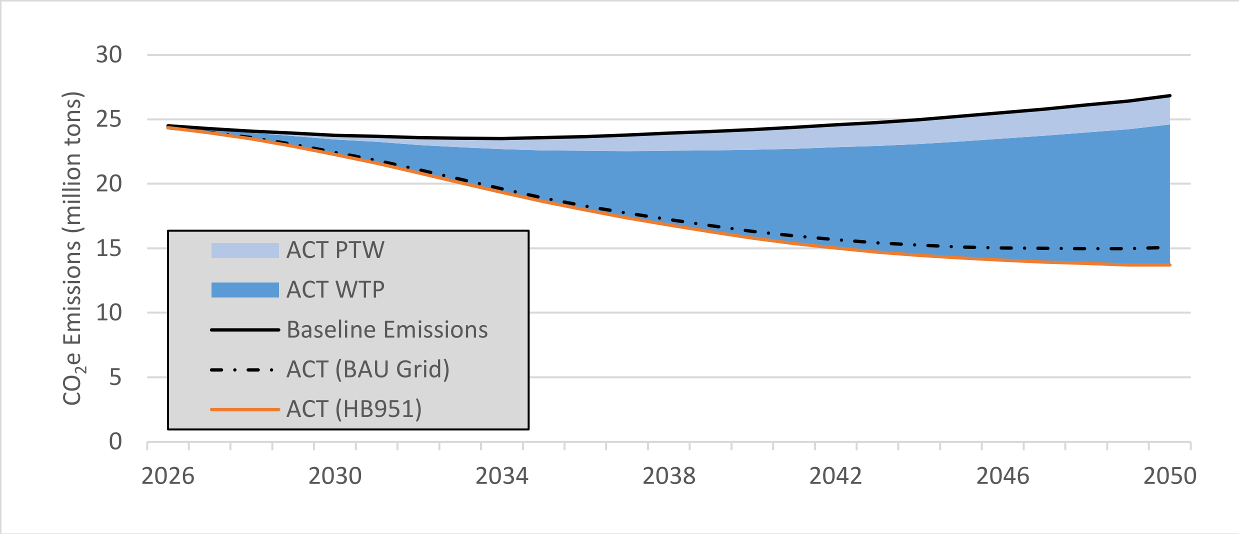
Note: Pump to Wheel (PTW) represents tailpipe emissions from MHDVs, Well to Pump (WTP) represents emissions from upstream activities associated with gasoline and diesel fuel production and supply.

Figure ES-5. $PM_{2.5}$ Emissions Reductions: 2026–2050



We also observed a net decrease in GHG emissions over the same period. Figure ES-6 Figure ES-6shows the reduction in CO_2 emissions reductions over the modeled period. By 2050, GHG emissions are cut in nearly half, falling to 49% of projected baseline emissions (28 million tons of CO_2) for the same year. Cumulatively, the emission reductions achieved are 177 million tons of CO_2, which is equivalent to avoiding 15.8 billion gallons of diesel fuel consumption or taking 35 million passenger vehicles off the road for one year.[4]

Figure ES-6. CO_2e Emissions Reductions Achieved under ACT + HDO (tons)



Note: CO_2e is inclusive of both carbon dioxide and methane. ACT WTP reductions include the emissions from increased electricity consumption.

[4] Equivalencies are based on the U.S. EPA Greenhouse Gas Equivalencies Calculator (March 2021). Available at: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

1. Introduction

The transportation sector is the largest source of Greenhouse gas (GHG) emissions in the United States. In North Carolina, the transportation sector has become the largest source of GHG emissions, overtaking the power sector which historically has been the dominant source of GHG emissions (NCDEQ, 2022). Avoiding the impacts of climate change, including increased flooding and increased frequency and intensity of tropical storms, requires dramatic reductions in the carbon intensity of North Carolina's economy.

Reducing North Carolina's GHG emissions will require the state to make significant reductions in GHGs through adoption of less carbon intensive technologies. Energy Solutions for North Carolina (HB951), passed in in October 2021, commits the state to cut carbon emissions from in-state generation by 70% in 2030 with the goal of reaching carbon neutrality by 2050.

In early 2022, NC Governor Roy Cooper signed Executive Order 246, which directs the NC Clean Transportation Plan to increase Zero Emission Vehicle (ZEV) use and find ways to decarbonize the transportation sector through reductions in vehicle miles traveled and increased adoption of zero emissions cars, trucks, and buses.

This report analyzes two[5] potential transportation policies for medium- and heavy-duty trucks in North Carolina starting in 2026, estimating the impacts out to 2050. For each policy, RTI calculated:

- GHG reductions
- changes in non-GHG pollution, such as particulate matter (PM) and oxides of nitrogen (NO_x)
- health benefits from non-GHG pollution reductions
- climate benefits from GHG emission reductions
- economic costs/benefits to vehicle owners

This study is organized into three major components:

- **Environmental impact analysis:** estimate the change in GHG and non-GHG emissions under each of the three alternative policy scenarios described below.
- **Health impacts assessment:** estimate the change in health impacts resulting from non-GHG emission reductions under each policy scenario.
- **Economic impact analysis:** estimate the net cost/benefit associated with each alternative policy.

The subsequent sections of this report describe our analysis of the impacts that ACT and HDO policies would have on North Carolina's transportation sector. Section 2 briefly defines these policies. Section 3 discusses our modeling approach, data used to develop baseline vehicle populations, and supporting inputs used to model the emissions from the electricity sector and gas/diesel fuel supply chain. Section 4 presents the air quality and climate impacts. Section 5 presents our economic analysis, which includes projections of monetized health and climate benefits as well as the projected private benefits/costs of transitioning to ZEV and lower NO_X-emitting vehicles. Finally, in Section 6 we summarize the total cumulative net benefits that would accrue to North Carolina with the adoption of ACT and HDO.

[5] Recent passage of new more stringent Federal emissions standards on passenger cars and light-duty trucks rendered the analysis of Advanced Clear Cars 1 (ACC1) largely moot. For this reason, the report only presents the analysis and findings for ACT and HDO policies. The analysis of ACC1 has been move to the appendix.

2. Policy Scenarios

In this study, RTI calculated the impacts of two transportation sector regulations modeled after existing rules adopted by the state of California for MHDVs. These policies include:

- **Advanced Clean Trucks (ACT):** The state adopts the requirements of the California Advanced Clean Trucks (ACT) Rule, mandating that an increasing percentage of new trucks purchased in North Carolina be ZEVs beginning with the 2026 model year. Sales targets vary by vehicle type, but for all types the required ZEV percentage increases in each model year between 2026 and 2035 (see Figure 1).
- **HDO:** The state adopts the requirements of the California Heavy Duty Omnibus (HDO) Rule, mandating exhaust emissions standard for heavy-duty vehicles with decreasing emissions limits over time, requiring an additional 75% reduction in NO_x emissions above previous standards for new trucks sold in model year 2026 and a 90% reduction for trucks sold beginning in the 2027 model year (Figure 2.).

For the purposes of this study, we have assumed 2026 is the earliest year that these regulations could take effect in North Carolina. Additionally, we have assumed that North Carolina adopts California's timeline for both initial ZEV sales targets and lower vehicle emissions standards at the scheduled levels specified for 2026. Figure 1 shows the ACT sales targets over time by regulatory class and model year. Figure 2. shows the schedule for reducing the fleet-wide NO_x emissions in subsequent years for MHDVs.

Figure 1. ACT ZEV Sales Targets to 2050 by Model Year

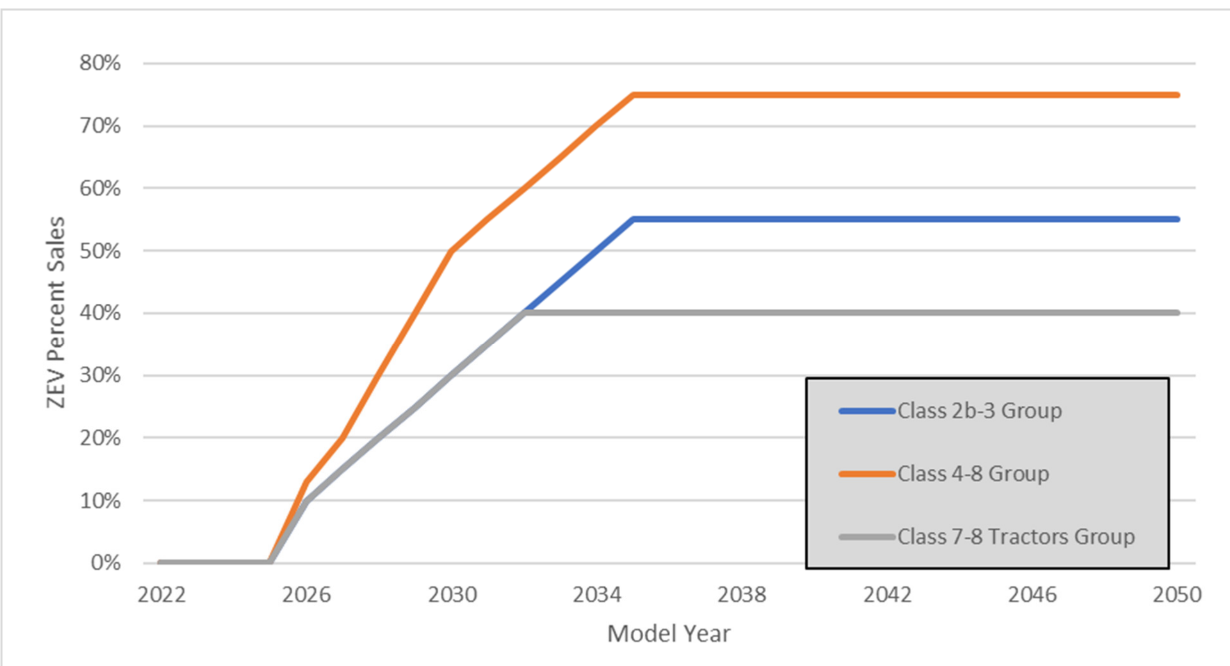
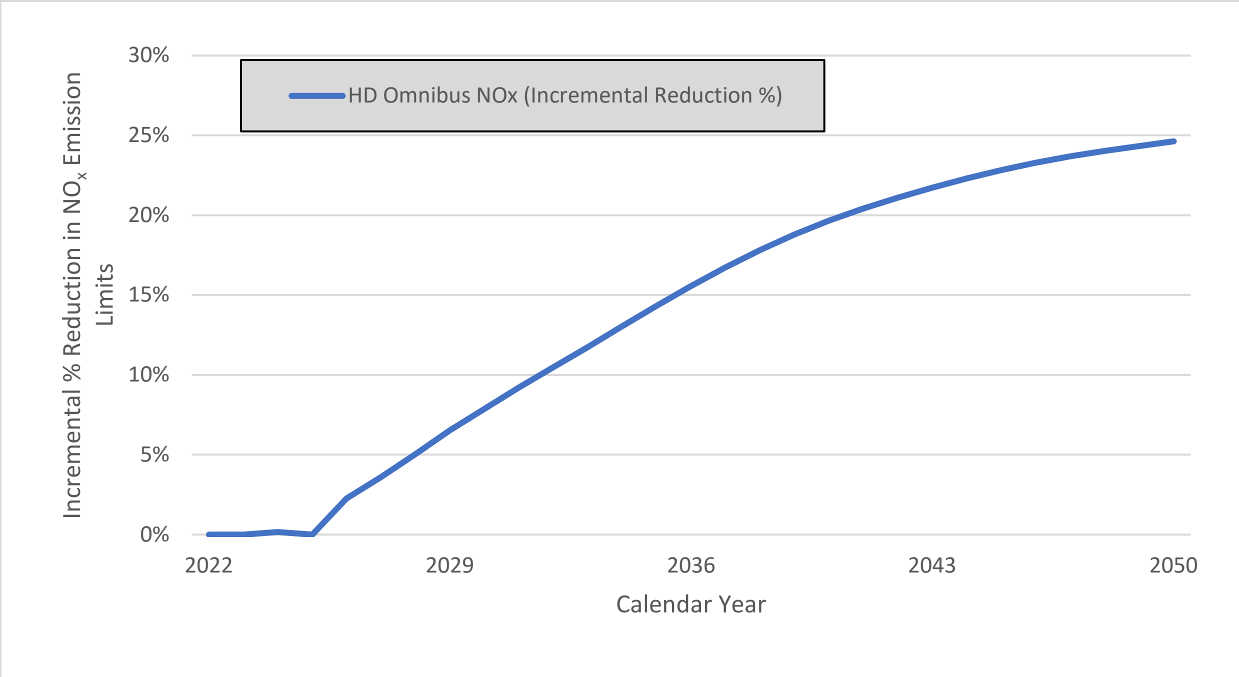


Figure 2. Heavy-Duty Omnibus Fleet NO_x Reductions % by Calendar Year



3. Analysis Framework

RTI developed this study to review and analyze the impact of two different policy scenarios on the MHDV fleet in North Carolina.[6] The study was conducted in the following steps:

- Establish baseline vehicle population and vehicle miles traveled (VMT) by source type and regulatory class.
- Update population and VMT due to implementation of each scenario.
- Calculate changes in fuel and electricity consumption and associated emissions changes.
- Estimate health impacts due to changes in NO_x and $PM_{2.5}$ emissions.
- Analyze economic impact of reduced fuel consumption, increased electricity consumption, and changes in vehicle costs, maintenance costs, and other infrastructure costs.

First, we used EPA's MOtor Vehicle Emission Simulator 3 (MOVES3) modeling system to develop a baseline for the vehicle population of MHDVs. Then we adjusted the baseline population based on the stated sales targets and emissions limits for each model year, as discussed in section 2.

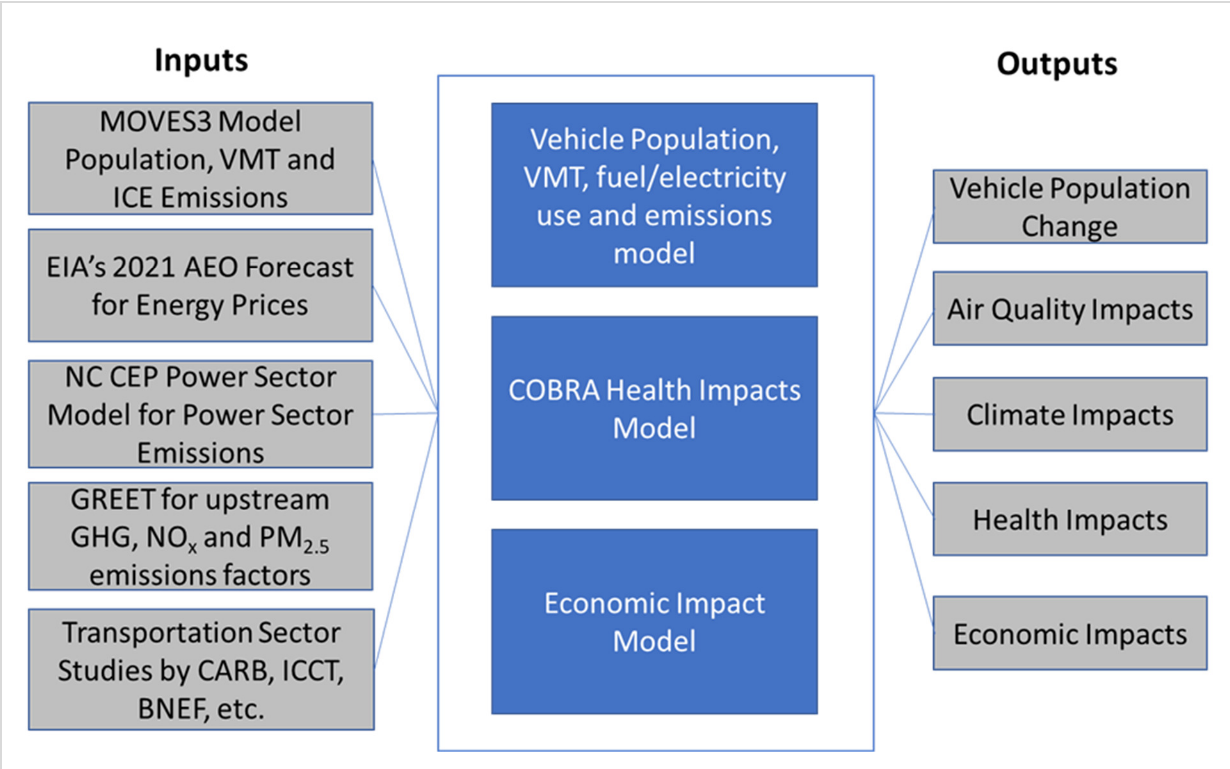
Next, RTI analyzed the fuel savings; increased electricity use and reduction in emissions from ACT and HDO policies using the emissions factors from the MOVES3 model for the ICE vehicles; and electricity grid emission factors based on two grid mix scenarios developed from recent power sector modeling for North Carolina's Clean Energy Plan (Konschnik, et al., 2021) and HB951's net-zero emission pathway. We modeled both the upstream (well-to-pump) and tailpipe (pump-to-wheel) emission reductions in GHGs, NO_x, and $PM_{2.5}$ associated with ACT and HDO.

Next our team calculated the human health impacts associated with emissions reductions of NO_x and $PM_{2.5}$ using the EPA's Co-Benefits Risk Assessment (COBRA) screening and mapping tool. COBRA is a widely accepted and commonly used model to monetize the human health cost savings resulting from improvements in local air quality[7].

Finally, RTI analyzed the private economic costs/benefits associated with ACT and HDO. Our analysis quantifies the benefits of the reduced fuel costs due to electrification of MHDVs, as well as the maintenance and infrastructure costs and savings associated with each policy. We calculated fuel benefits using the 2021 Annual Energy Outlook (AEO) projections for fuel and electricity costs in the South Atlantic region of the United States. The additional costs were developed using a variety of technology studies, predominantly California Air Resources Board's (CARB's) studies of the implementation of similar scenarios. Figure 3 shows the inputs and outputs of RTI's modeling process.

[6] RTI also analyzed ACC1; see appendix for analysis results for passenger vehicles and light-duty trucks.
[7] Other health benefit estimates exist through US EPA's *Environmental Benefits Mapping and Analysis Program (BenMAP)* which could result in higher health benefit estimates. Given the scope this study, the authors felt the estimates provided by COBRA were sufficient as a first-order estimate of potential health impacts.

Figure 3. Analysis Process



Note: CO_2e emissions factors from GREET are for gasoline and diesel fuel product streams.

3.1. Medium- and Heavy-Duty Vehicle Populations

This section of the report describes the modeling, assumptions and results of our vehicle modeling.

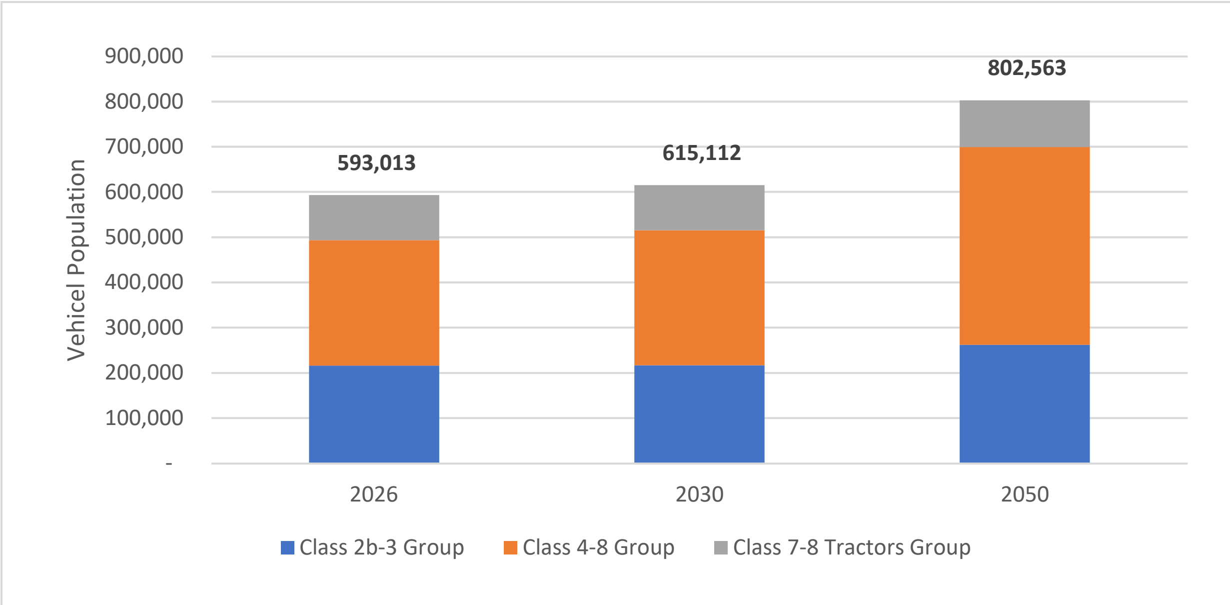
3.1.1. MHDV Population—Baseline

RTI's first step in the analysis was to develop a baseline projection of MHDV. On-road VMT and fuel use by source type, regulatory class, and fuel type were obtained from EPA's MOVES3 modeling system for all 100 counties in North Carolina. RTI aggregated the county data up to the state level for years 2022 through 2050. The appendix contains VMT, fuel type, and consumption details.

For the baseline projection of MHDVs, we assumed there would be no ZEV vehicle adoption, as the 2021 AEO reference case suggests that national ZEV sales of MHDV will not reach 1% of total annual auto sales before 2050.[8] Figure 4 shows projected population of MHDVs by group type for years 2026, 2030, and 2050.

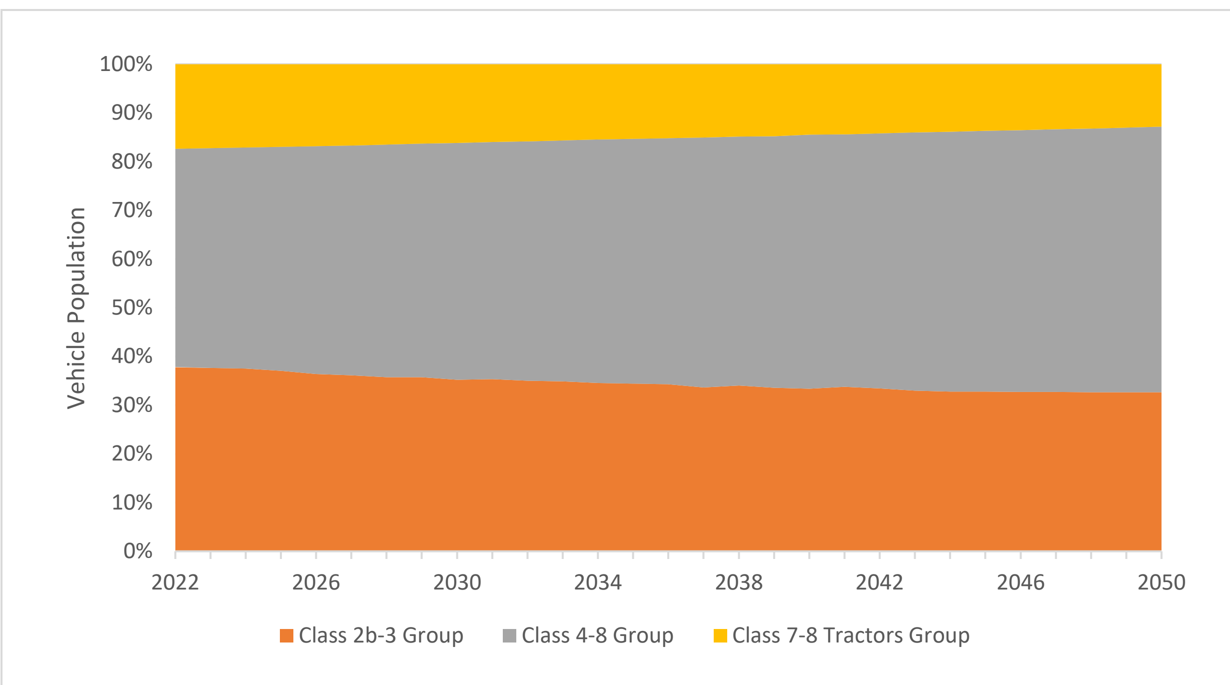
[8] https://www.rff.org/news/press-releases/without-subsidies-electric-trucks-and-buses-are-unlikely-to-achieve-significant-market-share/

Figure 4. North Carolina MHDV Population Projection



The total vehicle count increases 35% between 2026 and 2050, from 593,000 to more than 800,000. Class 4-8 Group accounts for more than 55% of the total MHDT population in 2050, expanding from 47% in 2026. Figure 5 shows the baseline distribution of MHDVs between 2022 and 2050.

Figure 5. Baseline MHDV Population Projection: % of Population



3.1.2. MHDV Population Under ACT Scenario

The California ACT regulation requires manufacturers to sell zero-emission trucks as an increasing percentage of their sales for model years 2024 through 2035, after which the percentage stays flat. The rule separates trucks into three different groups based on their vehicle type and regulatory class and there are different sales schedules for each group.

To model the ACT rule's impact in North Carolina, RTI used the vehicle population from MOVES3 grouped by source[9] and regulatory type. We mapped these vehicles to the groups designated in the California's ACT rule.

As discussed in section 2, RTI modeled implementation of the ACT rule in North Carolina beginning in 2026. We assumed that North Carolina matches the sales target scheduled for California starting in model year 2026.[10] The unshaded cells in Table 1 show the implementation schedule RTI used to model the ACT rule. These percentages apply to new vehicle sales within NC each year.

Table 1. ACT Implementation Schedule

Vehicle Type	Class 2b-3 Group	Class 4-8 Group	Class 7-8 Tractors Group	Total ZEV Sales
2024	0%	0%	0%	0%
2025	0%	0%	0%	0%
2026	10%	13%	10%	12%
2027	15%	20%	15%	18%
2028	20%	30%	20%	25%
2029	25%	40%	25%	33%
2030	30%	50%	30%	40%
2031	35%	55%	35%	45%
2032	40%	60%	40%	50%
2033	45%	65%	40%	55%
2034	50%	70%	40%	59%
2035	55%	75%	40%	63%

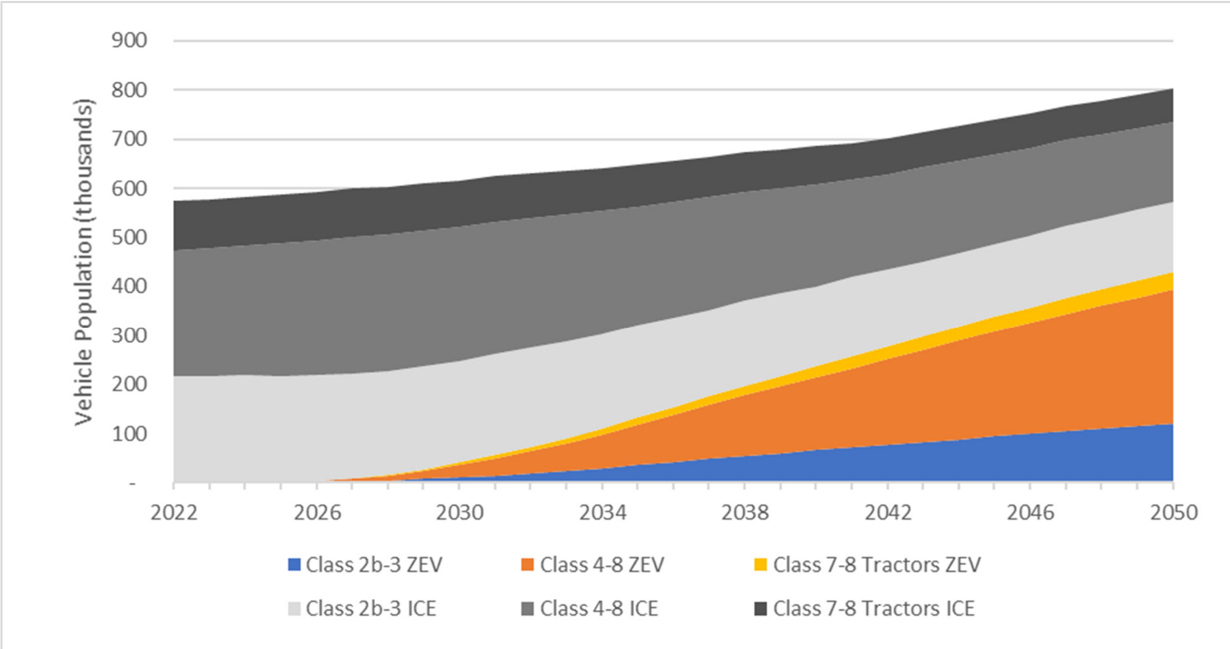
Source: Adapted from CARB Updated Analysis Regarding Increased Manufacturer Zero-Emission Vehicles Sales.

Adoption of the ACT rule for MHDVs would have a major impact on the ZEV portion of the fleet. By 2035, 20% of the MHDV fleet would be ZEV; by 2050, about 54% of the fleet would be ZEV. Figure 6 shows the shift in the makeup of the MHDV fleet through 2050.

[9] The term "source" is used in MOVES3 to describe the vehicle type (e.g. school bus, combination long haul tractor).

[10] https://ww2.arb.ca.gov/sites/default/files/2021-08/200625factsheet_ADA.pdf

Figure 6. ACT - ZEV Adoption 2022–2050

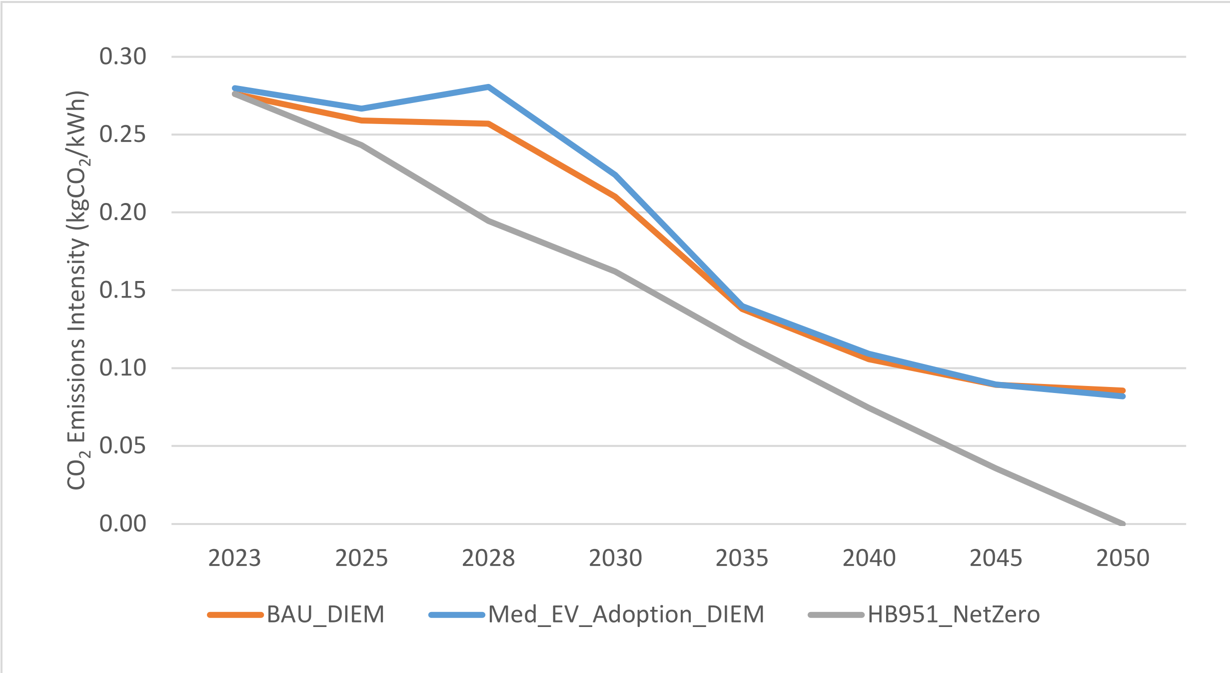


3.1.3. Electricity Grid Mix

The electricity generation mix on the grid is another critical element required to estimate the net change in emissions associated with electrification of transportation fleets. This study analyzed the impact of the ACT and the ACT+HDO policy scenarios under a grid mix that would meet the goals of NC's recently passed HB951: Energy Solutions for North Carolina. HB951 calls for a 70% reduction in carbon emissions from 2005 levels by 2030 from in-state generation and net-zero by 2050. To develop this grid mix, RTI began with the power sector model created by the Duke University Nicholas School of the Environment which was used to establish a baseline during the development of North Carolina's Clean Energy Plan, referred to as the Dynamic Integrated Economy/Energy/Emissions Model (DIEM) (Konschnik, et al. 2021). RTI developed an emissions factor for the base year of 2022 using the grid mix from this model and emission factors for CO_2e, NO_x and $PM_{2.5}$ from EPA's eGRID model. RTI then assumed a linear decline of CO_2e emissions to meet HB951 goals of 23.8 million metric tons of CO_2e by 2030. RTI then assumed a linear decline of CO_2e emissions from 2030 through 2050 to meet the 2050 goal of zero CO_2e emissions. To develop the time series of NO_X and $PM_{2.5}$ emission factors from 2023 through 2050, RTI matched the decline rate for the CO_2e emission factors until they were zero in 2050.

Figure 7 shows the resulting CO_2 emissions intensity for the HB951 grid mix along with two emissions scenarios obtained from the DIEM model. The business as usual (BAU) DIEM emissions scenario assumes a low penetration of EVs in North Carolina through 2050. The medium EV adoption DIEM scenario assumes a moderate adoption of EVs in NC. The carbon intensity of the medium EV adoption scenario is higher in the next decade as electricity demand increases, but the carbon intensity of the baseline and medium EV adoption scenarios converge after 2035, as the existing fleet of coal plants are retired, and additional renewable capacity is added to the grid mix. Unless otherwise stated, the grid mix used refers to HB951. Emissions under BAU grid mix are reported in the Appendix.

Figure 7. NC Power Sector CO_2 Emissions Intensity: 2023—2050



Source: Konschnik, et al. 2021. DIEM results, and Authors' calculation of HB951 CO_2 reduction pathway to net-zero by 2050.

4. Environmental Impacts

The modeled ACT and ACT+HDO policy scenarios produce significant reductions in NO_x, PM, and GHG emissions from the MHDV fleet. These net reductions account for the relatively small increase in electricity sector emissions associated with increased charging activity of ZEVs. Reductions in NO_x and PM will improve air quality, resulting in public health benefits from reduced mortality and hospital visits. Additionally, the reductions in GHG emissions will have sizable climate benefits that further North Carolina's goals of rapid decarbonization by mid-century. This section presents the modeled results of the ACT and HDO policies emission reductions on MHDVs through 2050.

4.1. Air Quality Impacts

RTI's analysis shows that implementation of the ACT rule would result in a substantial reduction in NO_X and $PM_{2.5}$ emissions, while the HDO rule would result in additional NO_X emission reductions. Implementation of the ACT rule would reduce annual MHDV NO_x emissions by over 50% annually—about 27,501 tons per year—by 2050. Additionally, the ACT rule would decrease $PM_{2.5}$ emissions by 73% annually—about 399 tons—by 2050. Implementation of the HDO rule in addition to the ACT rule would reduce MHDV NO_x emissions by an additional 24% from the new ACT rule scenario emissions—about 4,265 tons—annually by 2050.

RTI Analyzed the impact of the ACT rule using the tailpipe emission factors of NO_X and $PM_{2.5}$ from the MOVES3 model for ICE vehicles. The NO_X and $PM_{2.5}$ emissions from the electricity sector were estimated using the emission factors by generation source for North Carolina described in section 3.1.3.

RTI used the MOVES3 GHG tail pipe emissions and the DIEM electricity model to calculate the pump-to-wheel (PTW) emissions benefits after implementation of the ACT policy scenario. Additionally, there are upstream GHG reduction benefits from reduced energy use in the production and transport of those fuels, known as the well-to-pump (WTP) emissions. RTI calculated the additional upstream emission reductions due to decreased fuel use by applying an upstream emissions factor to the tailpipe emissions developed using the 2021 Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) Model from Argonne National Laboratory. The ratio of downstream NO_X and $PM_{2.5}$ to upstream emissions for NO_X and $PM_{2.5}$ functioned as a multiplier. For the MHDVs, the upstream emission factors were a weighted average of these ratios for the different vehicle types based on the NC fleet makeup. For the multipliers, a 1-gram reduction of tailpipe NO_x emissions would be accompanied by 0.3448 grams reduction of upstream NO_x emissions and a 1-gram reduction of $PM_{2.5}$ emissions would be accompanied by 1.2475-gram reduction of upstream $PM_{2.5}$ emissions.

The HDO rule requires an additional 75% reduction NO_x emissions from the engines in new gasoline and diesel trucks sold between model years 2025 and 2026, and a 90% reduction for trucks sold beginning in the 2027 model year. This reduction in NO_x emissions is based on the federal test procedures; actual NO_x emissions reductions from real-world activities will not be as high. To calculate the NO_x emissions reductions based on real-world driving conditions and the portion of the remaining ICE fleet that would be sold within the state, RTI followed California's Emissions Inventory Methods and Results for the Proposed Amendments and matched the annual calendar year percentage reduction in Table 7 of California's results. RTI assumed a fleet and percentage sales breakdown similar to California, as we were not able to obtain data from the NC DMV with enough detail to produce similar North Carolina-specific assumptions.

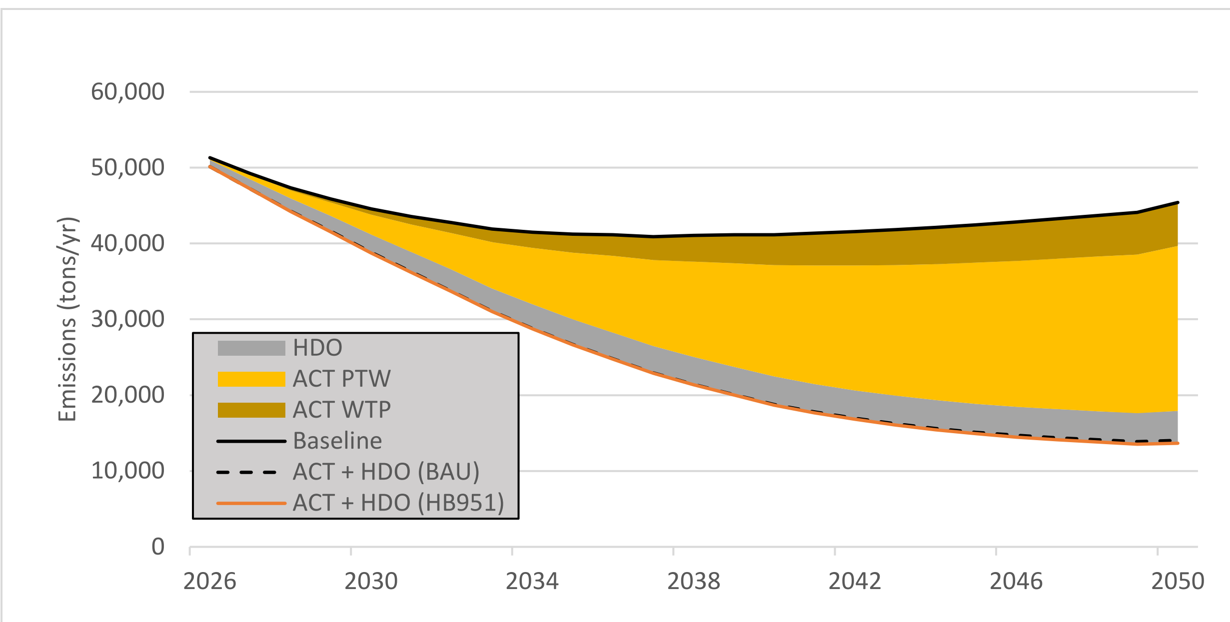
Table 2 and Figure 8 show the projected NO_x emissions reduction from the implementation of the ACT and HDO rules in North Carolina.

Table 2. Annual Change in WTW NO_x Emissions From MHDV Vehicles through ACT + HDO Adoption (HB951)

Year	Tons						
	Baseline NO_x Emissions	ICE NO_x Emissions Reduced through ACT*	Additional NO_x Emissions through Electricity Generation	Net NO_x Emissions Reduction from ACT	Total NO_x Emissions ACT Implementation	NO_x Emissions Reduction through Omnibus Rule	Total NO_x Emissions ACT + Omnibus
2026	51,317	-326	26	-300	51,018	-853	50,164
2030	44,558	-3,564	195	-3,368	41,190	-2,422	38,768
2035	41,240	-11,617	409	-11,208	30,032	-3,375	26,656
2040	41,162	-19,115	405	-18,710	22,452	-3,754	18,698
2045	42,475	-23,845	238	-23,607	18,868	-3,946	14,922
2050	45,428	-27,501	0	-27,501	17,927	-4,265	13,661

Note: *ICE reductions from ACT include the combined upstream and tailpipe emission changes.

Figure 8. Projected Annual NO_x Emissions for MHDV



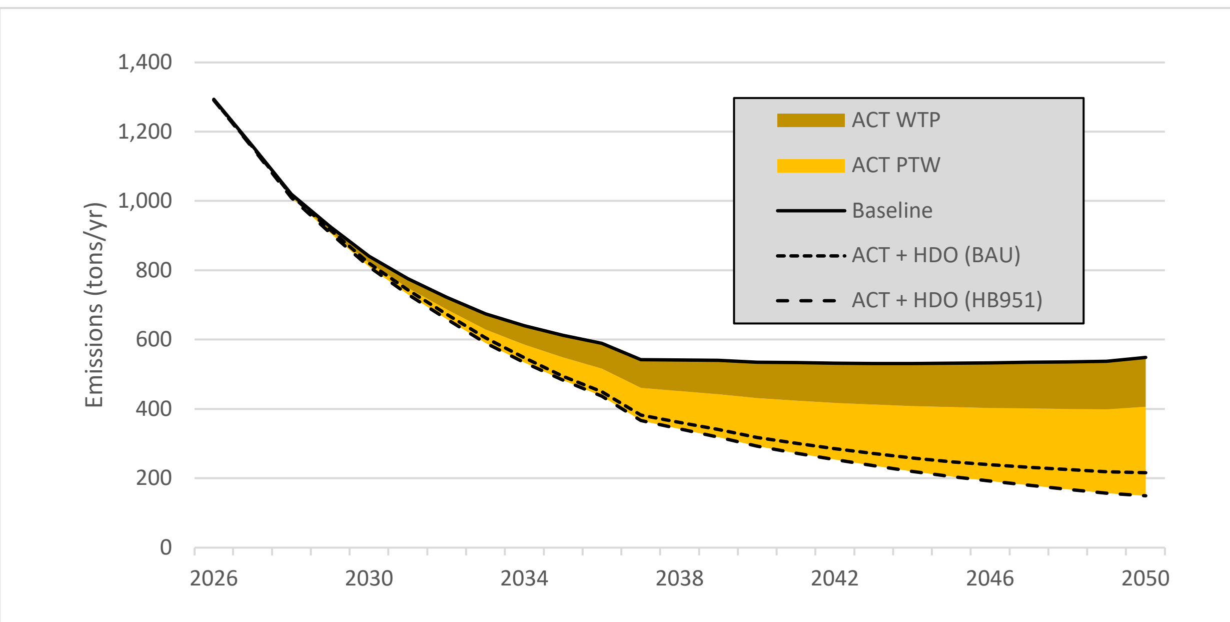
The ACT and HDO rules yield a substantial decrease in NO_X emissions, and the ACT rule also produces a substantial decrease in $PM_{2.5}$ emissions. The $PM_{2.5}$ emissions factor in eGRID (verified by other sources) is higher in North Carolina than throughout much of the United States: until the modeled decline of $PM_{2.5}$ emission is high enough, there are limited $PM_{2.5}$ benefits realized through electrification. Additional reductions in $PM_{2.5}$ grid emissions would also yield additional transportation benefits. RTI assumed that the HDO rule would not result in additional $PM_{2.5}$ emissions changes, aligning with CARB's analysis of the HDO rule.

Table 3 and Figure 9 show the projected $PM_{2.5}$ emissions reduction from the implementation of the ACT rule in North Carolina.

Table 3. Annual Change in WTW $PM_{2.5}$ Emissions From MHDV Vehicles through ACT (HB951)

Year	Tons				
	$PM_{2.5}$ Emissions Baseline	ICE $PM_{2.5}$ Emissions Reduced through ACT	Additional $PM_{2.5}$ Emissions through Electricity Generation	Net $PM_{2.5}$ Emission Reduction from ACT	Total $PM_{2.5}$ Emissions ACT Implementation
2026	1,293	-5	3	-2	1,291
2030	840	-54	23	-31	810
2035	612	-167	49	-118	494
2040	535	-291	48	-242	293
2045	532	-355	28	-327	205
2050	548	-399	0	-399	149

Figure 9. Projected Annual $PM_{2.5}$ Emissions for MHDV



4.2. Climate Impacts

One of the main potential benefits from the proposed policy scenarios is a reduction in GHG emissions from the transportation sector. These reductions can provide significant contributions to the state's net-zero targets. Implementation of the ACT policy will reduce annual GHG emissions from MHDVs by almost 50% annually—about 13 million tons—by 2050.

GHG reductions achieved under the ACT policy are the result of the electrification of portions of the MHDV fleets, which reduces vehicle fuel consumption, while also increasing electricity consumption. The ZEV adoption results in a net change in GHG emissions, which includes reductions in tailpipe and upstream emissions (lower fuel demand) combined with increased power sector emissions (higher charging demand).

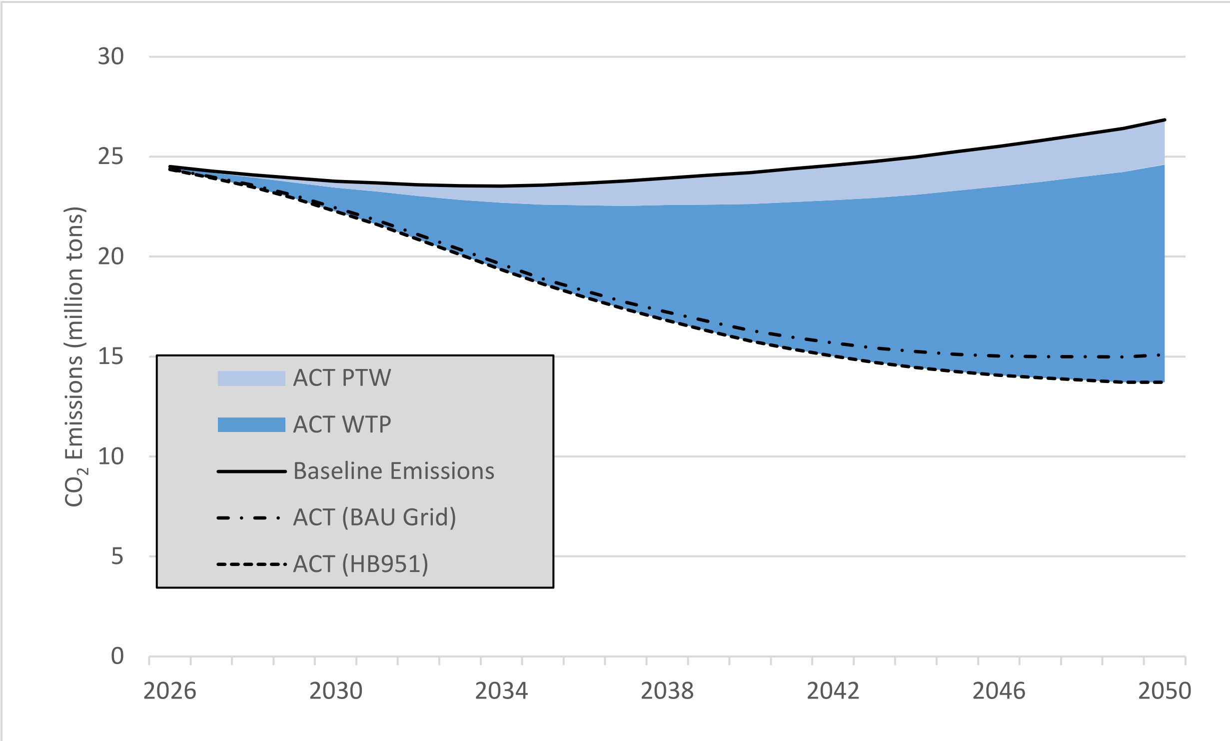
RTI used the MOVES3 GHG tail pipe emission and the DIEM electricity model to calculate the PTW emissions benefits from the implementation of the policy scenarios. Additionally, there are upstream WTP GHG reduction benefits from decreased fuel use. As with the upstream NO_x and $PM_{2.5}$ emissions discussed in the air quality impact section, RTI used a WTP CO_2 emissions factor developed using the 2021 GREET Model to calculate WTP GHG emissions benefits. This number was a multiplier applied to CO_2 exhaust emissions to calculate a corresponding downstream emissions quantity. For GHGs, 1 gram of tailpipe GHG emissions reduction would be accompanied by a 0.2055-grams reduction of upstream GHG emissions. For the MHDVs, the upstream emission factors were a weighted average of this ratio for the different vehicle types based on the NC fleet makeup. The combination of the PTW and WTP emissions are the total WTW emissions for the transportation activity.

The GHG emissions benefits for the MHDVs are all due to the ACT rule adoption scenario. The electrification of the portion of the MHDV fleet due to the ACT rule would result in a WTW GHG reduction of more than 13 million tons of CO_2e annually by 2050. Table 4 and Figure 10 detail the projected GHG reductions due to the ACT rule.

Table 4. WTW GHG Emissions Reduction through ACT Adoption (HB951)

Year	Tons CO_2e					
	Base Case Emissions	ICE PTW Emissions Reduced through ACT Rule Base Case Emissions	ICE WTP Emissions Reduced through ACT Rule Base Case Emissions	Additional Emissions through Electricity Generation	Net Emission Reduction from ACT Rule	ACT Rule Adoption Emissions
2026	24,494,600	-148,302	-30,471	49,055	-129,717	24,364,883
2030	23,764,660	-1,554,519	-319,396	367,307	-1,506,608	22,258,051
2035	23,576,662	-4,743,116	-974,536	768,966	-4,948,686	18,627,976
2040	24,198,793	-7,614,330	-1,564,465	761,595	-8,417,200	15,781,594
2045	25,246,087	-9,498,150	-1,951,520	447,070	-11,002,600	14,243,487
2050	26,847,114	-10,891,739	-2,237,851	0	-13,129,591	13,717,523

Figure 10. MHDV GHG Emissions Projections Under ACT



Note: CO_2e is inclusive of both carbon dioxide and methane. ACT WTP reductions include the emissions from increased electricity consumption.

5. Economic Cost/Savings Analysis

As the final step in our analysis, we estimated the economics benefits and costs to owner/operators of medium- and heavy-duty trucks. This analysis focuses on the private investments required to transition the MHDVs to ZEVs and low-NO_x–emitting vehicles in North Carolina. A broader assessment of the full economic impact of the ACT and HDO policy implementation could estimate the polices' impact on state utilities, rate payers, required changes in fiscal spending, and the macroeconomic impact on state gross domestic product and employment.

5.1. Monetized Health Impacts

We calculated the potential health benefits of reduced emissions under the policy scenarios using the EPA's COBRA screening and mapping tool (version 4.1, updated in 2021). COBRA provides preliminary estimates of how changes in air pollution would impact health outcomes, then monetizes those health outcomes. Using year-specific data on county population, underlying incidence of health conditions, and health valuations, COBRA takes changes in specific air pollutants as inputs, and outputs county-specific estimates of health conditions and their valuations. Reducing NO_X and $PM_{2.5}$ levels improves overall public health through reduced incidences of mortality, infant mortality, non-fatal heart attacks, cardiovascular hospital admissions, emergency room visits for asthma, and the number of lost workdays.

Under each scenario, we calculated the health impacts from changes in the MHDV-related emissions. This includes the reduction in tailpipe emissions resulting from increased adoption of electric vehicles and low-NO_x–emitting ICE vehicles, increased emissions from the power sector due to increased charging demand, and the upstream emission reductions from refineries due to decreased consumption of gasoline and diesel fuels.

We modeled emissions reductions from vehicles in the "Highway Vehicles" tier, which includes heavy- and light-duty highway vehicles fueled by gasoline and diesel. We modeled emissions increases in the "Fuel Combustion: Electric Utility" tier, which includes emissions from coal, oil, gas, and internal combustion at electric utilities. Lastly, we modeled reductions from refineries in the "Petroleum Refineries & Related Industries" tier, which includes emissions from fluid catalytic cracking units, vacuum distillation, process unit turnarounds and petroleum refinery fugitives. Selecting a tier establishes the baseline of emissions against which health benefits or costs can be calculated. For additional detail on modeling inputs and results, see the Appendix.

Using population projections for North Carolina and the rest of the United States in combination with the COBRA results for 2028, detailed in the Appendix, we projected the value of health benefits resulting from each policy through 2050. NC population projections every 10 years between 2020 and 2050 were obtained from the Office of State Budget and Management's (OSBM's) Count/State Population Projection.[11] The projection for the Rest of U.S. population was obtained from the U.S. Census Bureau's 2020 current population report (2020).[12]

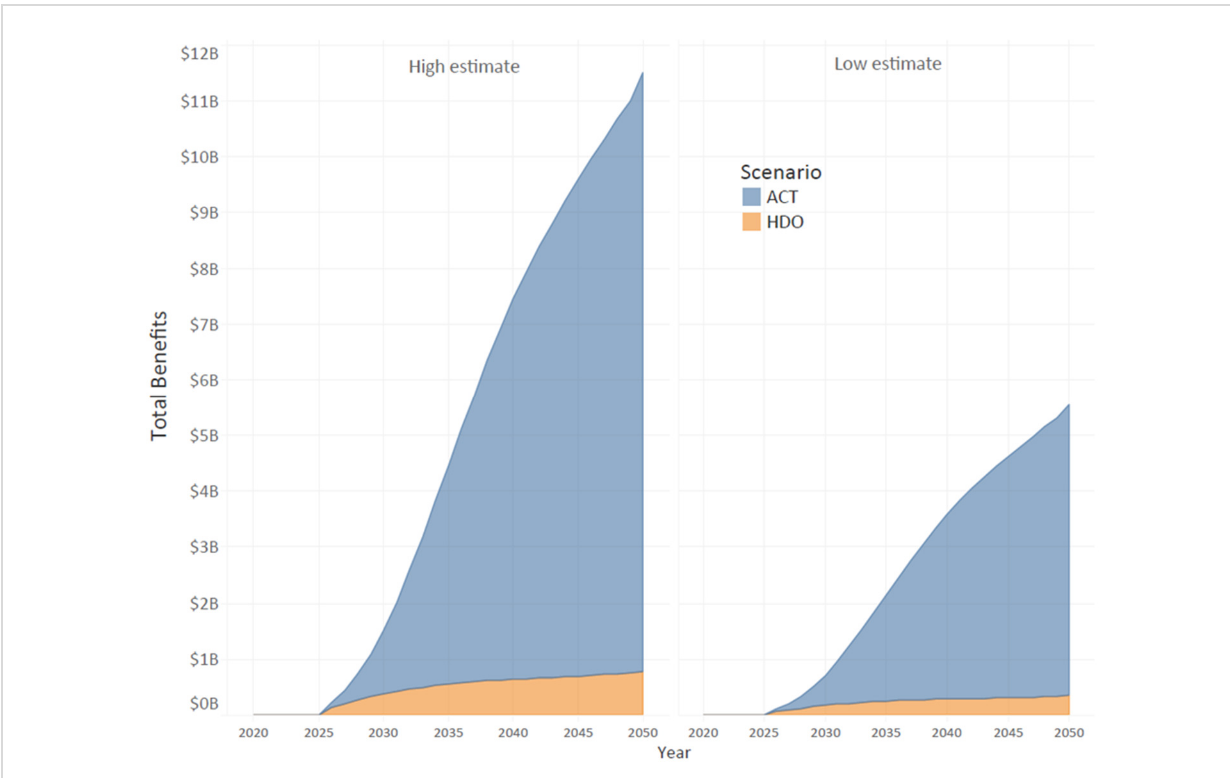
[11] NC Office of State Budget and Management (OSBM). 2021. *Count/State Population Projections*. Available at: https://www.osbm.nc.gov/facts-figures/population-demographics/state-demographer/countystate-population-projections .

[12] US Census Bureau. 2020. *Demographic Turning Points for the United States: Population Projections for 2020 to 2060*. Available at: https://www.census.gov/content/dam/Census/library/publications/2020/demo/p25-1144.pdf

Using the default low and high health impacts per incidence and dividing by population for 2028 and the corresponding NO_X and $PM_{2.5}$ emission reductions in 2028, we developed a constant health impacts multiplier which is then used to estimate health impacts in future years, scaling by the emission reductions and population in each year back to 2026 and forward to 2050.

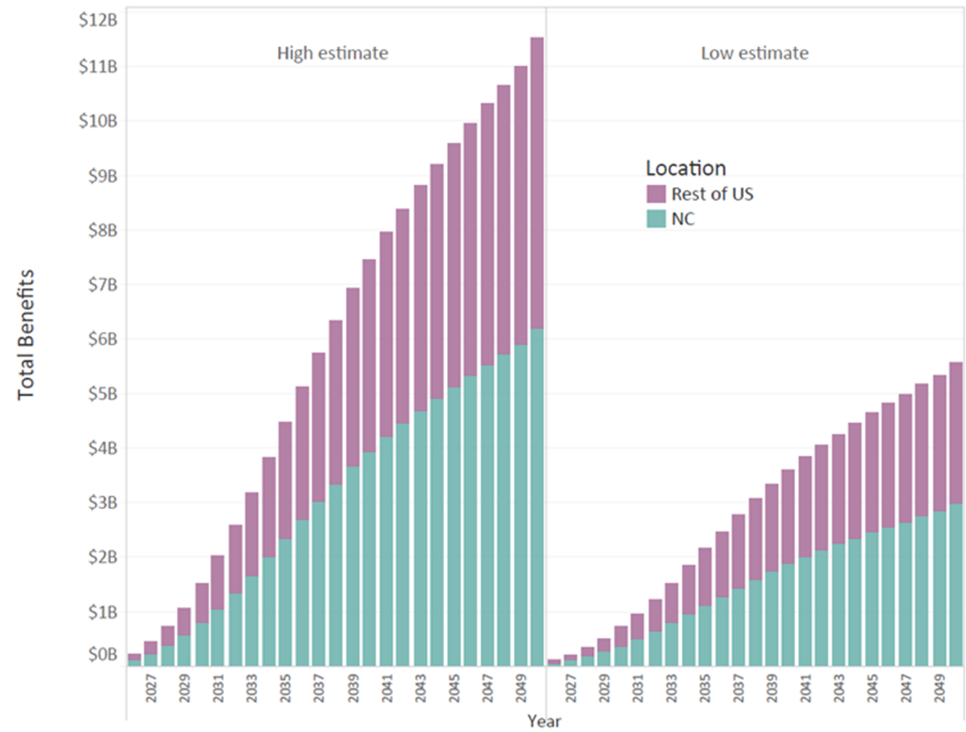
We projected that the health benefits of both the ACT and HDO policies would continue to grow over this period; benefits from the ACT scenario grow sharply each year, while benefits from the HDO scenario level off somewhat. We estimated total benefits of the ACT and HDO scenarios to fall between $5.56 billion and $11.51 billion in the year 2050. Figure 11 illustrates the high and low estimates of each policy's total benefits from 2020 to 2050.

Figure 11. Annual Health Benefits by Policy, High and Low Estimates, 2020–2050



Slightly more than half of the annual health benefits would occur in North Carolina, with the remainder impacting other states. In 2050, the total annual benefits of the two policies in North Carolina would fall between $2.97 billion and $6.2 billion, with an additional $2.6 to $5.3 billion occurring in the rest of the United States. Figure 12 displays the division of annual benefits between North Carolina and the rest of the U.S. for each year of this analysis.

Figure 12. Annual Health Benefits by Location, High and Low Estimates, 2020–2050



Cumulatively, the ACT and HDO policies would result in between $72 billion and $149 billion in health benefits between 2020 and 2050. Table 5 gives high and low estimates of the cumulative benefits of each policy, within and outside North Carolina.

Table 5. Cumulative Total Health Benefits within and outside North Carolina, 2020–2050

		ACT	HDO	ACT + HDO Combined
Within NC	*Low estimate*	$34.4 billion	$3.5 billion	$37.9 billion
	High estimate	$71.3 billion	$7.9 billion	$79.2 billion
Other States	*Low estimate*	$31.3 billion	$2.6 billion	$34.0 billion
	High estimate	$63.9 billion	$6.0 billion	$69.9 billion

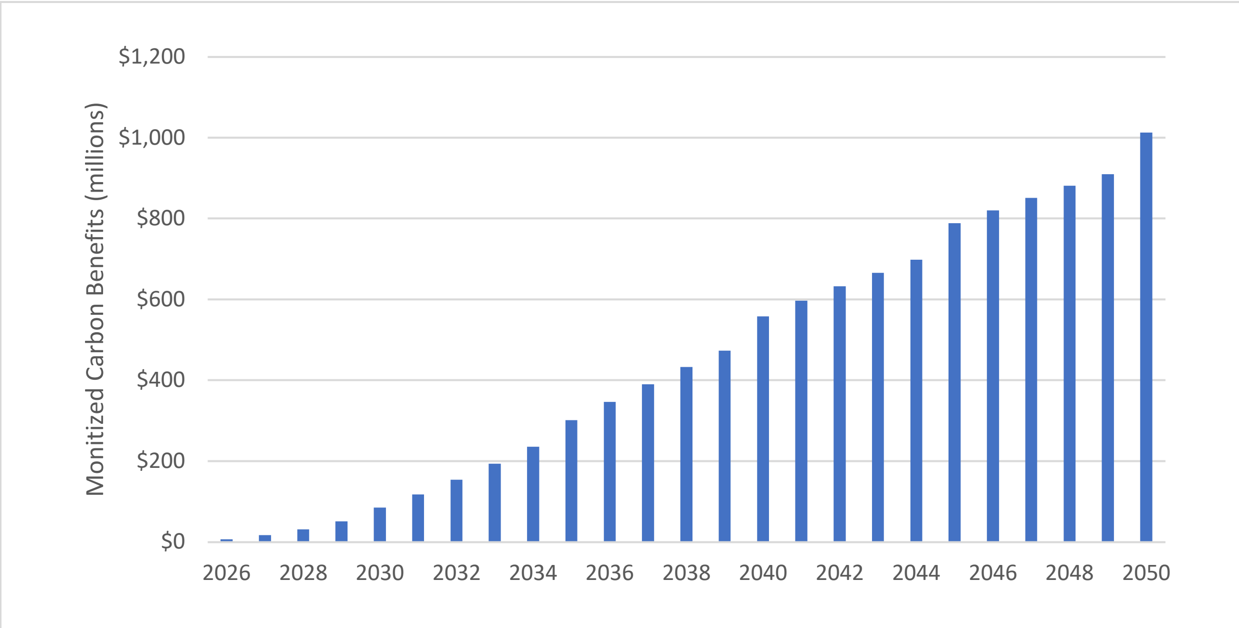
5.2. Monetized Climate Benefits

To monetize the climate benefits associated with the GHG emissions reductions under ACT, we used the Interim Estimates under Executive Order 13990 (2021) for the social cost of carbon, assuming a 3% average discount rate[13]. To calculate the monetized climate benefits RTI multiplied the annual WTW carbon emissions reduced through implementation of the ACT by the anticipated social cost of carbon in

[13] Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

that year. Figure 13 details the annual monetized climate benefits of ACT implementation. By 2050 the benefits exceed $1 billion annually.

Figure 13. Annual monetized climate benefits through ACT



5.3. Owner Economic Costs

5.3.1. ACT Owner Cost/Savings

Offsetting the incrementally higher purchase prices is the significant fuel cost savings. Per energy unit, electricity is significantly cheaper than gas or diesel fuels, suggesting that ZEVs will have significantly lower annual fuel costs compared to ICE vehicles. Additionally, ZEVs are expected to have lower maintenance costs over their useful lifetimes compared to ICE vehicles, as electric motors have fewer moving parts, do not require frequent oil changes, and are expected to have less brakeware due to regenerative braking mechanisms (Lowell, et. al, 2021).

The increased adoption of ZEV and low-NO_x vehicles have an incremental purchase price that is, at least currently, higher than conventional gas- or diesel-powered vehicles. Additionally, purchasing electric vehicles requires the purchase of vehicle chargers and/or investment in charging infrastructure. Combined, these expenses make current ZEVs cost more up front than their conventional alternatives. However, we anticipate that as battery technology and charging infrastructure improves, the incremental costs of new ZEV vehicles is expected to fall as prices converge and then fall below comparable vehicles with ICE engines.

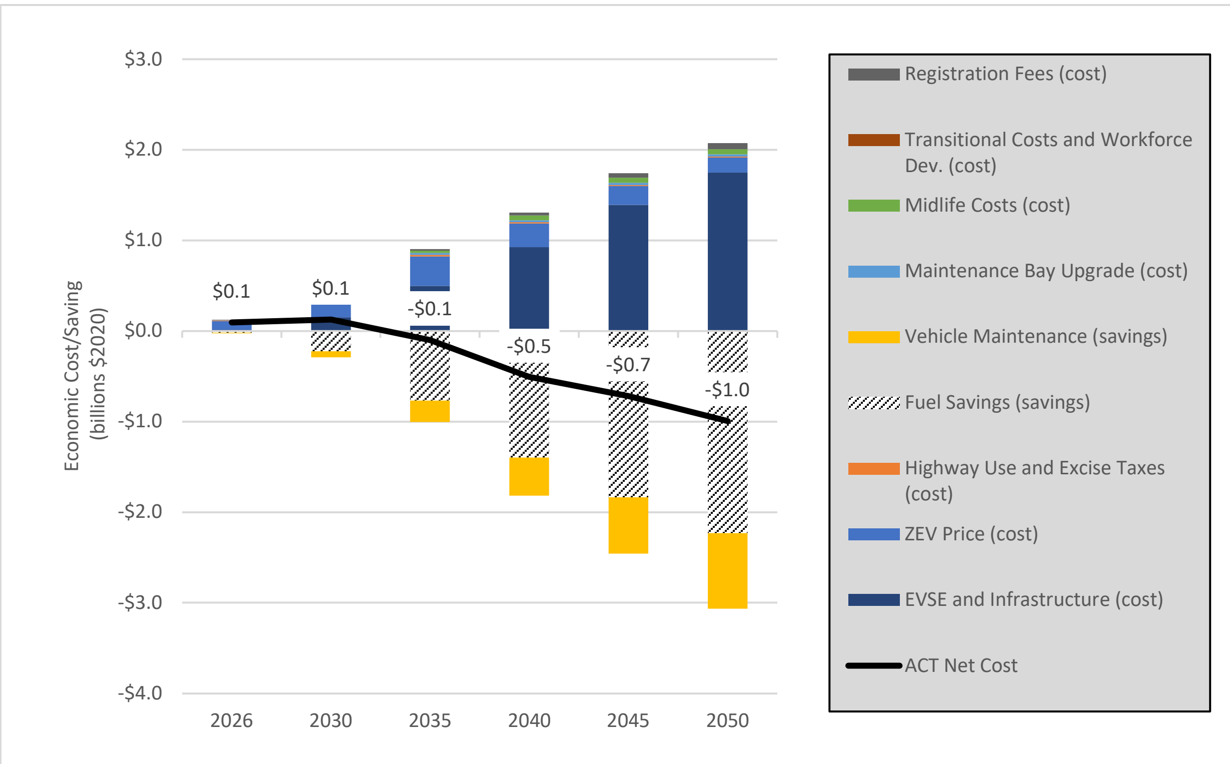
ZEV characteristics were based on the methodology provided by CARB's 2019 rulemaking documents[14] and North Carolina's projected fleet composition, as discussed in section 3.1.

[14] California Air Resources Board. (2019) Attachment C: Updated Costs and Benefits Analysis for the Proposed Advanced Clean Trucks Regulation. Page 11 and presented in original estimate. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/30dayattc.pdf

Costs consisted of higher initial vehicle costs and associated highway use taxes, higher registration and other fees, initial infrastructure investments, and minor expenses associated with workforce training. These costs are offset by extensive savings in the form of lower fuel and maintenance costs starting in 2034. **When costs and benefits are assessed for the period between 2026 and 2050,** cumulative net benefits total nearly $8.8 billion in net savings. **The net present value of the ACT policy in 2026 is a savings of more than $2 billion.**

Figure 14. shows the aggregate incremental cost of ownership in NC over the 25-year period. Over time, the incremental purchase price is falling despite increasing share of new ZEVs being purchased each year. The charging infrastructure costs are increasing proportionally to the number of new ZEVs entering the fleet each year.

Figure 14. Projected Incremental Cost of New ZEVs Compared to Conventional Vehicles



For Class 2b–3 ZEVs, it was assumed that 70% of vehicles were fleet vehicles and 30% were owned by individuals. All individually owned vehicles were modeled as having long-range batteries, whereas fleet vehicles were modeled with lower-range batteries. The Class 2b–3 vehicles were further classified as replacing either an existing gasoline (43%) or diesel engine (57%). All new Class 4 through Class 8 vehicles replaced diesel engine vehicles. After 2030, half of all new ZEVs in Classes 2b-3 through Class 8 were modeled with long-range batteries. This analysis did not include hydrogen fuel cell electric tractor trailers (Class 7-8).

Baseline vehicle prices and estimated incremental ZEV costs from 2026 to 2030 were taken from CARB's initial Standardized Regulatory Impact Assessment (SRIA).[15]After 2030, ZEV costs were modeled to decline at a rate of 6% per year through 2050. This analysis does not include any federal or state incentives that might reduce the cost of fleet vehicles. Midlife ZEV costs were restricted to a single battery replacement for Class 7–8 vehicles in the eighth year of operation. The anticipated battery price per kWh is $93 and this value remains constant throughout this analysis. This figure was taken from a recent working paper presented by the International Council on Clean Transportation and represents an average estimate from several independent researchers.[16]

Fueling infrastructure costs were estimated by multiplying the annual number of new vehicles in each vehicle class and type by a per vehicle charger and per infrastructure upgrade cost, presented in Table C–17 on page 44 of the SRIA report. For vehicle fleets, the number of chargers required is 80% of the total of new vehicles because in a fleet setting, a single charger may be used for more than a single vehicle in some instances. In addition, fleet depot and on-route chargers require regular maintenance. These costs were estimated at $500 per year for each charger. To support electric vehicles, maintenance bay upgrades are needed at fleet depots. These bays are used to perform routine and preventative maintenance, repairs, and other services. Electric vehicles require separate diagnostic tools and equipment. These costs are estimated at $25,000 per every 25 trucks.

Due to higher initial costs, electric vehicles generate more highway use tax in North Carolina, which is equivalent to a 3% tax on the total purchase price. In addition, Class 7–8 tractor trailers are subject to a first-time purchase federal excise tax of 12%.[17]

Further, at this time electric vehicles in North Carolina are assessed $130 more in registration and other fees each year than conventional vehicles.[18] This higher registration fee serves as a way for the state to recoup some of the lost state revenues from fuel taxes. The total annual cost associated with the EV registration fees grow over time under ACT, due to the increases in the number of registered ZEVs. Finally, transitioning to a new technology will entail some deployment costs, such as shifts in operations and maintenance practices. These recurring costs include workforce training, software upgrades, additional spare parts, and other miscellaneous expenses. RTI uses the same convention as the CARB's SRIA report and estimates these expenses as equal to 2.5% of the incremental cost difference between baseline ICE vehicle prices and an equivalent ZEV.[19]

Class 2b–3 through Class 8 ZEVs have higher up-front capital costs for the vehicle and infrastructure investments, but lower operating costs over the ownership lifetime, resulting in lower overall costs for

[15] California Air Resources Board. (2019). Advanced Clean Trucks Regulation: Standardized Regulatory Impact Assessment (SRIA). Table G8, page 31. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/appc.pdf

[16] International Council on Clean Transportation. (2022). Cost of electric commercial vans and pickup trucks in the United States through 2040. Page 7. https://theicct.org/wp-content/uploads/2022/01/cost-ev-vans-pickups-us-2040-jan22.pdf

[17] National Tank Truck Carriers. The Federal Excise Tax on Tractors and Trailers Should be Repealed. https://www.tanktruck.org/Public/Advocacy/Issue-Pages/Federal-Excise-Tax.aspx

[18] NC First Commission. (2020). Revenue Impact from Electric and Hybrid Vehicles. Issue brief Edition 8. Page 1. https://www.ncdot.gov/about-us/how-we-operate/finance-budget/nc-first/Documents/nc-first-brief-edition-8.pdf

[19] California Air Resources Board. (2019). Advanced Clean Trucks Regulation: Standardized Regulatory Impact Assessment (SRIA). Page 45. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/appc.pdf

truck ownership and operation. These savings can be summarized as reductions in fuel and maintenance expenses that would be incurred with ICEs.

Net fuel savings were calculated using the 2021 AEO projections for fuel and electricity costs in the U.S.'s South Atlantic region. Fuel costs savings reflect the difference in annual fuel costs after shifting from gasoline/diesel fuels to electricity.

Maintenance cost savings are estimated as the incremental difference between traditional gasoline and diesel engines and ZEV maintenance costs per mile of driving. This analysis uses the CARB estimates for vehicle miles traveled. Class 2b–3 vehicles are driven 15,000 miles per year, Class 4–8 vehicles are driven 24,000 miles per year, and Class 7–8 vehicles have an annual mileage of 54,000[20]. Per mile costs are presented in Table 6.

Table 6. Per Mile Maintenance Costs by Vehicle Class

Vehicle Class	$/mi.		
	Gasoline/Diesel	Battery-Electric	Cost Savings
Class 2B-3	$0.17	$0.13	$0.04
Class 4-5	$0.31	$0.23	$0.08
Class 6-7	$0.31	$0.23	$0.08
Class 8	$0.31	$0.23	$0.08
Class 7-8 Tractor	$0.19	$0.14	$0.05

Source: California Air Resources Board, 2019.

When costs and benefits are assessed for the period between 2026 and 2050, the net present value of the ACT proposal is a savings of more than $2 billion. This analysis uses a 7% discount rate. Realized savings will be influenced by future changes in the costs associated with electric vehicles, including components such as batteries; electricity, diesel, and gasoline; and infrastructure improvement investments.

5.3.2. HDO Manufacturer Costs

The proposed HDO regulations would require medium- and heavy-duty engine manufacturers to develop lower-NO_x–emitting engines. Most costs associated with this proposal consist of increased up-front production and operational costs compared to existing engines. Other significant costs include longer warranties[21], increased consumption of diesel exhaust fluid, and Emissions Warranty Information and Reporting (EWIR) and corrective action amendments. Alone, the HDO policies would have a net present value cost of $1.7 billion dollars. **Together**, i**mplementation of ACT and HDO policies would have net present value savings totaling $362 million between 2026 and 2050.**

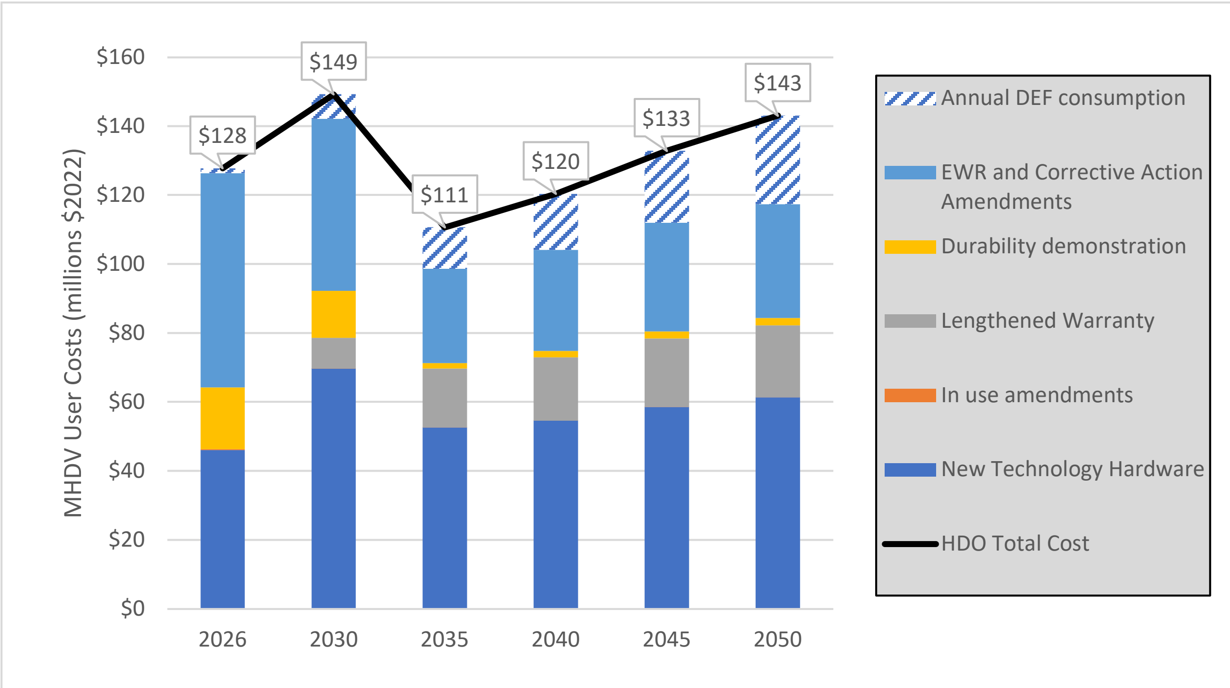
Figure 15 shows the aggregate incremental cost of HDO rule implementation in North Carolina over the 25-year period. As time passes, the cost of HDO implementation is relatively stable; following some

[20] Annual mileage estimates were obtained from CARB ACT analysis, *Appendix H: Draft Advanced Clean Trucks Total Cost of Ownership Discussion Document*. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/apph.pdf

[21] Many of these repairs would not have been required before the legislation. It reduces the failure threshold that triggers a recall and expands the number of parts covered.

initial up-front equipment costs, the annual costs grow proportionally to the number of new low-NO_x ICE vehicles sold. Specific HDO provisions are described in detail below.

Figure 15. HDO Rule Projected Costs to 2050



The summary of direct proposal costs and savings are presented in Appendix. Unless otherwise noted, all methodologies and specific cost estimates were taken from the CARB's Omnibus Initial Statement of Reasons and associated appendices.[22]

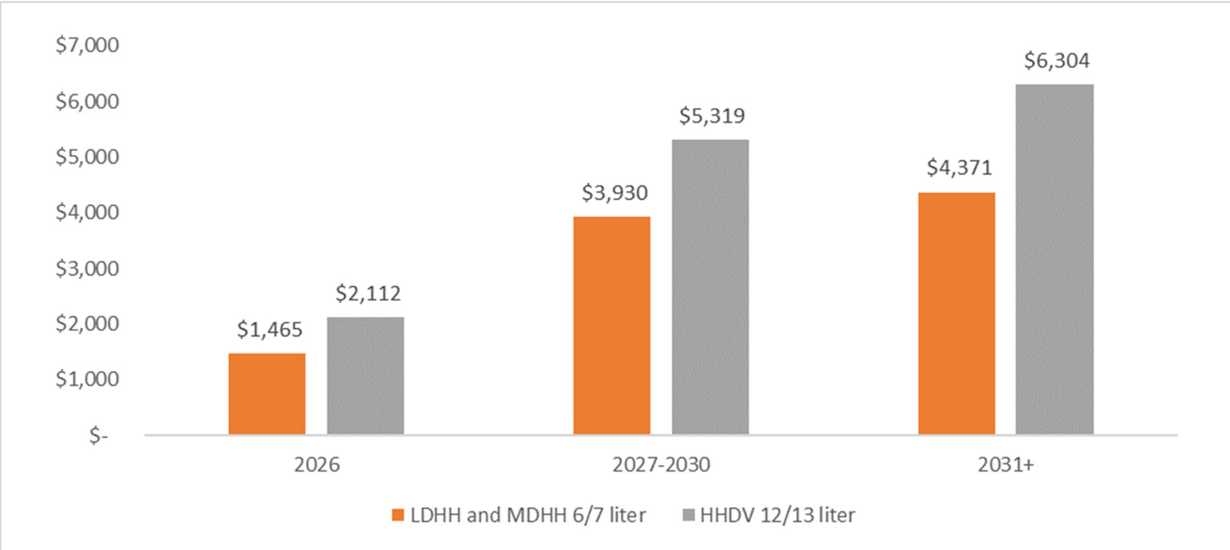
New Technology and Equipment

New technology costs for meeting more stringent NO_x standards include engine improvements, aftertreatment technology, and incremental costs to simultaneously meet federal Phase 2 GHG standards. These per vehicle costs are scaled up in 2027 and again in 2031 to account for implementation of specific policy provisions. The costs for these different time periods are presented in Figure 16.

As in previous EPA analyses, we applied a learning curve adjustment to these costs to reflect improvements and cost reductions in the manufacturing processes of engine and aftertreatment systems. After 2 years of implementation for each policy implementation, costs decline by 20%. After 2033, equipment and technology costs remain constant. Because manufacturers will already have made changes to their products to sell in California's market, this analysis does not include any research and development costs for developing compliant technologies. Additionally, this analysis assumes that all new vehicles purchases are in North Carolina and comply with these proposed rules.

[22] California Air Resources Board, Further Detail of Costs and Economic Analysis: Appendix C-3. Pages 3–9. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2020/hdomnibuslownox/appc3.pdf

Figure 16. Per Vehicle Cost for Engine Improvements and Aftertreatment Technology by Engine Size



Source: California Air Resources Board, 2019.

Lengthened Warranties

Warranty costs are either included in the original purchase price of a vehicle or may be included at an additional cost at the time of purchase through available extended warranty coverage. The incremental cost associated with the HDO rule consists of additional repairs that would be performed under longer warranty periods. These costs will be borne by manufacturers but may be recouped via higher warranty prices for vehicle purchasers. To determine these costs, RTI relied on CARB methodology and data. Additional average repair costs, including new emissions components, are multiplied by the percentage of vehicles under warranty and a ratio that indicates how much additional mileage will be covered with lengthened warranties. These increased costs will be implemented incrementally, with some additional costs incurred for model year 2027 vehicles and additional repair costs starting for model year 2031 vehicles.

Increased Diesel Exhaust Fluid Consumption

Diesel exhaust fluid (DEF) is a liquid used to reduce the amount of air pollution created by a diesel engine. Specifically, DEF is an aqueous urea solution made with urea and deionized water. DEF is consumed in a selective catalytic reduction (SCR) that lowers the concentration of NO_x in the exhaust emissions from a diesel engine. Because the proposal would require SCR systems to operate during more of the vehicles' operation hours, DEF consumption and cost will increase. Incremental annual DEF consumption costs by engine class and model year were taken from the previously cited CARB report and applied to North Carolina's remaining diesel vehicle still sold under the ACT + HDO policy scenario.

Total incremental costs are presented in Table 7.

Table 7. Incremental DEF Consumption Costs by Engine Size and Model Year

Model Years	6/7 Liter Diesel (MHDV)			12/13 Liter Diesel (HHDV)		
	2026	2027–2030	2031+	2026	2027–2030	2031+
Incremental hardware cost	$1,365	$3,830	$4,271	$1,611	$4,818	$5,803
Incremental cost of Phase 2 GHG Standards	$100	NA	NA	$501	NA	NA
Total incremental cost	$1,465	$3,830	$4,271	2,112	$4,818	$5,803

Source: California Air Resources Board, 2019.

EWIR and Corrective Action Amendments

The corrective action proposals would require manufacturers to conduct recalls for components that have failure rates greater than or equal to 25% within 5 years. An estimate of the repair cost for components and other assumptions used to generate this estimate of incremental cost were taken from CARB's previously cited work. It is assumed that 70% of repairs will be software updates, at a cost of $400 each, and that 30% of repairs will be the replacement of a component at a cost of $756.

Longer warranty periods will require manufacturers to spend more effort and time on reporting for longer periods of time than for current warranties. The reporting period will increase from 5 years in 2026 to 7 years in 2027 and 10 years in 2031. These additional costs were determined by calculating the increased number of reports and documents that need to be submitted and the time required to produce them.

Other Costs

Less significant costs include durability demonstrations and in-use amendments. Due to a lack of North Carolina-specific information about the number of manufacturers and the number of parent engine groups to be tested, this figure was estimated as a proportion of total incremental costs based on California's analysis. In-use amendments would require manufacturers of heavy-duty vehicles to implement additional heavy-duty in-duty testing. Costs include staff time to set up reporting systems, hardware costs, and ongoing testing expenses.

Alone, the HDO policies would have a net present value cost of $1.7 billion dollars. **Together, implementation of ACT and HDO provisions would have net present value savings totaling $362 million between 2026 and 2050.** The costs and benefits presented in this section do not include the significant climate and health benefit enumerated in Section 4.

6. Conclusion and Discussion

The Intergovernmental Panel on Climate Change's Sixth Assessment Report, published in 2022, concludes that human activity is the main driver of climate change, which, if unchecked, will lead to more intense weather events, such as flooding, heat waves, rising sea levels and increased ocean temperatures. Immediate and dramatic reductions in GHG emissions are necessary to avoid reaching an irreversible tipping point for climate change. In the United States, rapid large-scale efforts are being undertaken to transform energy systems and transportation services to low-carbon technologies capable of delivering deep reductions in GHG emissions. Along with many other states, North Carolina is already undertaking energy transitions to make dramatic reductions in carbon intensity. The transportation sector represents another area where deep decarbonization and non-carbon pollution reduction is needed. North Carolina could begin to decarbonize its transportation sector by adopting California's ACT clean air standards for MHDVs. Adopting HDO rules, under Section 177 of the Federal Clean Air Act would provide additional NO_x reductions and health benefits.

The net benefits from the modeled ACT + HDO rule include monetized public health and climate benefits, in addition to the private economic costs and savings presented in the earlier sections of this report. Figure 17 presents annual net social benefits over time by policy and component. The earliest years of implementation for both policies include some initial higher-than-baseline incremental costs, but by 2030, the public health and climate benefits of the two rules are net positive and only increase into the future.

Figure 17. Summary of Net Cost/Benefits of ACT + HDO in North Carolina

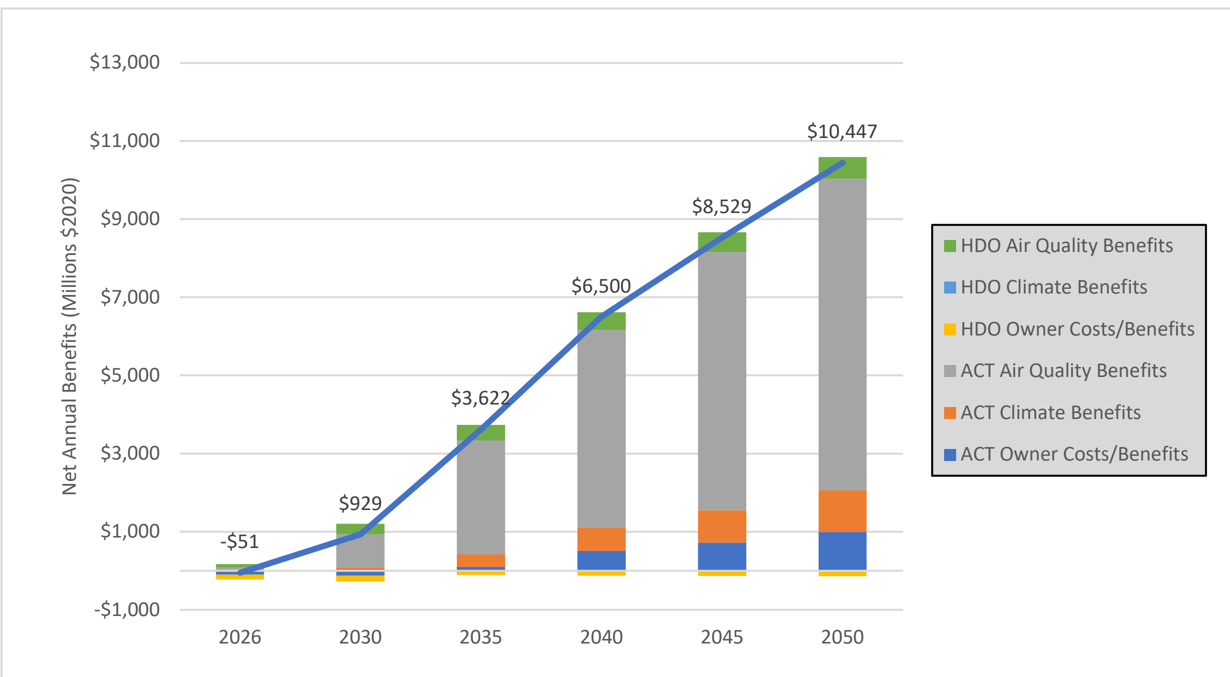
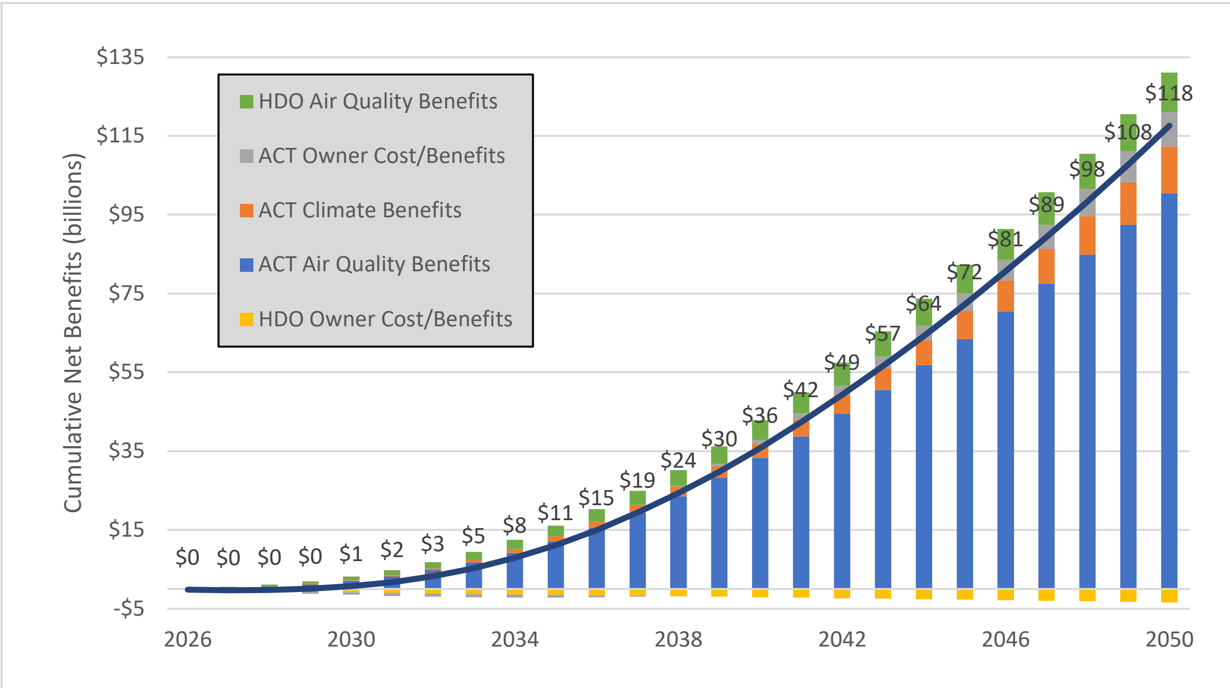


Figure 18. shows the resulting cumulative net benefits estimated in this study. The average health savings due to improved air quality over the 25-year period is approximately $110 billion. The climate benefits associated with reductions of GHG emissions provides an additional $12 billion. Cumulative economic cost savings of $5.3 billion are also achieved over the same period, driven largely by incremental savings in fuel and annual ZEV truck maintenance, compared to traditional ICE trucks.

Figure 18. Cumulative Net Benefits of ACT and HDO



Transportation is the largest source of GHG emissions in North Carolina (NCDEQ, 2022). Under HB951, North Carolina is already undertaking steps to decarbonize the power sector, targeting power sector net-zero emissions by 2050. Similar emissions reductions are possible in the transportation sector with relatively low cost to consumers. Adopting ACT to lower emissions from MHDVs provides a cost-saving option for taking a first step in decarbonizing the transportation sector. Adding HDO would provide added NO_x reductions and health benefits.

7. References

Clark-Sutton, K., J. Fletcher, J. Petrusa, and K. Franzen. 2018. *Evolving Transportation in North Carolina: An Analysis of Emission Reduction Pathways for North Carolina's Transportation Sector*. A report prepared for the Southern Environmental Law Center (SELC) and the National Resource Defense Council (NRDC).

Interagency Working Group on Social Cost of Greenhouse Gases, United States Government. 2021. *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990*. Available at: https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

Konschnik, K., M. Ross, J. Monast, J. Weiss, and G. Wilson. 2021. *Power Sector Carbon Reduction: An Evaluation of Policies for North Carolina*. NI R 21-01. Durham, NC: Duke University. Available at: https://nicholasinstitute.duke.edu/publications/power-sector-carbon-reduction-evaluation-policies-north-carolina.

Lowell, D., A. Saha, M. Freeman, D. MacNair, D. Seamonds, and T. Langlois. 2021. *Clean Trucks Analysis Costs & Benefits of State-Level Policies to Require No- and Low-Emission Trucks. Technical Report- Methodologies & Assumptions.* A report developed for NRDC and the Union of Concerned Scientists. Available at: https://www.mjbradley.com/reports/clean-trucks-analysis-costs-benefits-state-level-policies-require-no-and-low-emission-trucks

Lowell, D., A. Saha, M. Freeman, D. MacNair, D. Seamonds, and T. Langlois. 2021. *New York Clean Trucks Program: An Analysis of the Impacts of Zero-Emission Medium and Heavy-Duty Trucks on the Environment, Public Health, Industry, and the Economy*. A report developed for NRDC and the Union of Concerned Scientists. Available at: https://www.mjbradley.com/reports/new-york-clean-trucks-report

North Carolina Department of Environmental Quality (NCDEQ). 2022*. North Carolina Greenhouse Gas Inventory (1990-2030)*. Available at: https://deq.nc.gov/energy-climate/climate-change/greenhouse-gas-inventory

Appendix—Supplemental Data and Analysis Results

Supplemental MHDV Data

This appendix section provides additional characterization of the underlying MHDV fleet used for this analysis.

The baseline projections for VMT and fuel use were also developed using the MOVES3 default data for distance traveled and energy consumption with no adjustments. Figure A-1shows the projected baseline of vehicle miles traveled per year (VMTY) by vehicle type, while Figure A-2 shows the baseline projected energy consumption by vehicle and fuel type for the MHDV population.

Figure A-1. Baseline MHDV VMT Projection

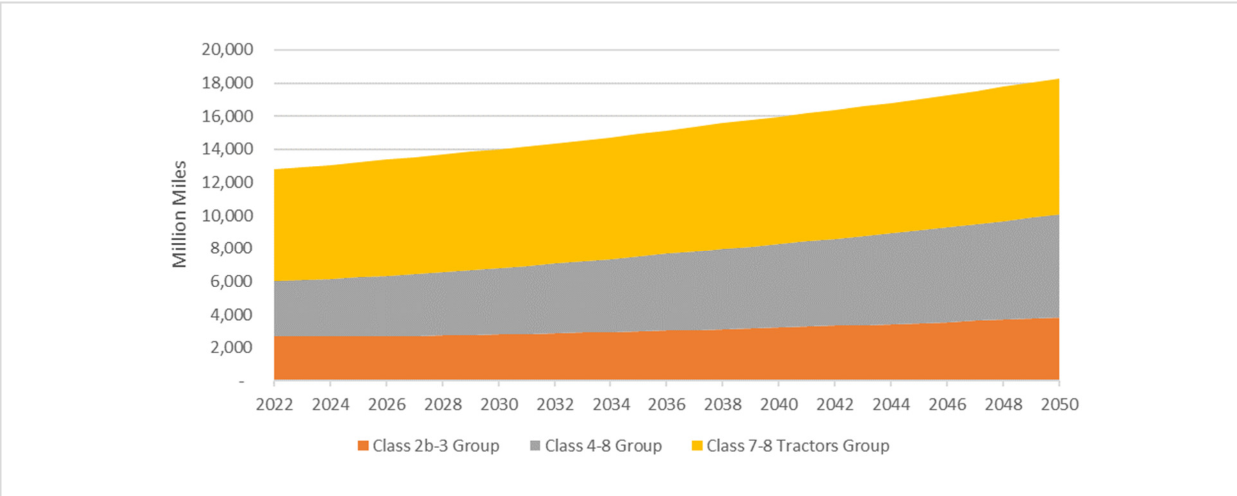
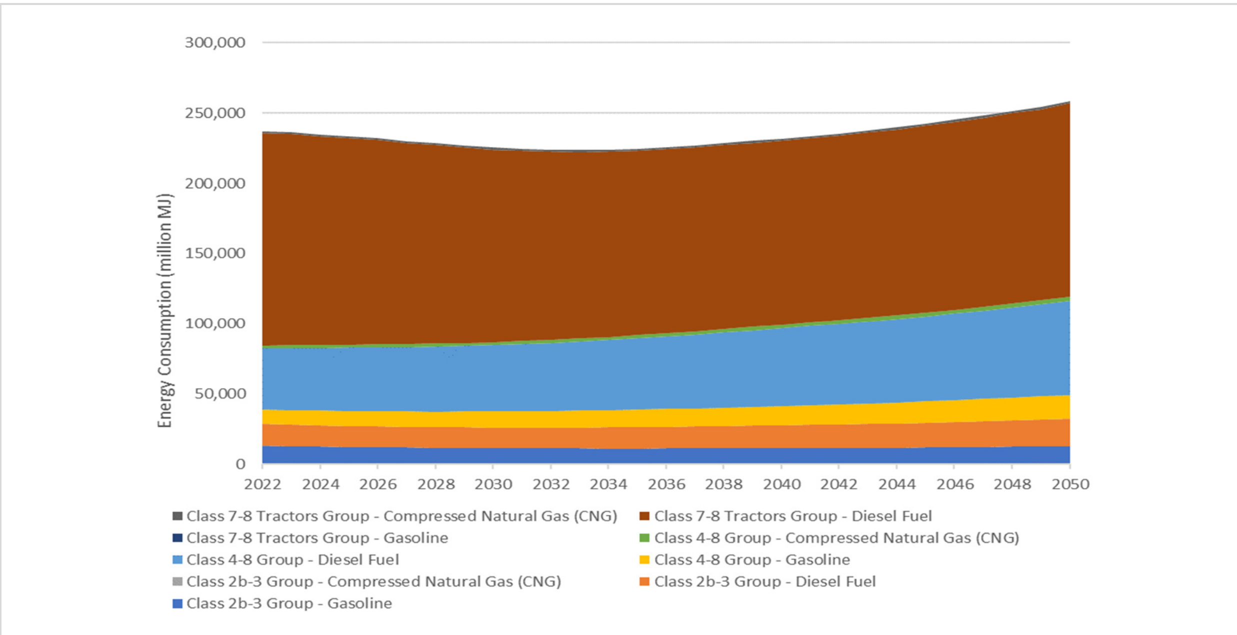


Figure A-2. Baseline MHDV Fuel Consumption Projection



DIEM Power Sector Fuel Mix

Table A-1. Baseline with NREL Medium EV Electricity Demand Growth (DIEM)

% of In State Generation								
Generation Type	**2023**	**2025**	**2028**	**2030**	**2035**	**2040**	**2045**	**2050**
Coal	19%	19%	20%	14%	7%	2%	0%	0%
Gas	35%	35%	35%	34%	21%	22%	22%	19%
Zero-Emitting	46%	46%	44%	52%	72%	75%	78%	81%

Table A-2. Baseline from DIEM

% of In State Generation								
Generation Type	**2023**	**2025**	**2028**	**2030**	**2035**	**2040**	**2045**	**2050**
Coal	19%	18%	17%	13%	6%	2%	0%	0%
Gas	35%	34%	36%	31%	23%	24%	23%	23%
Zero-Emitting	46%	48%	47%	56%	71%	75%	77%	77%

ACT + HDO Scenario Results

Figure A-3. shows the shift in VMT by year due to the implementation of the ACT rule in North Carolina. By 2050, there would be a reduction of almost 10 million VMT by ICE engines for MHDVs across the state.

Figure A-3. VMT by Vehicle Type with ACT Rule Adoption

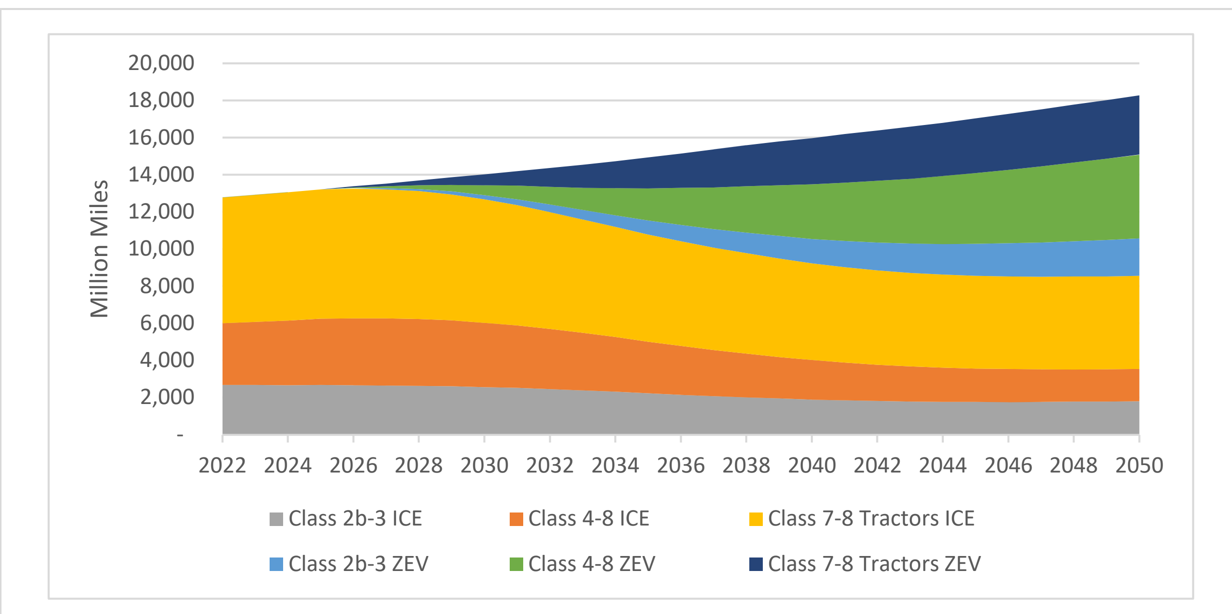


Table A-3 quantifies the fuel savings for gasoline and diesel fuel along with the increase in electricity generation due to implementation of the ACT rule. The electricity economy for each vehicle type used in the analysis was pulled from the EMFAC2021 Technical document. The consumption rates used were the default rates of 20 mph (including 15% energy loss from grid to vehicle battery) with no speed correction factor applied. The emissions impact from the fuel consumption changes are discussed in section 3.2, while the changes in costs are discussed in section 3.3.

Table A-3. Annual Change in Fuel/Electricity Consumption through ACT Adoption

Year	Million Gallons						ACT Adoption Scenario Electricity Use (GWh)
	Baseline Gasoline Use	ACT Adoption Scenario Gasoline Use	ACT Adoption Scenario Gasoline Reduction	Baseline Diesel Use	ACT Adoption Scenario Diesel Use	ACT Adoption Scenario Diesel Reduction	
2026	185	184	-2	1,489	1,477	-12	199
2030	185	168	-18	1,438	1,318	-120	2,191
2035	192	134	-58	1,425	1,062	-362	6,688
2040	204	105	-99	1,464	889	-575	10,689
2045	220	91	-129	1,526	814	-712	13,291
2050	241	89	-152	1,621	810	-812	15,144

Note: Does not include reduction in compressed natural gas consumption.

ACC1 Policy Analysis

Originally, this study was designed to include the analysis of Advanced Clean Cars 1 (ACC1) to assess the environmental, health and economic impacts on the passenger vehicles and light-duty truck segment of the North Carolina transportation fleet. In January 2022 the Federal government finalized a set of GHG emissions standards for passenger cars and light-duty trucks model years, 2023 through 2026 referred to as the Safer Affordable Fuel Efficiency Vehicles (SAFE2). These new SAFE2 light-duty vehicle emissions standards represent a significant increase in stringency over pervious federal GHG emissions standards (SAFE). Passage of the federal SAFE2's more stringent emissions standards means that baseline emission from light-duty vehicles starting in 2026 will exceed the emission reductions achievable under California's ACC1 rule. As a result, we elected move the presentation of our modeled ACC1 results.

The following subsections of this appendix present the analysis we developed for light-duty vehicles under ACC1.

Passenger Vehicle Populations

Baseline Scenario—Passenger Vehicles

RTI developed the baseline for vehicle population (VPOP); vehicle miles traveled (VMT); and fuel use by source type, regulatory class and fuel type using EPA's MOtor Vehicle Emission Simulator 3 (MOVES3) modeling system.[23] RTI downloaded the default data from MOVES3 for the state of North Carolina, aggregated at the state level for years 2022–2050.

To provide a more realistic baseline population, we augmented the default data available in MOVES3 and used the ZEV light-duty vehicle percentage of sales projections from the U.S. Energy Administration EIA's 2021 Annual Energy Outlook (AEO) for the South Atlantic region of the United States. The portion of electric vehicles by model year was calculated as the percentage of full electric vehicle sales for passenger vehicles by year compared to all vehicle sales. The baseline projection of ZEV adoption was calculated separately for passenger cars and passenger trucks.

Figure A-4 shows the growth in North Carolina's passenger vehicle population. Total passenger vehicles grow from 8.6 million in 2026 to 9.4 million in 2050. Passenger cars account for just under 50% of the North Carolina population in 2026, growing to 55% of the population by 2050. Passenger trucks include all vehicles with source type "passenger trucks" from the MOVES3 model, which have a regulatory class of light-duty truck, Class 2 truck or Class 3 truck. Passenger truck population falls slightly from 52% to 45% of the population over the same time.

Figure A-4. North Carolina Passenger Vehicle Population

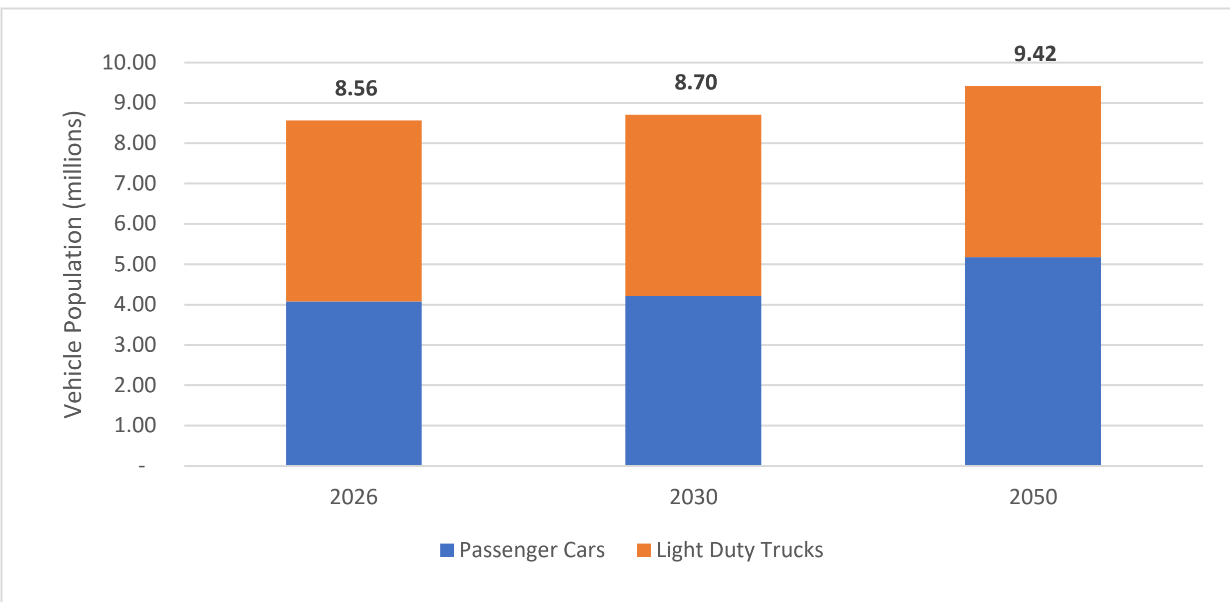
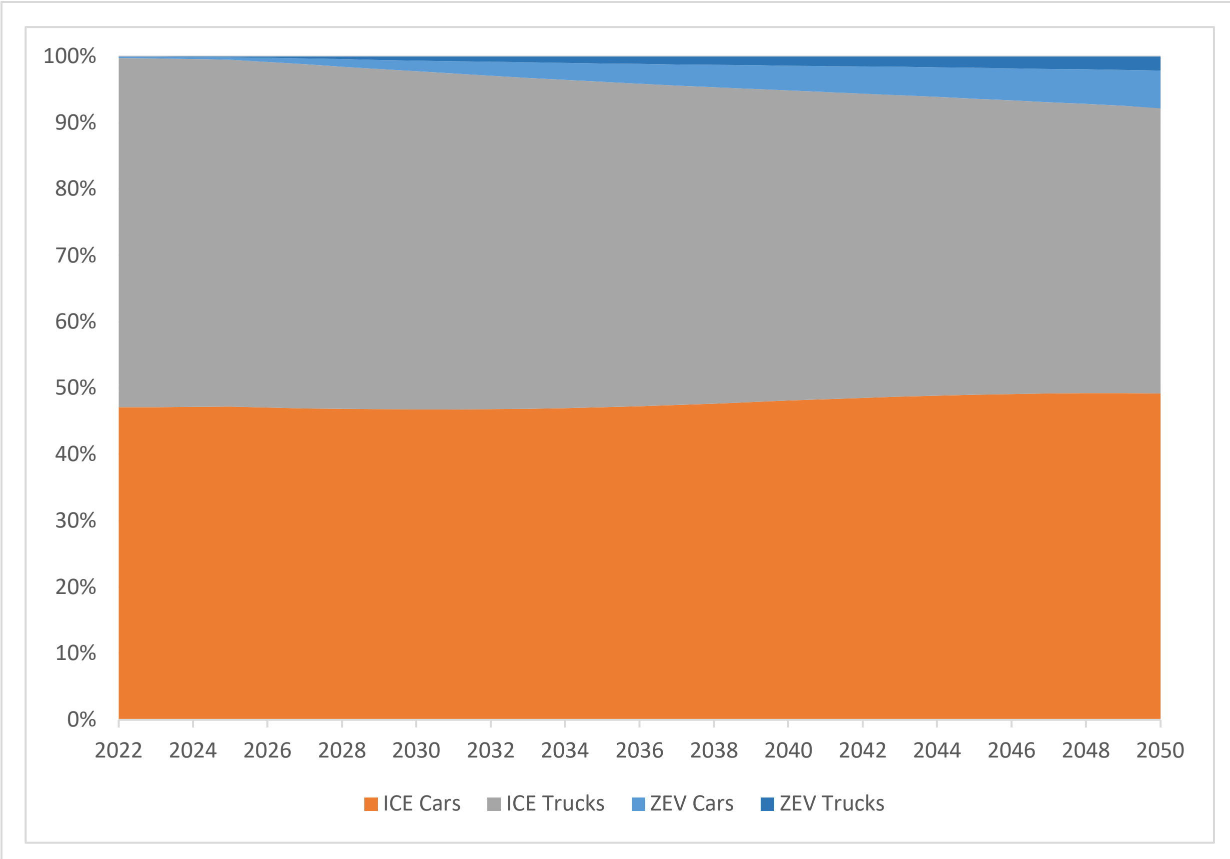


Figure A-5 shows the baseline vehicle composition by type through 2050 calculated using the MOVES3 output and AEO ZEV sales data. ZEVs account for less than 1% of in-use vehicles in 2026 growing to 7.4% by 2050 in baseline scenario.

[23] U.S. Environmental Protection Agency. (2021). Latest Version of MOtor Vehicle Emission Simulator (MOVES). https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves

Figure A-5. Baseline Passenger Vehicle Projection: Percentage of In-Use Population

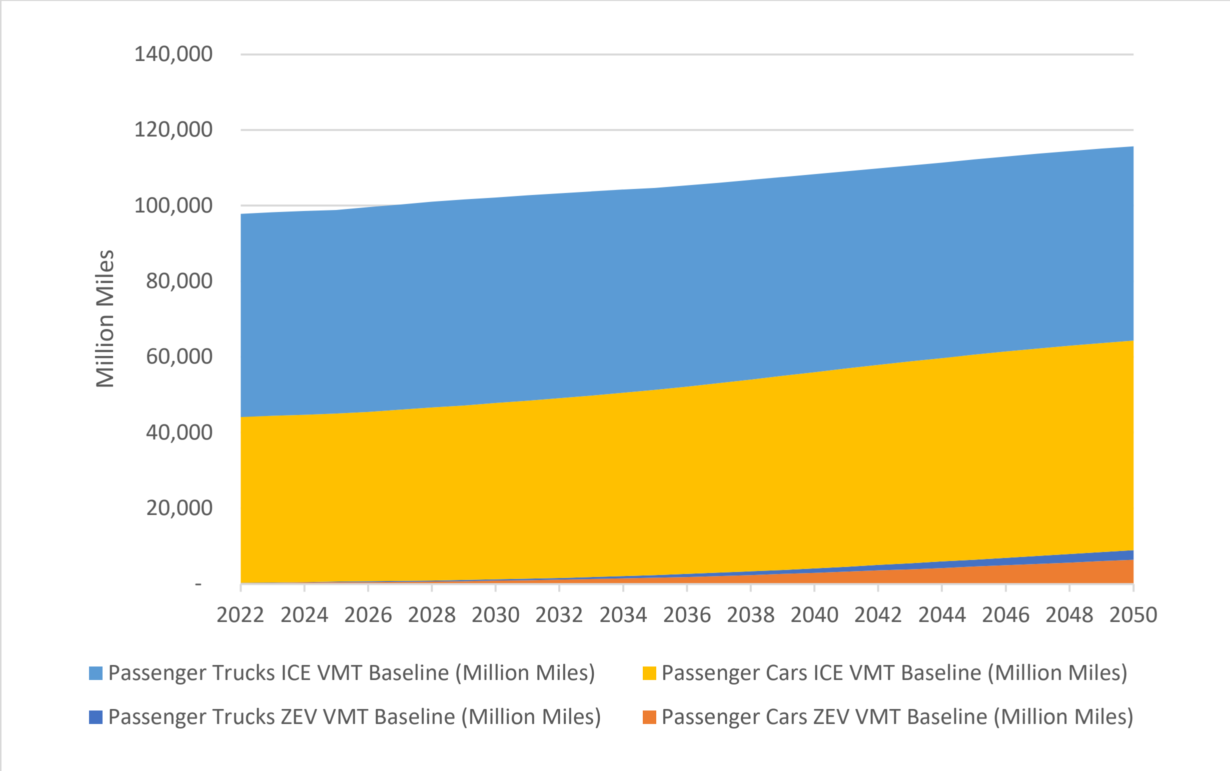


Supplemental Passenger Vehicle Data

Baseline VMT projections for passenger vehicles, the total VMT by vehicle type was estimated by using the output from MOVES3 and allocating mileage by vehicle type to ZEV vehicles proportionally based on the AEO baseline ZEV sales projections. shows the VMT by vehicle type in the baseline projection.

Figure A-6 presents the baseline passenger vehicle VMT by vehicle type.

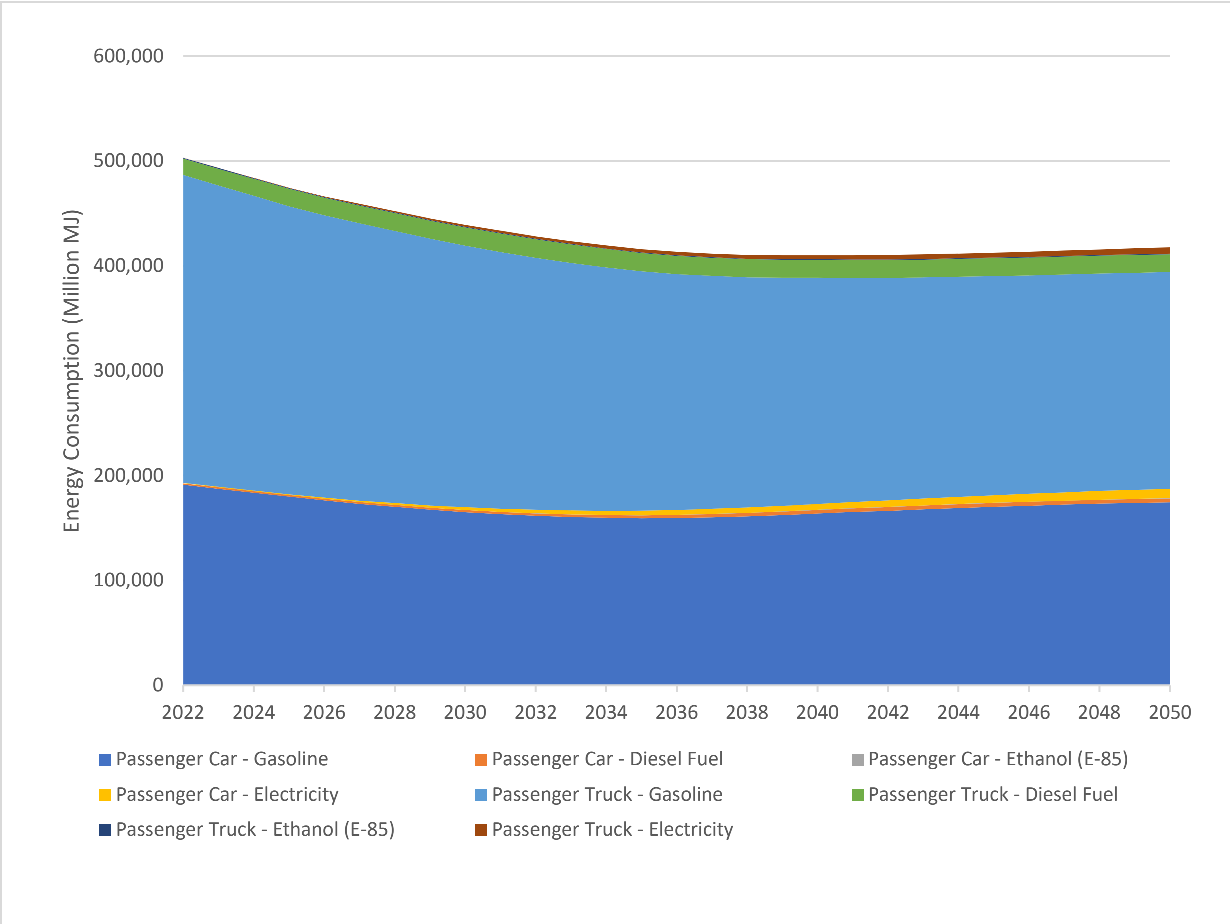
Figure A-6. Baseline Passenger Vehicle VMT Projection



The fuel usage for passenger vehicles was developed using the energy output from MOVES3. For the ZEV portion of the fleet, RTI used the VMT for ZEVs in the baseline scenario and applied an average fuel economy of 0.375 kWh/mile for passenger cars and 0.6 kWh/mile for passenger trucks. This is consistent with estimates used in California's EMission FACtor (EMFAC)[24] model and the current fuel economy standards for electric vehicles[25]. Figure A-7 shows the energy use by fuel type for passenger vehicles in the baseline scenario.

[24] https://ww2.arb.ca.gov/sites/default/files/2021-08/emfac2021_technical_documentation_april2021.pdf
[25] www.fueleconomy.gov

Figure A-7. Baseline Passenger Vehicle Energy Use by Fuel Type



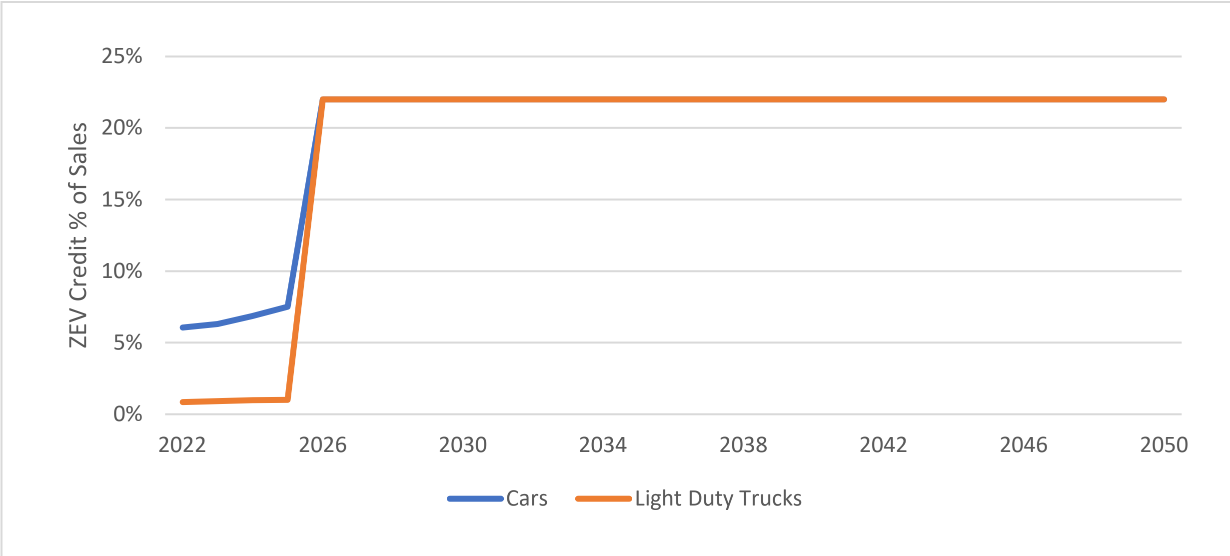
Passenger Vehicle Population Under ACC Scenario

This section presents the changes to the light-duty fleet after implementing ACC1.

Under the ACC1 policy scenario, North Carolina adopts the requirements of the California Advanced Clean Cars (ACC1) regulation that combines the control of smog-causing (criteria) pollutants and GHG emissions in a single coordinated package of regulations.[26] It includes both a Low Emissions Vehicle (LEV) regulation that limits criteria and GHG emissions in vehicles powered by conventional internal combustion engines (ICEs). ACC1 also includes mandatory sales requirements based on a crediting system and the total number of cars sold in the state each year. Vehicles receive credits based on the size of electric range, with the goal of increasing the adoption in the ZEV technologies for light-duty passenger cars and trucks up to 22% of new model year sales starting in 2026. (see Figure A-8).

[26] California Air Resources Board. Advanced Clean Cars Program. https://ww2.arb.ca.gov/our-work/programs/advanced-clean-cars-program

Figure A-8. ACC1 ZEV Credits 2022–2050



For passenger vehicles, the "business as usual" (BAU) scenario already includes a small percentage of ZEV vehicles purchased each year until 2050.

Under the ACC1 scenario, RTI models the adoption of California's ACC1 program, which includes a ZEV crediting sales target and a LEV III rule. The ZEV rule requires that the manufacturer achieve a predetermined percentage of ZEV "credits." The credit requirement is set relative to the manufactures overall sales. The credit value of ZEVs varies based on the battery range of the vehicle sold. Electric vehicles with longer-range batteries have the most credit value, while lower battery range vehicles receive a smaller credit value. When ACC1 was adopted in California, the vehicle credit levels were:

- BEV150: 2.643
- BEV200: 3.357
- BEV250: 4.0

For this analysis, RTI adjusted the credit system to match the AEO 2021 outlook BEV vehicle types:

- BEV100: 2.643
- BEV200: 3.357
- BEV300: 4.0

These credit levels would require an increasing amount of vehicles sold within the state to be ZEV, leading to a credit requirement of 22% of vehicles by 2025. RTI modeled the impact of implementing the ACC1 program in North Carolina by calculating the credit level that would be reached, assuming the AEO 2021 reference case projection of ZEVs sold by range and calculating an adjustment factor needed to meet the 22% requirement from 2026 through 2039—the year where the reference case projection exceeded the credit level. We then calculated the ACC1 scenario ZEV population by applying that adjustment factor to the reference case population to scale it up to meet the ZEV rule credit requirement. This analysis resulted in an annual ZEV sales target of just over 7% of passenger vehicle sales in 2026.Figure A-9 compares the resulting new ZEV sales required under ACC1 to our baseline ZEV sales between 2022 to 2050. The crediting system has very limited impact on the number of new ZEVs sold each year between 2026 and 2039. Cumulatively, the adoption of the ZEV crediting sales target would lead to about 189,000 ZEV passenger vehicle sales from 2026 through 2038.

Figure A-9. Comparing ZEV Sales under ACC

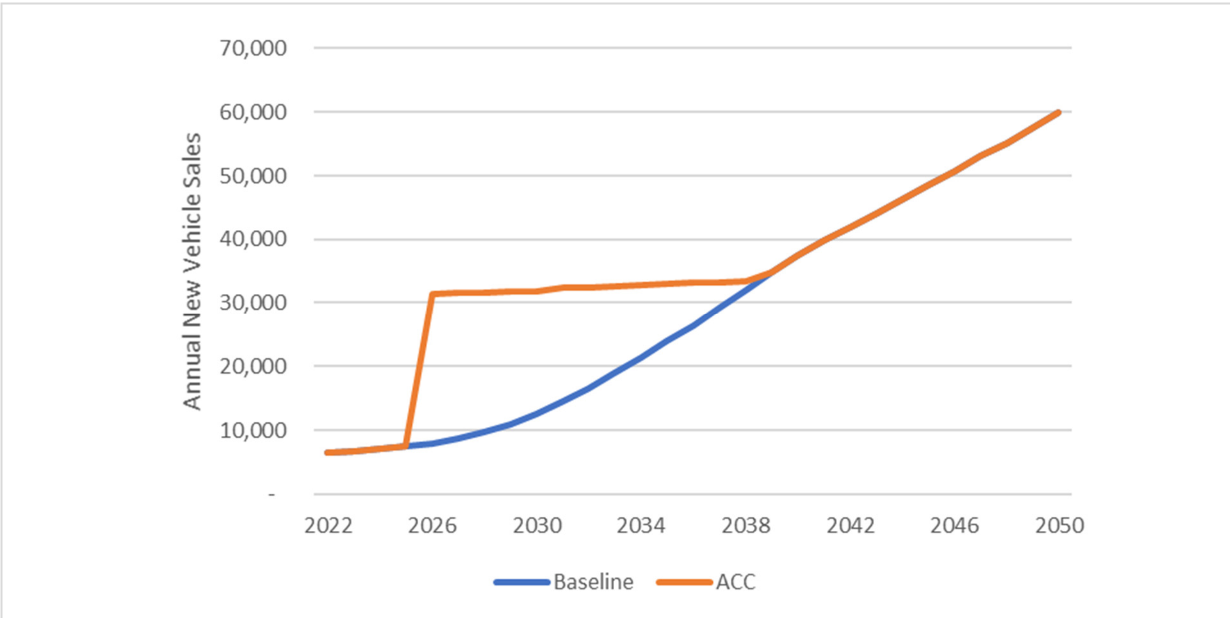


Figure A-10 shows the resulting vehicle population by vehicle type under modeled under adoption of ACC. Figure A-11 shows VMT by vehicle type after implementation of ACC1. Table A-4 shows the annual change in fuel/electricity consumption under ACC1.

Figure A-10. ACC1 Passenger Vehicle Projection: Percentage of In-Use Population

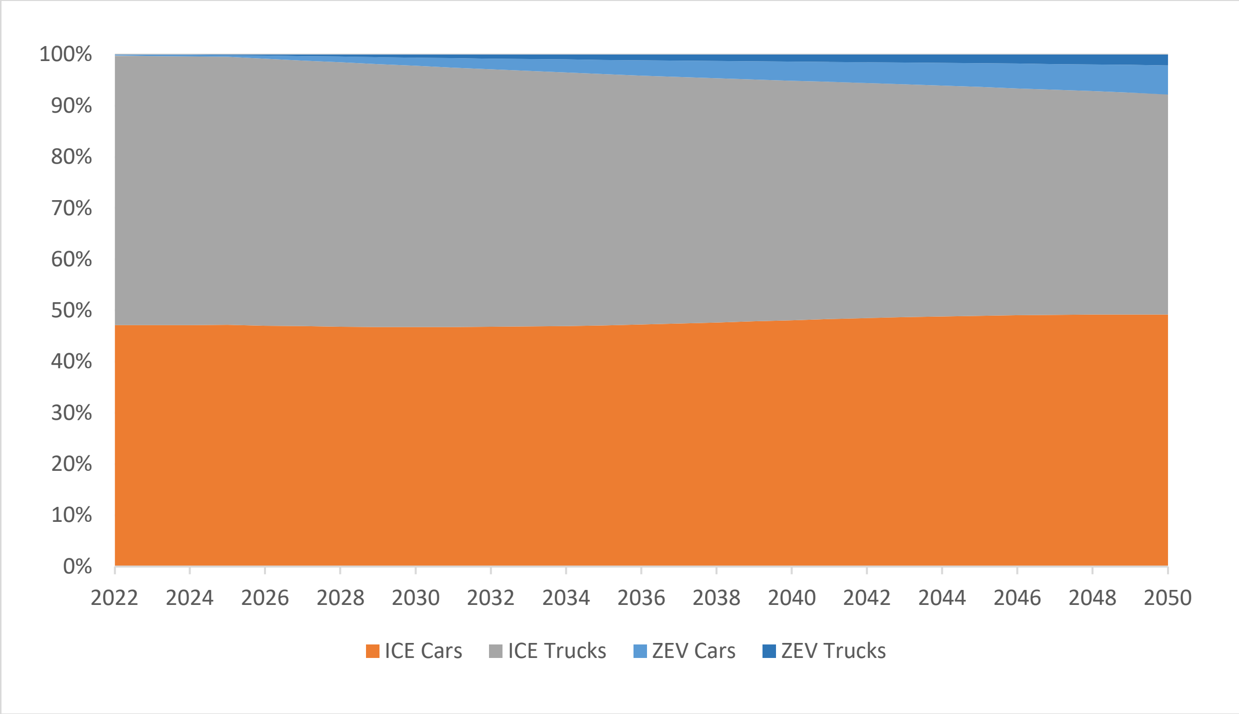


Figure A-11. VMT by Vehicle Type with ZEV Rule Adoption

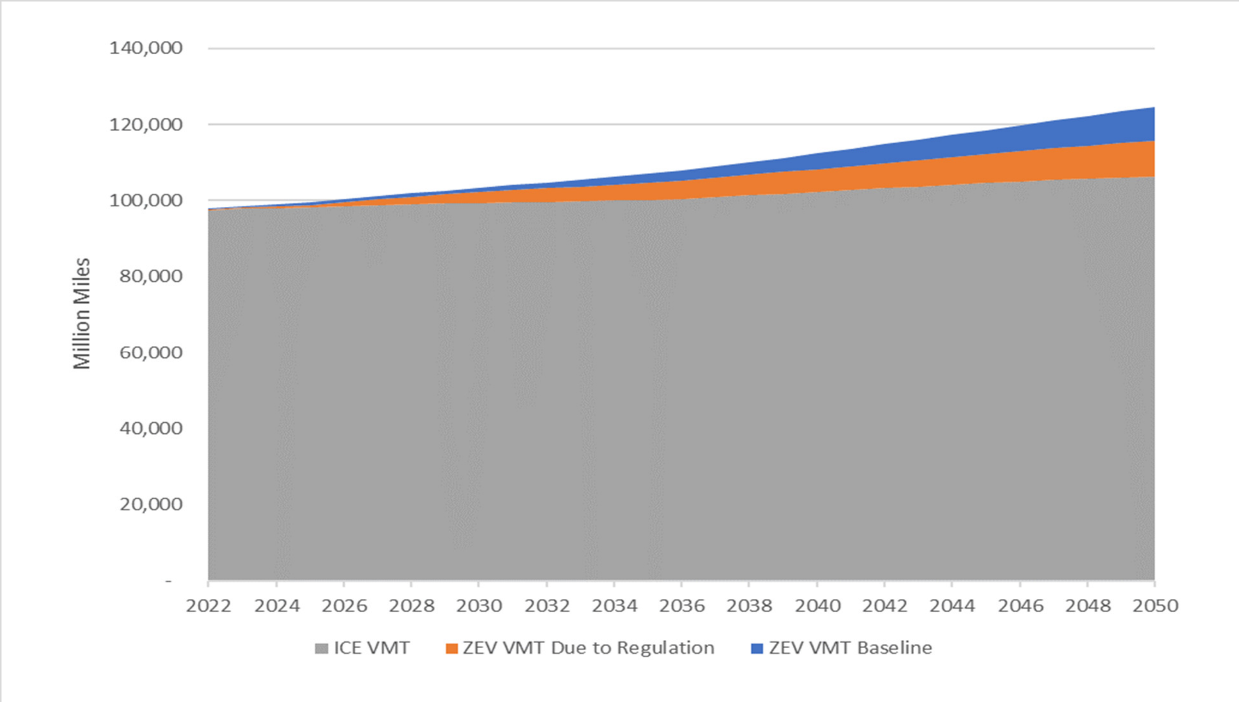


Table A-4. Annual Change in Fuel/Electricity Consumption Through ACC1 Adoption

Year	Million Gallons						GWh		
	Baseline Gasoline Use	ACC1 Adoption Scenario Gasoline Use	ACC1 Adoption Scenario Gasoline Reduction	Baseline Diesel Use	ACC1 Adoption Scenario Diesel Use	ACC1 Adoption Scenario Diesel Reduction	Baseline Electricity Use	ACC1 Adoption Scenario Electricity Use	ACC1 Adoption Scenario Electricity Increase
2026	3,618	3,608	-10	132	132	0	296	452	156
2030	3,400	3,357	-43	141	140	-2	527	1,218	692
2035	3,201	3,138	-63	149	146	-3	1,023	2,027	1,004
2040	3,125	3,073	-52	150	148	-2	1,811	2,643	832
2045	3,101	3,070	-32	152	150	-1	2,804	3,314	510
2050	3,101	3,086	-15	151	150	-1	3,916	4,164	248

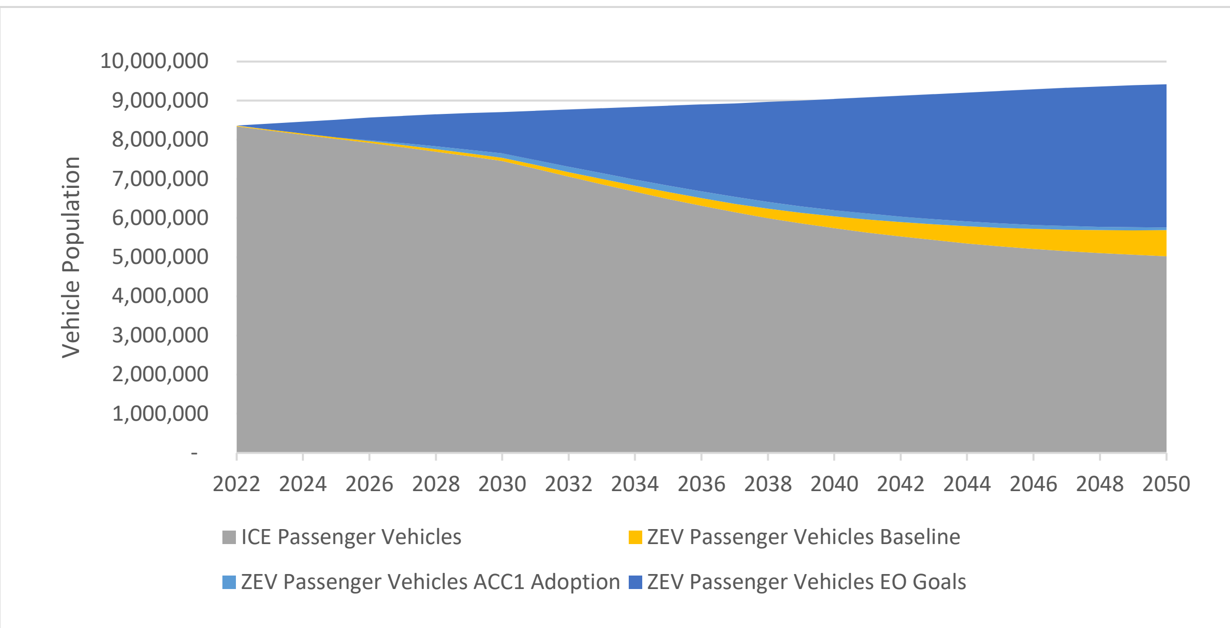
Note: There are additional reductions in Ethanol (E-85) consumption not included in this table

Comparing ACC1 to EO 246 North Carolina's Transformation to a Clean and Equitable Economy

On January 7, 2022, Governor Cooper signed executive order No. 246 (EO 246): North Carolina's Transformation to a Clean and Equitable Economy. EO 246 establishes two transportation goals for NC: to increase the ZEVs registered in NC to 1.25 million by 2030 and increase the portion of in-state sales of ZEVs to 50% by 2030. The goals of EO 245 are much more aggressive than the ZEV requirements set in ACC. If ACC1 was implemented, 6.5% of light-duty sales would be ZEV starting in 2026, but to meet the goals of EO 246, light-duty ZEV sales would need to be 33% by 2026 and 50% of sales by 2030.

Figure A-12. compares the ZEV share of all passenger vehicles in NC, if the goals of the EO 246 are met compared to the ZEV population under implantation of the ACC1 rule.

Figure A-12. Total Light-Duty ZEV Population If EO 246 Goals Are Met Compared to ACC1 Implementation



Environmental Impacts

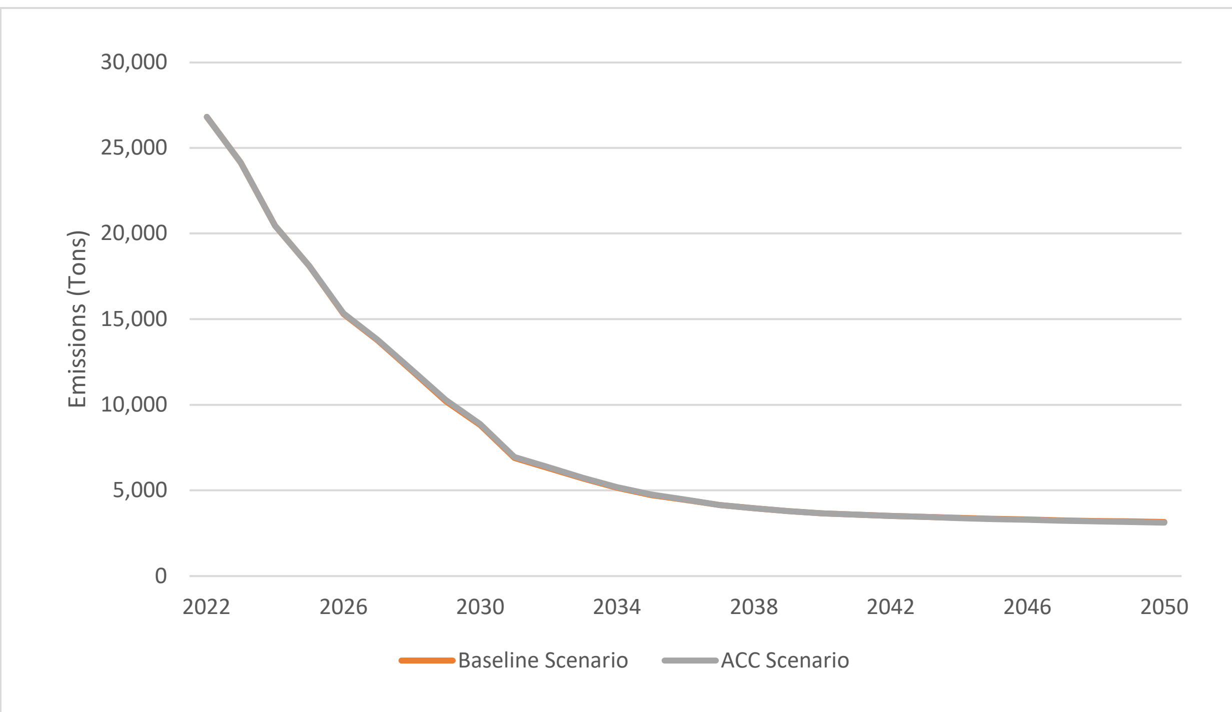
ACC1—Air Quality Impacts

The impact of ACC1 on NO_x emissions are negligible and will mainly be realized through the transition of ICE to ZEV vehicles due to the ZEV rule. The MOVES3 model incorporates the impacts of EPA's Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule, which calls for a substantial reduction in NO_x emissions for ICE vehicles, so RTI did not model additional NO_x reductions due to the ZEV III rule. Table A-5 and Figure A-13. detail the change in NO_x emissions through the shift in vehicle fleet from the ZEV rule.

Table A-5. Annual Change in NO_x Emissions from Passenger Vehicles through ACC1 Adoption

Year	Tons				
	Baseline NO_x Emissions	ICE NO_x Emissions Reduced ACC Rule	Additional NO_x Emissions through Electricity Generation	Net NO_x Emission Change from ACC Rule	ZEV Passenger Vehicle Rule Adoption NO_x Emissions
2026	15,301	-8	21	2	15,303
2030	8,796	-35	59	-22	8,774
2035	4,722	-54	55	-71	4,650
2040	3,630	-49	22	-92	3,538
2045	3,269	-31	2	-72	3,197
2050	2,987	-16	0	-36	2,951

Figure A-13. Projected Annual NO_x Emissions for Passenger Vehicles

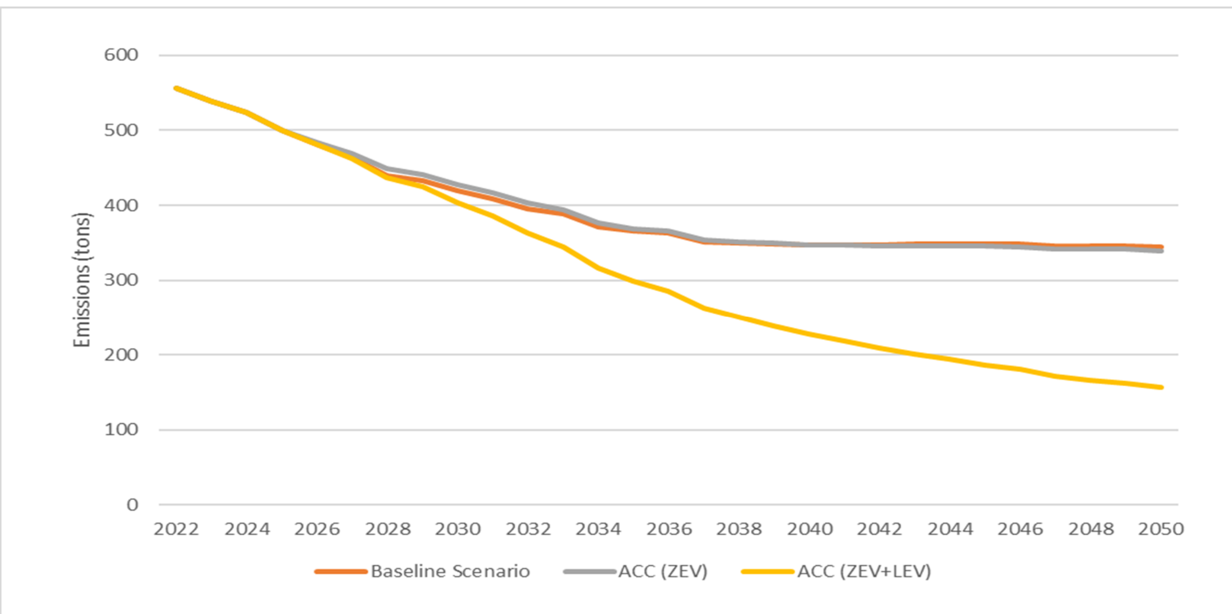


Similar to NO_x emissions, the ZEV rule does not cause a substantial change in $PM_{2.5}$ emissions through the shift of ICE vehicles to ZEV vehicles through 2050. The LEV III rule does set a new limit of $PM_{2.5}$ emissions for passenger vehicles of 0.001 g/mile, which will be phased in from 2025 through 2028.[27] To calculate the potential reduction in $PM_{2.5}$ emissions through the LEVIII rule, RTI applied this updated rate to all vehicles post 2028 that had a $PM_{2.5}$ emission rate above the limit. Table A-6 and Figure A-14. detail the change in $PM_{2.5}$ emissions through the adoption of the ACC1 rule.

Table A-6. Annual Change in $PM_{2.5}$ Emissions from Passenger Vehicles through ACC Adoption

Year	Tons						
	Baseline Emissions	ICE $PM_{2.5}$ Emissions Reduced through ZEV Rule	Additional $PM_{2.5}$ Emissions through Electricity Generation	Net $PM_{2.5}$ Emissions Change from ZEV rule	ZEV Rule Scenario $PM_{2.5}$ Emissions	$PM_{2.5}$ Emissions Reduced through LEV III	ZEV + LEV III Passenger Vehicle Rule Adoption $PM_{2.5}$ Emissions
2026	481	-1	2	1	482	-3	479
2030	417	-3	7	1	418	-23	394
2035	364	-5	7	-5	359	-69	290
2040	344	-6	3	-10	335	-119	215
2045	339	-4	0	-9	329	-159	171
2050	324	-3	0	-6	318	-183	135

Figure A-14. Projected Annual $PM_{2.5}$ Emissions for Passenger Vehicles



[27] Table A-6: LEV III emission standards, durability 150,000 miles, FTP-75 https://dieselnet.com/standards/us/ld_ca.php#leviii

ACC1—Climate Impacts

The LEV III portion of the ACC1 rule plays a much larger role in reducing GHG emissions through 2050 for passenger vehicles. ZEV adoption represents a much smaller contribution to annual GHG reductions. The ZEV requirement accounts for only 5% percent of reduction (~700 thousand tons of CO_2e emissions in 2035 falling to 200,000 tons of annual GHG reductions in 2050). The LEV III rule leads to an increasing annual GHG emission reduction level, up to 14.2 million tons in 2050. The LEV III rule sets a CO_2 emissions standard of 144 g/mile for passenger cars and 200 g/mile for passenger trucks by 2025.[28] RTI applied this emissions standard to all ICE vehicles from model year 2026 onward to calculate the emissions for the ACC adoption scenario. Table A-7 details the annual PTW emissions changes due to the adoption of the ACC rule.

Table A-7. PTW GHG Emissions Reduction through ACC Adoption

Year	Base Case Emissions (tons)	ICE PTW Emissions Reduced through ZEV Rule Base Case Emissions (tons)	Additional ZEV Emissions through Electricity Generation (tons)	Net Emission Reduction from ZEV Rule (tons)	ZEV Passenger Vehicle Rule Adoption Emissions (tons)	Emissions PTW Reduced through LEV III (tons)	ZEV + LEV III Passenger Vehicle Rule Adoption Emissions (tons)
2026	45,914,869	-100,516	37,675	-86,368	45,828,501	-805,489	44,834,478
2030	43,390,271	-445,135	110,151	-439,173	42,951,098	-3,841,888	38,209,971
2035	41,100,454	-646,140	101,837	-695,540	40,404,914	-7,110,338	31,630,318
2040	40,215,943	-536,149	39,859	-621,782	39,594,160	-9,506,168	27,862,961
2045	39,916,257	-328,348	1,335	-403,867	39,512,391	-10,862,749	26,107,088
2050	39,795,444	-158,300	0	-195,352	39,600,093	-11,542,444	25,356,004

Additionally, there are upstream well-to-pump (WTP) GHG emissions benefits to the reduction of gas and diesel fuel used by ICE engines. Table A-8 details the WTP GHG emissions benefits calculated using the WTP emissions factor developed by ICCT.

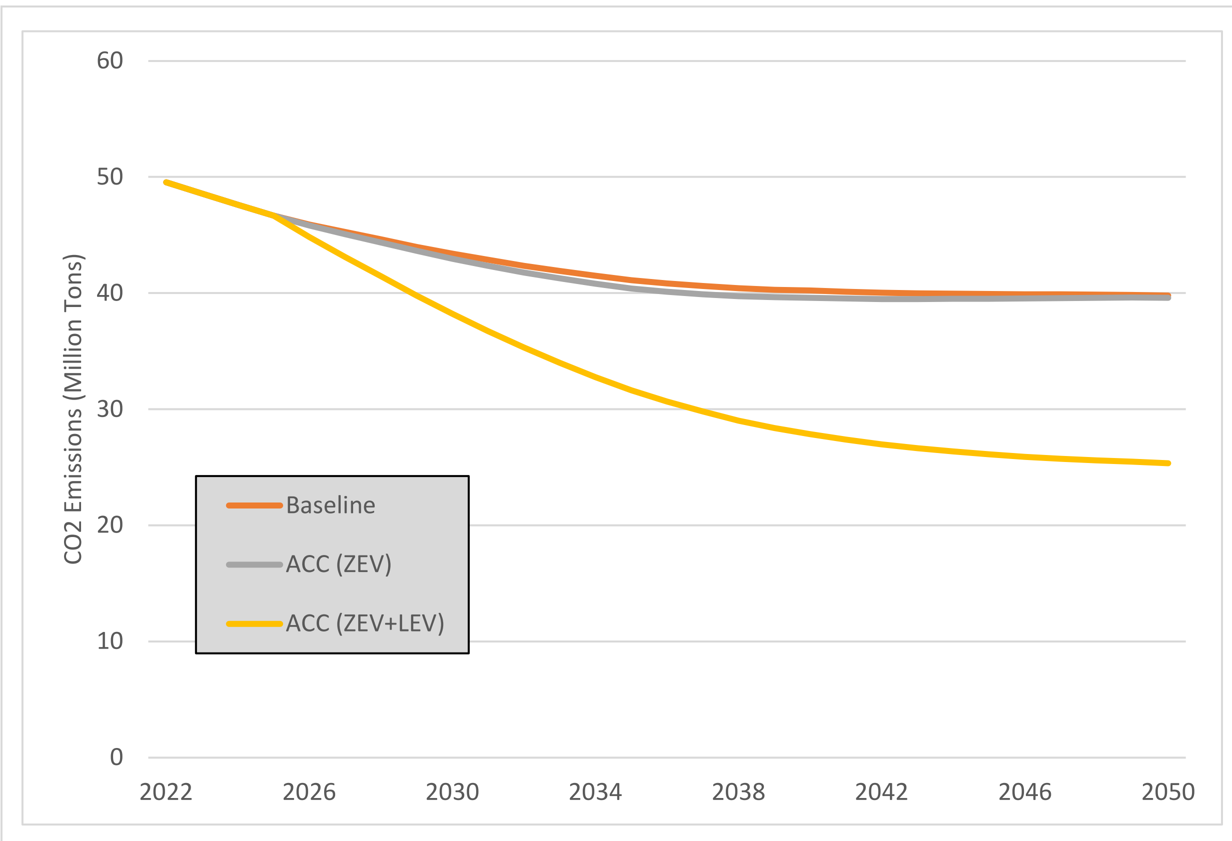
[28] https://www.transportpolicy.net/standard/california-light-duty-ghg/#:~:text=Overview%20For%20cars%20with%20the%20model%20year%20of,4.5%25%20per%20year%20for%20light%20trucks%20through%202025.

Table A-8. Additional WTP GHG Emissions Reduction through ACC1 Adoption

Year	Tons	
	ICE WTP Emissions Reduced Through ZEV Rule	Emissions WTP Reduced Through LEV III
2026	-23,527	-188,534
2030	-104,189	-899,239
2035	-151,237	-1,664,258
2040	-125,492	-2,225,030
2045	-76,854	-2,542,554
2050	-37,052	-2,701,645

Figure A-15. shows the comparison of the projected baseline scenario WTW GHG emissions to the potential policy scenarios.

Figure A-15. WTW Passenger Vehicle GHG Emissions Projections Under ACC1



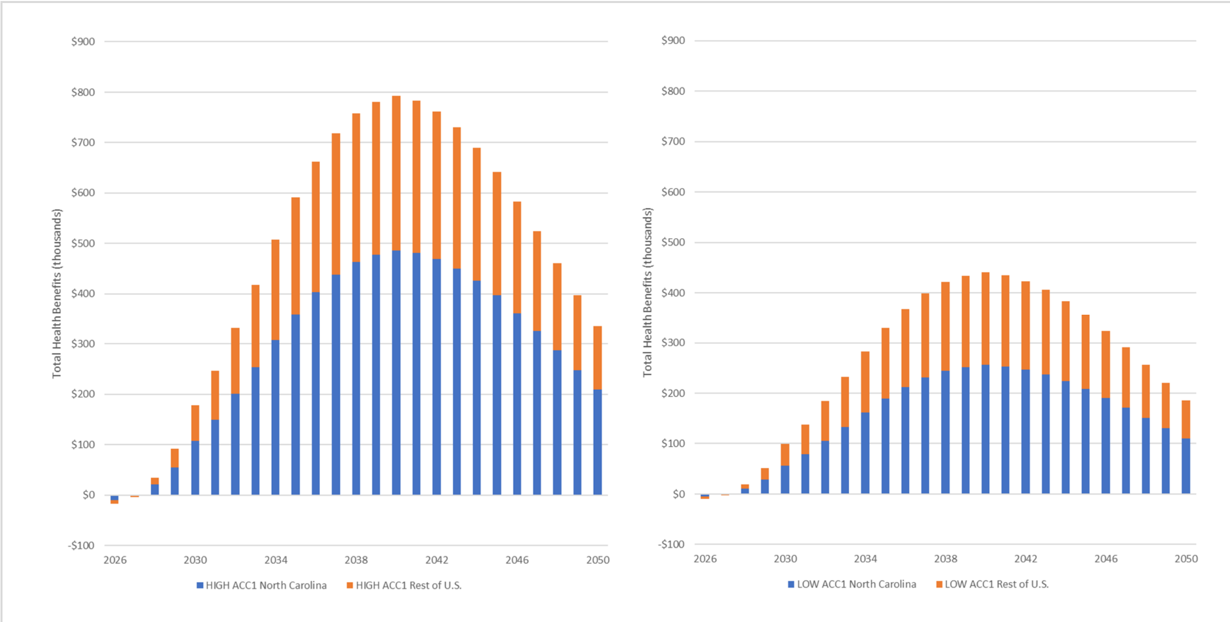
Economic Cost/Savings Analysis

Monetized Health Impacts

ACC1 monetized health impacts are calculated as described in the report under section 5.1.

Figure A-16 shows the high and low estimated health benefits of ACC1.

Figure A-16. Total Health Benefits under ACC1 by Location, High and Low Estimates, 2020–2050



Cumulatively, the ACC1 would result in between $6.7billion and $12 million in health benefits between 2026 and 2050. Table A-9 gives high and low estimates of the cumulative benefits of each policy, within and outside North Carolina.

Table A-9. Cumulative Total Health Benefits of ACC1 within and outside North Carolina, 2020–2050

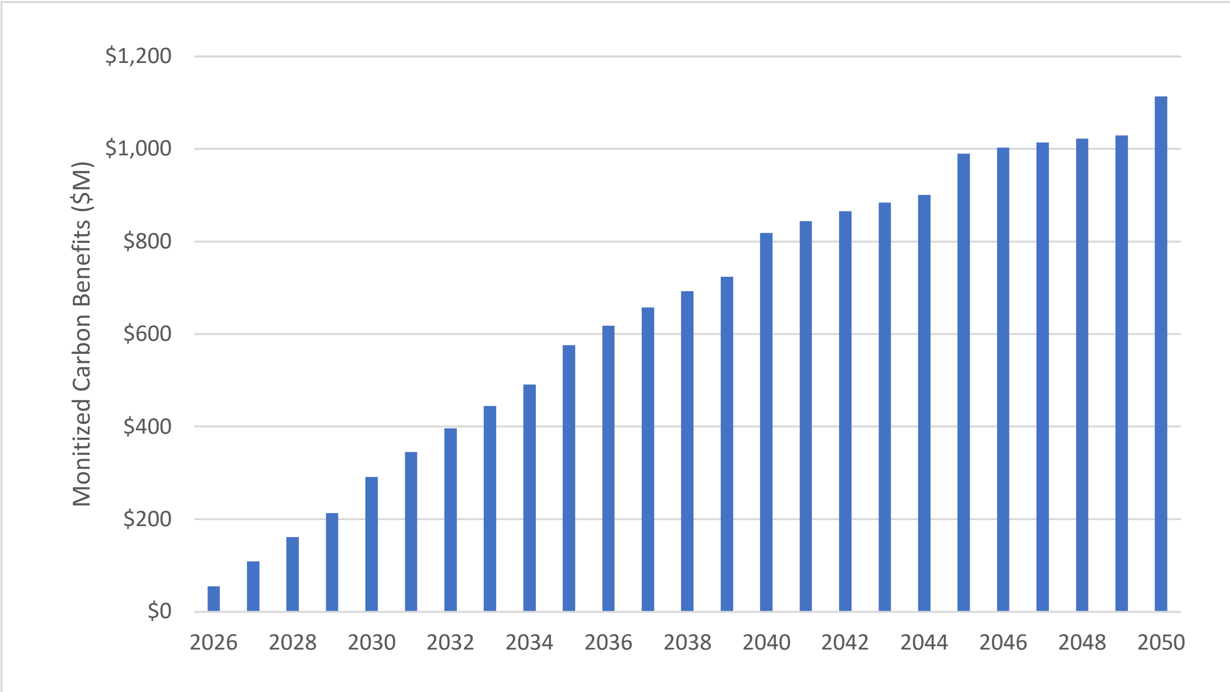
		ACC1
Within NC	*Low estimate*	$3.9 million
	High estimate	$7.4 million
Other States	*Low estimate*	$2.8million
	High estimate	$4.6million

Monetized Climate Benefits

To monetize the climate benefits associated with the GHG emissions reductions under ACC1, we used the Interim Estimates under Executive Order 13990 (2021) for the social cost of carbon, assuming a 3% average discount rate[29]. To calculate the monetized climate benefits RTI multiplied the annual WTW carbon emissions reduced through implementation of the ACC1 by the anticipated social cost of carbon in that year. Figure details the annual monetized climate benefits of ACC1 implementation. By 2050 the benefits exceed $1 billion annually.

[29] Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide. https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf

Figure A-17. Annual Monetized Climate Benefits through ACC1



Owner Economic Costs

Using the estimated incremental change in number of ZEV vehicles outlined in section 4. 1, RTI produced a summary of direct costs and benefits incurred between 2026 and 2050. Costs consisted of higher initial vehicle costs and associated highway use taxes, higher registration and other fees, and initial infrastructure investments. These costs are eclipsed by fuel and maintenance savings and the value of the existing federal ZEV tax credit. **The net present value of this policy is a savings of $695 million using a 7% discount rate.**

The estimated incremental vehicle costs for BEV200 and BEV300 cars and passenger trucks in 2025 and 2030 were provided by the Environmental Defense Fund.[30] The incremental cost for BEV100 cars and trucks was estimated to be half the incremental cost of BEV200 vehicles. The cost per battery type was multiplied by the estimated proportion of the fleet using each battery size by year. Vehicle cost declines between 2025 and 2030 were made by taking the absolute reduction and apportioning it equally by year. After 2030, no additional vehicle cost declines were assumed.

Due to higher initial costs, electric vehicles generate more Highway Use Tax, which is equivalent to a 3% sales tax on the total purchase price. In addition, ZEV in North Carolina are assessed $130 more in registration and other fees each year.[31]

Infrastructure costs consist of vehicle chargers, installation costs and an annual maintenance expense. The initial cost of a vehicle charger was estimated at $500 per vehicle and installation costs were

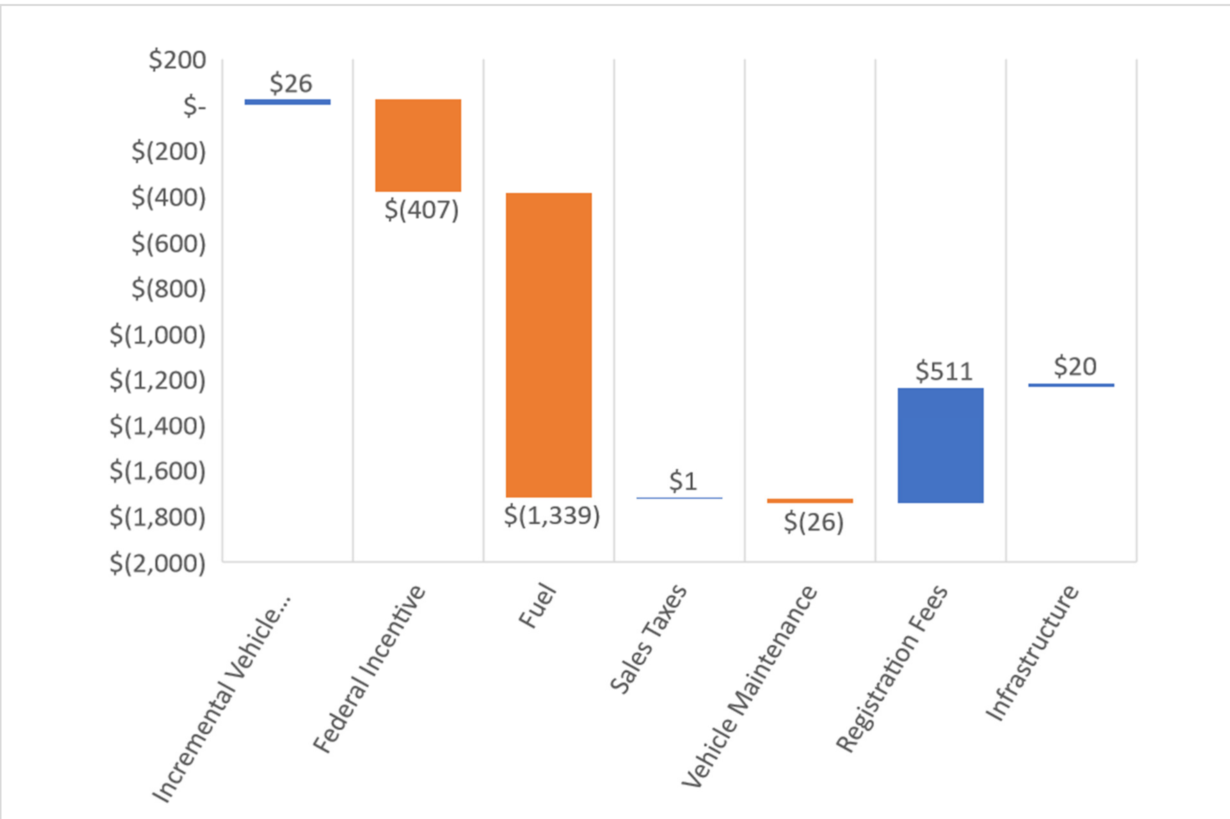
[30] Environmental Defense Fund. Unpublished material conveyed in personal communication. January 31, 2022.
[31] NC First Commission "Revenue Impact from Electric and Hybrid Vehicles" Issue brief Edition 8, May 2020. Page 1. https://www.ncdot.gov/about-us/how-we-operate/finance-budget/nc-first/Documents/nc-first-brief-edition-8.pdf

estimated at $1,250 per vehicle. In addition, the infrastructure, installation, and maintenance costs include a $5 per unit annual maintenance cost for home chargers.[32]

Benefits consisted of lower fuel costs, reduced maintenance costs, and the federal tax credit for ZEV. The net fuel benefits were calculated using the 2021 AEO projections for fuel and electricity costs in the South Atlantic region. Fuel costs are the change between using less gasoline and diesel fuel and more electricity. Maintenance costs were estimated to be 26% less for ZEV than ICEs. This was based on an AAA 2021 cost comparison of operating an electric car with a mid-sized sedan.[33] The same cost reduction percentage was applied to passenger trucks. For this analysis, the federal ZEV tax credit of $7,500 continues until 2030. Since the tax credit does not carry over into future years and is non-refundable, each vehicle was awarded $3,750 in credit.

Aggregate information about the value of specific costs and benefits is presented in Figure A-18.

Figure A-18. Undiscounted Cumulative Total Costs and Savings by Category for ACC1



The net present value of this policy is a savings of $695 million using a seven percent discount rate. The cost savings provided by lower fuel and maintenance costs, coupled with the federal tax incentive

---

[32] California Air Resources Board. "Attachment C: Updated Costs and Benefits Analysis for the Proposed Advanced Clean Trucks Regulation" Page 11. 2019. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/30dayattc.pdf

[33] AAA (Triple A) "Your Driving Costs 2021" comparison of medium sedan and electric vehicle driving 15,000 per year. Rate per mile for electric vehicle is 7.7 cents and 10.4 cents per conventional car. https://newsroom.aaa.com/wp-content/uploads/2021/08/2021-YDC-Brochure-Live.pdf

for purchasing electric vehicles, outweigh the higher vehicle purchase prices, infrastructure costs, sales taxes, and registration fees. A yearly summary of costs and benefits to presented in Appendix.

Supplemental Information on the Health Benefits Modeling

COBRA Modeling Results Detail

This section provides additional detail on the modeled health impacts obtained from COBRA.

COBRA includes baseline data gathered for the years 2016, 2023, and 2028; for this analysis, we modeled each scenario in the year 2028. Highway vehicle and electric utility emissions changes took place in North Carolina, with results available at the county level inside and outside the state. Upstream emission reductions are assumed to occur outside of North Carolina. In practice, it is reasonable to assume that a percentage of the upstream benefits occur inside the state. However, modeling the precise location of all upstream emissions was outside the scope of this analysis.

Table A-10 shows the changes in emissions used as inputs to COBRA.

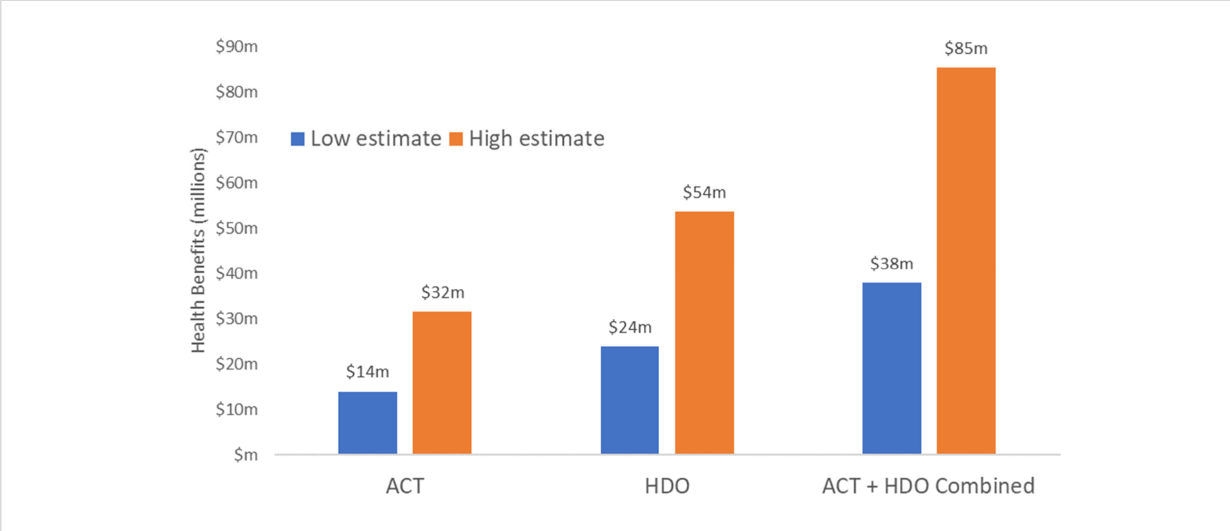
Table A-10. COBRA Inputs for Modeled Year 2028

Policy	Emissions (*change in tons*)					
	Highway		Power Sector		Upstream	
	NO_x	*$PM_{2.5}$*	*NO_x*	*$PM_{2.5}$*	*NO_x*	*$PM_{2.5}$*
ACT	-881.89	-6.55	102.97	12.32	-304.07	-8.16
HDO	-1,713.16	0.00	0.00	0.00	0.00	0.00

Inputs for HB951 GRID Scenario (net-zero). For BAU scenario inputs.

Figure A-19 presents the results of health benefits from COBRA model runs for modeled year 2028. We found that the ACT and HDO scenarios combined would result in $38 million and $85.7 million in health benefits. If implemented alone, ACT would generate an estimated $14 to $32 million in health benefits, while HDO would generate $24 to $54 million in health benefits. Readers should note that the benefits reported in figure A-19 below reflect the relative change in emission from ACT and HDO in the year 2028. Moving out in time, as presented in the body of the report, the health impacts from electrification under ACT quickly outweigh HDO, becoming the largest contribution to total health impacts in the early 2030s.

Figure A-19. Total Health Benefits by Scenario for 2028



The total monetary value of health benefits is based on the number of health outcomes avoided or added in each scenario. Table A-11 provides an overview of the number of each type of health outcome avoided by reduced emissions. We estimate the combined ACT and HDO policies would, in 2028, save between three and seven lives; avoid up to three heart attacks, three hospital admissions, and 226 cases of acute bronchitis, asthma exacerbation, and upper and lower respiratory symptoms; and prevent the loss of more than 546 workdays.

Table A-11. Annual Avoided Negative Health Outcomes by Policy

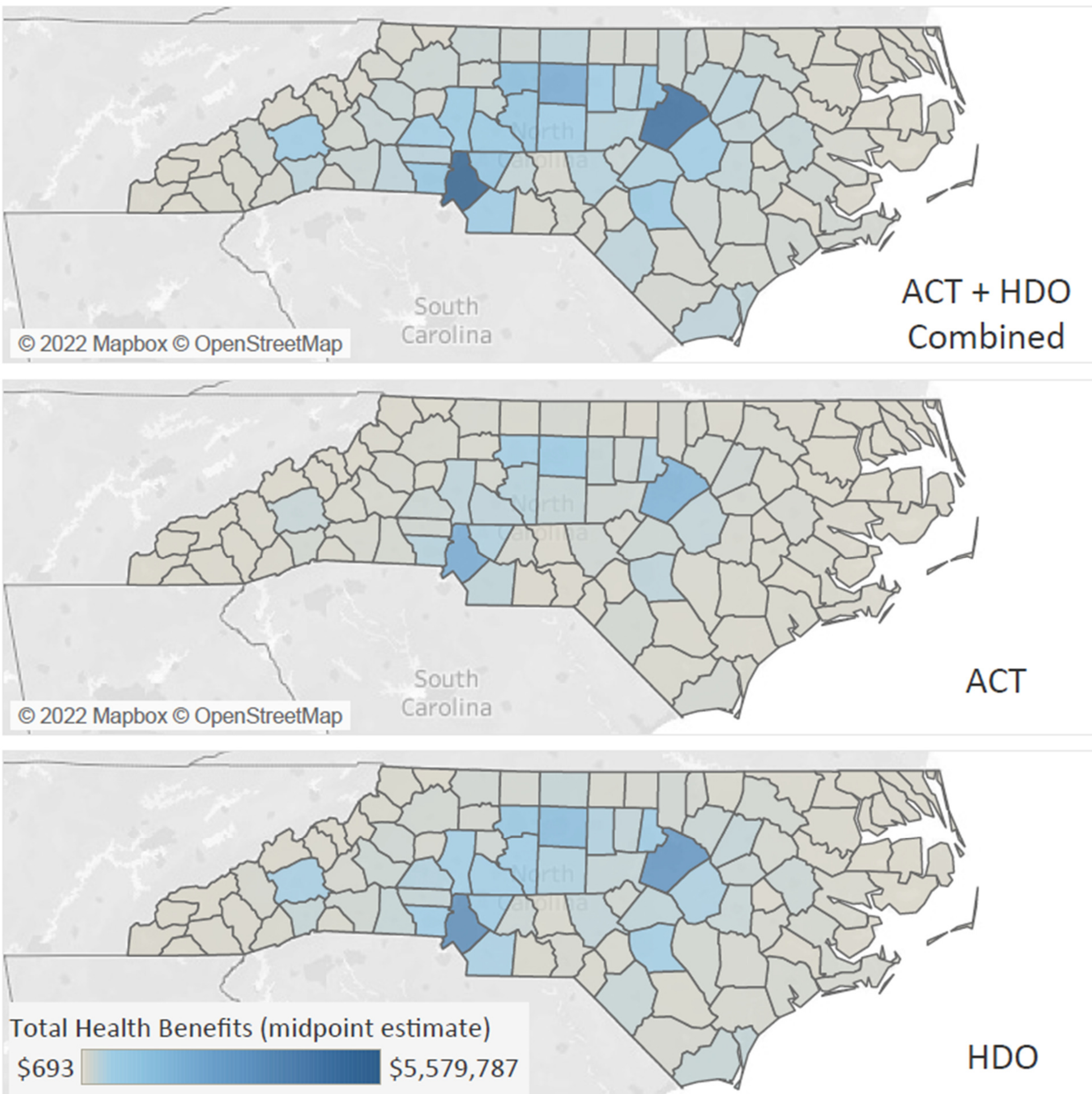
	Policy					
	ACT		HDO		ACT + HDO Combined	
Health Outcome	*Low estimate*	*High estimate*	*Low estimate*	*High estimate*	*Low estimate*	*High estimate*
Mortality	1.22	2.77	2.08	4.71	3.31	7.48
Infant mortality	0.01		0.02		0.03	
Non-fatal heart attacks	0.14	1.27	0.23	2.17	0.37	3.44
Cardiovascular hospital admissions (except heart attacks)	0.33		0.56		0.88	
Respiratory hospital admissions (asthma, chronic lung disease)	0.32		0.55		0.87	
Emergency room visits for asthma	0.69		1.16		1.86	
Asthma exacerbation	31.24		51.54		82.79	
Acute bronchitis	1.70		2.80		4.50	
Upper and lower respiratory symptoms	52.43		86.38		138.81	
Work loss days	148.49		396.92		545.41	
Minor restricted activity days	872.65		2,333.18		3,205.84	

Geographic Variation of Health Impacts

Health benefits varied across North Carolina counties. Benefits were highest in densely populated areas of the Triangle, Triad, and Charlotte, where larger numbers of people would experience the health impacts of air quality changes. Health benefits under each scenario are positive in every county; in the combined scenario, it ranges from a few thousand dollars in smaller counties to $5.6 million in Mecklenburg County.

Figure A-20 illustrates the midpoint between the high and low estimated benefits occurring in each NC county under the three scenarios.

Figure A-20. Total Health Benefits by NC County Under Each Policy Scenario



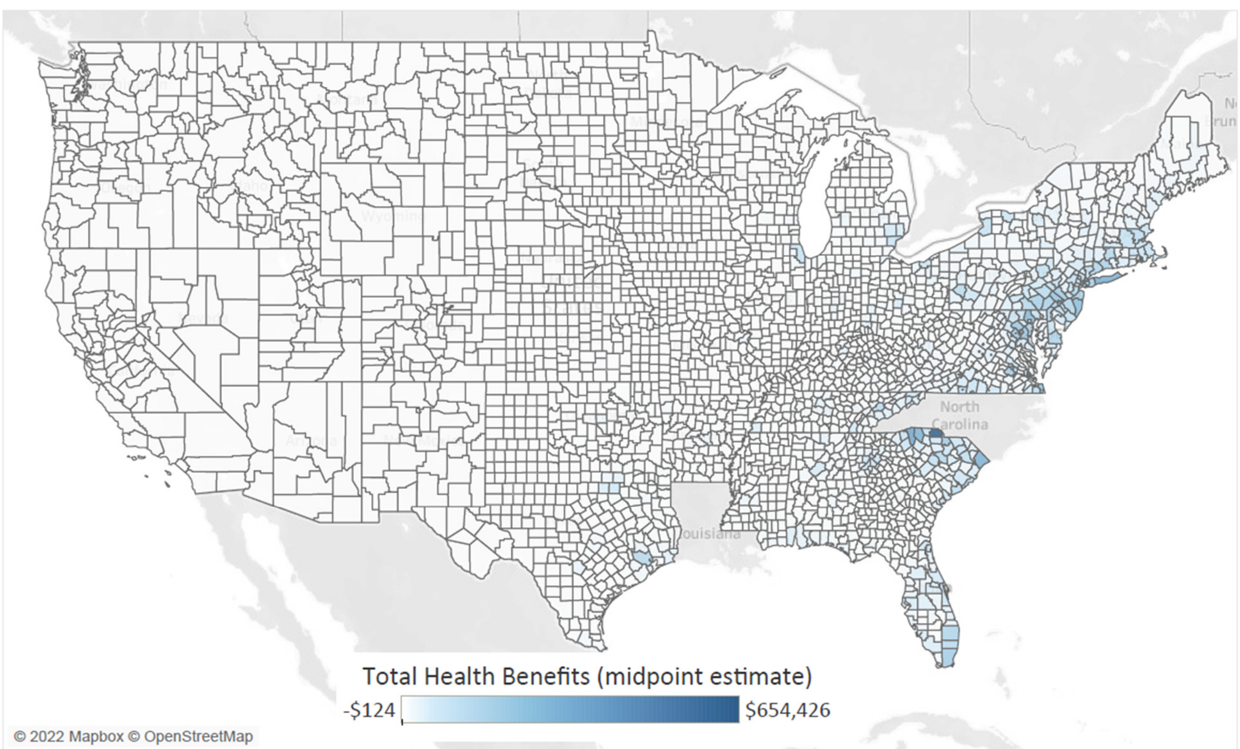
In addition, although we modeled policy changes only in specific states, the air quality improvements within the state would also impact health outcomes in neighboring states. In the ACT and HDO scenarios, 50% and 55% of benefits occurred within North Carolina, respectively. Table A-12 reports high and low estimates of benefits accruing in North Carolina and in other states.

Table A-12. Total Health Benefits within and outside North Carolina

		ACT	HDO	ACT + HDO Combined
Within NC	*Low estimate*	$7,125,130	$13,315,724	$20,440,855
	High estimate	$16,046,465	$29,991,303	$46,037,768
Rest of USA	*Low estimate*	$6,921,938	$10,675,689	$17,597,628
	High estimate	$15,602,874	$24,066,293	$39,669,167

Figure A-21 illustrates the midpoint between high and low benefits estimates for all areas outside of North Carolina, under the two combined policies. Outside these two states, benefits are highest in counties adjacent to North Carolina; for example, York County, SC, would experience more than $654,000 in health benefits. Dense urban areas along the east coast, including counties that include the cities of Miami, Washington, DC, New York, and Boston, and cities further west (e.g., Chicago and Houston) also see larger benefits. Outside these areas, estimated benefits are small, but non-zero health benefits occur under this scenario in nearly all counties in the United States.

Figure A-21. Midpoint Estimate of Benefits Occurring outside of North Carolina and Louisiana



Health Impacts for BAU Grid Mix Scenario

This section includes inputs and results from COBRA modeling (discussed in section 4.3) for the BAU scenario, rather than the HB 951 scenarios discussed in the body of this report. The HB 951 scenarios involve decarbonizing the electrical grid, so the BAU scenarios involves more emissions from electricity generation and, thus, reduced health benefits. HDO inputs and results do not change between the HB 951 and BAU scenarios.

This Appendix also reports inputs and results for the ACC I (Passenger ZEV/LEV) scenario.

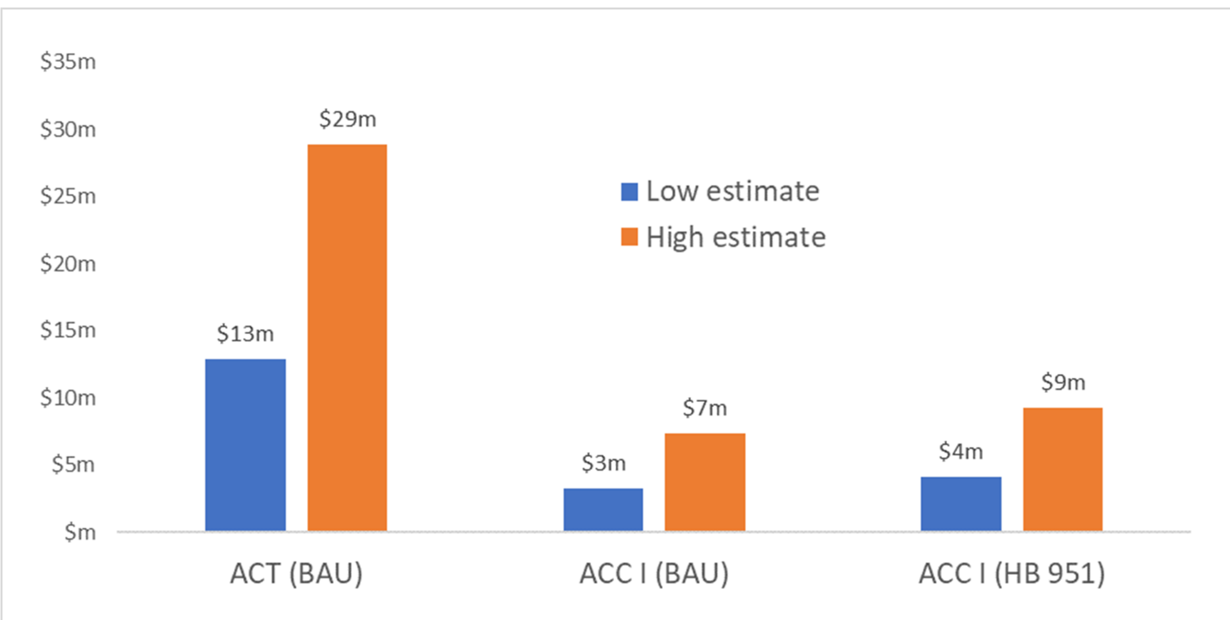
Table A-13 gives the inputs used for modeling these policy scenarios.

Table A-13. COBRA Inputs for ACC I and BAU Scenarios

Policy	Emissions *(change in tons)*					
	Highway		Power Sector		Upstream	
	NO_x	$PM_{2.5}$	NO_x	$PM_{2.5}$	NO_x	$PM_{2.5}$
ACT (BAU)	-881.89	-6.55	160.86	19.25	-314.33	-8.16
ACC I (BAU)	-22.43	-13.32	85.91	10.28	-30.16	-15.18
ACC I (HB 951)	-22.43	-13.32	48.22	5.77	-30.16	-15.18

Figure A-22 shows high and low estimates of total benefits in these scenarios.

Figure A-22. Total Health Benefits for ACC I and BAU Scenarios



Avoided negative health outcomes for each policy are shown in Table A-14.

Table A-14. Avoided Negative Health Outcomes for ACC I and BAU Scenarios

	Policy					
	ACT (BAU)		ACC I (BAU)		ACC I (HB 951)	
Health Outcome	*Low estimate*	*High estimate*	*Low estimate*	*High estimate*	*Low estimate*	*High estimate*
Mortality	1.12	2.53	0.28	0.64	0.36	0.81
Infant mortality	0.01		0.00		0.00	
Non-fatal heart attacks	0.13	1.17	0.03	0.29	0.04	0.37
Cardiovascular hospital admissions (except heart attacks)	0.30		0.08		0.09	
Respiratory hospital admissions (asthma, chronic lung disease)	0.29		0.07		0.09	
Emergency room visits for asthma	0.64		0.17		0.21	
Asthma exacerbation	28.91		8.09		9.69	
Acute bronchitis	1.57		0.44		0.53	
Upper and lower respiratory symptoms	48.53		13.62		16.29	
Work loss days	137.22		37.74		45.43	
Minor restricted activity days	806.19		221.27		266.63	

Distribution of health impacts within and outside of NC state borders are displayed in Table A-15. More than half of benefits are accrued within the state in each scenario.

Table A-15. Total Health Benefits within and outside North Carolina for ACC I and BAU Scenarios

		ACT (BAU)	ACC I (BAU)	ACC I (HB 951)
Within NC	*Low estimate*	$6,565,441	$1,967,255	$2,331,712
	High estimate	$14,785,094	$4,429,108	$5,250,489
Rest of USA	*Low estimate*	$6,264,188	$1,305,089	$1,769,425
	High estimate	$14,120,106	$2,940,788	$3,987,527

Future benefits projections for the year 2050, and projected cumulative benefits between 2020 and 2050, are displayed in Table A-16 and Table A-17.

Table A-16. Total Health Benefits within and outside North Carolina, Year 2050, for ACC I and BAU Scenarios

		ACT (BAU)	ACC I (BAU)	ACC I (HB 951)
Within NC	*Low estimate*	$2.51 billion	$131,709	$109,978
	High estimate	$5.65 billion	$296,532	$208,905
Other states	*Low estimate*	$2.17 billion	$79,220	$75,666
	High estimate	$4.90 billion	$178,508	$125,758

Table A-17. Cumulative Total Health Benefits within and outside North Carolina, 2020–2050, for ACC I and BAU Scenarios

		ACT (BAU)	ACC I (BAU)	ACC I (HB 951)
Within NC	*Low estimate*	$31.3 billion	$2.18 million	$3.88 million
	High estimate	$70.6 billion	$4.92 million	$7.37 million
Other states	*Low estimate*	$28.0 billion	$1.36 million	$2.79 million
	High estimate	$63.2 billion	$3.06 million	$4.64 million

Economic Cost Analysis Tables

This appendix provides the timeseries of owner benefit/costs estimates for ACT, HDO and ACC1.

Table A-18. Summary of Economic Benefit Costs under ACT

Year	ZEV Price (cost)	Highway Use and Excise Taxes (cost)	Fuel Savings (savings)	Vehicle Maintenance (savings)	Maintenance Bay Upgrade (cost)	Midlife Costs (cost)	EVSE and Infrastructure (cost)	Transitional Costs and Workforce Dev. (cost)	Registration Fees (cost)	ACT Net Cost
2026	$95,095,720	$6,306,233	($18,983,018)	($5,738,422)	$3,292,145	$0	$13,063,166	$2,377,393	$469,861	**$95,883,078**
2027	$132,014,114	$8,650,097	($46,164,723)	($14,525,932)	$5,038,235	$0	$33,621,367	$3,300,353	$1,187,595	**$123,121,106**
2028	$171,005,105	$10,762,270	($88,858,623)	($27,268,532)	$7,280,213	$0	$63,435,814	$4,275,128	$2,217,815	**$142,849,189**
2029	$203,084,150	$12,500,798	($145,398,847)	($44,075,094)	$9,582,423	$0	$102,755,945	$5,077,104	$3,568,637	**$147,095,117**
2030	$228,597,130	$13,875,693	($224,269,134)	($65,227,229)	$12,043,940	$0	$152,222,515	$5,714,928	$5,262,049	**$128,219,893**
2031	$286,280,841	$16,311,481	($309,794,640)	($89,391,855)	$13,797,557	$0	$208,802,994	$7,157,021	$7,207,556	**$140,370,957**
2032	$303,483,543	$17,414,504	($417,841,553)	($140,622,069)	$15,509,130	$0	$272,375,763	$7,587,089	$9,398,937	**$67,305,344**
2033	$311,622,608	$17,205,332	($523,121,951)	($170,250,010)	$17,095,071	$13,769,148	$341,645,099	$0	$11,821,292	**$19,786,589**
2034	$320,152,402	$17,071,355	($646,165,842)	($202,632,009)	$18,819,786	$20,429,616	$417,159,018	$0	$14,494,255	**($40,671,419)**
2035	$324,387,290	$16,730,010	($767,392,456)	($237,523,637)	$20,412,518	$26,794,908	$498,366,007	$0	$17,399,515	**($100,825,846)**
2036	$308,595,875	$15,798,490	($898,084,748)	($272,794,669)	$20,641,932	$33,250,546	$580,730,841	$0	$20,336,726	**($191,525,008)**
2037	$295,892,688	$15,057,147	($1,024,919,280)	($308,722,417)	$21,029,338	$40,042,057	$664,573,792	$0	$23,328,224	**($273,718,450)**
2038	$284,381,729	$14,396,703	($1,158,955,694)	($345,400,936)	$21,467,474	$46,878,963	$750,138,430	$0	$26,380,959	**($360,712,372)**
2039	$272,405,595	$13,717,615	($1,262,500,421)	($382,712,537)	$21,839,596	$53,661,385	$837,161,104	$0	$29,485,779	**($416,941,883)**
2040	$260,733,324	$13,050,582	($1,395,748,333)	($420,633,367)	$22,202,084	$53,972,272	$925,571,482	$0	$32,641,551	**($508,210,405)**
2041	$249,748,386	$12,426,982	($1,510,665,369)	($459,194,894)	$22,583,437	$54,568,093	$1,015,441,025	$0	$35,851,009	**($579,241,331)**
2042	$239,097,329	$11,839,353	($1,606,144,786)	($498,380,374)	$22,949,877	$54,409,608	$1,106,747,101	$0	$39,111,759	**($630,370,133)**
2043	$229,332,893	$11,300,368	($1,708,733,671)	($538,267,901)	$23,362,833	$54,096,358	$1,199,656,658	$0	$42,430,462	**($686,822,001)**
2044	$220,026,616	$10,771,857	($1,786,660,369)	($578,875,406)	$23,793,797	$54,379,591	$1,294,201,020	$0	$45,810,020	**($716,552,873)**
2045	$211,020,150	$10,267,711	($1,837,262,937)	($620,195,346)	$24,217,653	$54,901,027	$1,390,375,722	$0	$49,249,213	**($717,426,807)**
2046	$201,599,224	$9,738,118	($1,952,515,601)	($662,062,567)	$24,554,135	$55,220,786	$1,475,477,590	$0	$52,736,271	**($795,252,043)**
2047	$192,515,104	$9,241,504	($2,020,960,608)	($704,460,276)	$24,874,009	$55,388,820	$1,555,274,287	$0	$56,268,408	**($831,858,753)**
2048	$183,255,523	$8,740,741	($2,095,448,741)	($747,252,167)	$25,113,584	$55,610,405	$1,627,605,230	$0	$59,834,134	**($882,541,291)**
2049	$174,927,582	$8,284,731	($2,150,869,652)	($790,552,719)	$25,423,545	$55,945,798	$1,692,477,293	$0	$63,443,589	**($920,919,834)**
2050	$166,827,929	$7,847,570	($2,230,971,764)	($834,319,104)	$25,706,680	$56,378,601	$1,749,221,173	$0	$67,092,856	**($992,216,059)**
									Cumulative Total (millions)	**($8,781)**
									NPV(@7%) (millions)	**($2,030)**

Table A-19. Summary of Economic Benefit Costs under HDO

Year	New Technology Hardware	In Use Amendments	Lengthened Warranty	Durability Demonstration	EWR and Corrective Action Amendments	Manufacturers Cost	Annual DEF Consumption	HDO Total Cost
2026	$46,056,259	$200,844	$0	$17,982,457	$62,079,163	$126,318,723	$1,459,533	**$254,096,978**
2027	$161,746,116	$64,274	$0	$3,600,607	$57,884,751	$223,295,748	$3,094,692	**$449,686,188**
2028	$106,544,686	$58,550	$11,195,717	$941,137	$62,449,448	$181,189,538	$4,581,012	**$366,960,089**
2029	$77,207,166	$52,971	$10,032,137	$1,251,080	$55,986,705	$144,530,059	$5,923,550	**$294,983,668**
2030	$69,645,699	$47,749	$8,928,749	$13,568,737	$49,890,125	$142,081,060	$7,131,852	**$291,293,972**
2031	$91,398,094	$44,606	$8,326,410	$2,272,486	$46,446,691	$148,488,288	$8,258,449	**$305,235,024**
2032	$84,427,789	$41,018	$22,540,962	$1,749,044	$35,312,328	$144,071,141	$9,293,255	**$297,435,537**
2033	$61,918,803	$38,089	$20,807,927	$1,616,041	$32,807,347	$117,188,207	$10,262,769	**$244,639,182**
2034	$57,458,230	$35,182	$19,077,060	$1,644,747	$30,319,609	$108,534,828	$11,168,018	**$228,237,675**
2035	$52,589,976	$31,789	$17,072,543	$1,536,541	$27,400,135	$98,630,985	$11,996,175	**$209,258,144**
2036	$51,600,989	$32,025	$17,216,481	$1,575,331	$27,594,656	$98,019,483	$12,828,809	**$208,867,774**
2037	$52,165,812	$32,519	$17,498,015	$1,634,367	$28,017,026	$99,347,739	$13,673,091	**$212,368,570**
2038	$52,991,713	$33,093	$17,822,866	$1,686,677	$28,513,097	$101,047,446	$14,531,428	**$216,626,319**
2039	$53,811,355	$33,571	$18,094,548	$1,738,012	$28,922,735	$102,600,221	$15,401,151	**$220,601,593**
2040	$54,557,459	$34,029	$18,355,886	$1,781,632	$29,310,680	$104,039,686	$16,281,391	**$224,360,764**
2041	$55,293,288	$34,519	$18,633,790	$1,828,467	$29,725,326	$105,515,391	$17,172,958	**$228,203,740**
2042	$56,007,582	$34,991	$18,902,195	$1,871,869	$30,130,923	$106,947,560	$18,075,836	**$231,970,957**
2043	$56,817,957	$35,535	$19,208,922	$1,903,985	$30,596,945	$108,563,343	$18,991,807	**$236,118,493**
2044	$57,720,123	$36,091	$19,523,880	$1,952,252	$31,065,539	$110,297,885	$19,920,512	**$240,516,281**
2045	$58,551,618	$36,633	$19,831,834	$1,990,910	$31,524,501	$111,935,496	$20,861,733	**$244,732,726**
2046	$59,297,707	$37,046	$20,068,175	$2,026,848	$31,861,646	$113,291,422	$21,811,484	**$248,394,328**
2047	$59,857,602	$37,435	$20,292,195	$2,063,853	$32,185,729	$114,436,815	$22,769,656	**$251,643,285**
2048	$60,319,373	$37,697	$20,448,152	$2,096,418	$32,400,475	$115,302,114	$23,732,943	**$254,337,171**
2049	$60,814,682	$38,057	$20,658,592	$2,132,765	$32,697,029	$116,341,125	$24,703,590	**$257,385,839**
2050	$61,300,259	$38,378	$20,847,473	$2,171,087	$32,961,017	$117,318,213	$25,680,697	**$260,317,124**
							Cumulative Total (millions)	**$6,478**
							NPV(@7%) (millions)	**$3,194**

Table A-20. Summary of Economic Benefit Costs under ACC1

Year	Incremental Vehicle Cost	Federal Incentive	Fuel	Sales Taxes	Vehicle Maintenance	Annual Registration Fees	EV Infrastructure, Installation, and Maintenance	ACC1 Net Total
2026	$34,993,736	($88,227,791)	($8,574,621)	$1,049,812	($9,204,068)	$3,058,563	$117,637	**($66,786,730)**
2027	$23,045,610	($86,208,531)	($17,144,420)	$691,368	($2,319,151)	$6,047,126	$232,582	**($75,655,417)**
2028	$11,661,286	($82,497,713)	($26,610,019)	$349,839	($2,247,565)	$8,907,047	$342,579	**($90,094,548)**
2029	$903,016	($77,942,735)	($35,362,533)	$27,090	($2,114,179)	$11,609,061	$446,502	**($102,433,777)**
2030	($8,408,679)	($72,590,551)	($45,764,434)	($252,260)	($1,981,153)	$14,125,534	$543,290	**($114,328,254)**
2031	($7,863,963)	$0	($53,199,404)	($235,919)	($1,807,006)	$16,446,479	$632,557	**($46,027,256)**
2032	($6,986,298)	$0	($61,774,457)	($209,589)	($1,601,979)	$18,509,223	$711,893	**($51,351,207)**
2033	($6,124,124)	$0	($67,409,093)	($183,724)	($1,373,520)	$20,296,785	$780,646	**($54,013,029)**
2034	($5,188,470)	$0	($72,895,392)	($155,654)	($1,143,716)	$21,798,441	$838,402	**($56,746,389)**
2035	($4,156,587)	$0	($76,280,424)	($124,698)	($896,692)	$22,988,583	$884,176	**($57,585,641)**
2036	($3,050,360)	$0	($79,523,698)	($91,511)	($645,674)	$23,853,931	$917,459	**($58,539,853)**
2037	($1,883,047)	$0	($80,636,487)	($56,491)	($393,714)	$24,385,305	$937,896	**($57,646,539)**
2038	($660,449)	$0	($80,223,468)	($19,813)	($136,263)	$24,570,570	$945,022	**($55,524,403)**
2039	$0	$0	($76,420,278)	$0	$0	$24,570,570	$945,022	**($50,904,686)**
2040	$0	$0	($74,653,129)	$0	$0	$24,570,570	$945,022	**($49,137,537)**
2041	$0	$0	($71,244,935)	$0	$0	$24,570,570	$945,022	**($45,729,343)**
2042	$0	$0	($66,905,255)	$0	$0	$24,570,570	$945,022	**($41,389,663)**
2043	$0	$0	($62,042,749)	$0	$0	$24,570,570	$945,022	**($36,527,158)**
2044	$0	$0	($56,486,028)	$0	$0	$24,570,570	$945,022	**($30,970,436)**
2045	$0	$0	($49,781,888)	$0	$0	$24,570,570	$945,022	**($24,266,297)**
2046	$0	$0	($45,386,838)	$0	$0	$24,570,570	$945,022	**($19,871,246)**
2047	$0	$0	($40,145,051)	$0	$0	$24,570,570	$945,022	**($14,629,460)**
2048	$0	$0	($35,083,384)	$0	$0	$24,570,570	$945,022	**($9,567,793)**
2049	$0	$0	($30,063,834)	$0	$0	$24,570,570	$945,022	**($4,548,243)**
2050	$0	$0	($25,795,528)	$0	$0	$24,570,570	$945,022	**($279,937)**
							Cumulative Total (millions)	**($1,215)**
							NPV (@7%) (millions)	**($695)**

RTI International is an independent, nonprofit research institute dedicated to improving the human condition. Clients rely on us to answer questions that demand an objective and multidisciplinary approach—one that integrates expertise across the social and laboratory sciences, engineering, and international development. We believe in the promise of science, and we are inspired every day to deliver on that promise for the good of people, communities, and businesses around the world.

For more information, visit www.rti.org.