Investigation of Environmental Measures for P8.0

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16. Abstract

NCDOT's Office of Strategic Initiatives and Program Support (SIPS), and the Strategic Prioritization Office of Transportation (SPOT) are exploring the consideration of environmental measures to be included in the prioritization of highway mode projects for P8.0. The first phase for introducing environmental measures focused on greenhouse gas (GHG), criteria pollutants (CPs), and mobile source air toxins (MSATs). These measures are in alignment with NCDOT, FHWA, and the Governor's Office priorities related to clean energy and clean transportation requirements.

This TAR (or technical assistance request) documents the first phase of this effort in a white paper that includes a literature and state of the practice review focused on methods and data for including GHGs, CP, and MSATs in the evaluation and prioritization of highway mobility projects. This White Paper discusses viable options for developing an environmental measure for NCDOT's prioritization process. The research team recommends using the Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES) model to generate an emissions factor lookup table that can be referenced within the SPOT Office's highways master spreadsheet.

Further research is still required to implement an environmental measure within NCDOT's highway mobility scoring process, as quantification formulas need to be developed for all 24 highway mobility Specific Improvement Types (SITs). To aid further research, four "starter" formulas are shown within the SPOT Process Integration section of the White Paper. Additionally, a process map was developed to demonstrate the modeling and data requirements for emissions quantification, monetization, the establishment of an environmental measure, and where in the prioritization process that measure should be located.

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Executive Summary

This White Paper discusses viable options for developing an environmental measure for NCDOT's prioritization process. The research team recommends using the Environmental Protection Agency's Motor Vehicle Emission Simulator (MOVES) model to generate an *emissions factors lookup table* as part of a new environmental measure for NCDOT's prioritization process that can be referenced within the SPOT Office's highways master spreadsheet. To align with USDOT's Benefit-Cost Analysis (BCA) guidance, this lookup table could contain emissions per mile factors for carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter ($PM_{2.5}$) that vary by vehicle type (truck vs. automobile), facility type (interstate, national highway system, STRAHNET, or toll facilities; US and NC Routes; and secondary roads), and land use context (rural, suburban, urban). If the methods being developed to quantify emissions cannot garner consensus, then the research team recommends that NCDOT considers a qualitative approach. There are several state DOTs that can offer guidance on purely qualitative methods, such as Delaware, Vermont, and Washington, as well as several other state DOTs that can provide guidance on a blend of qualitative and quantitative techniques such as the approaches used in California, Colorado, Massachusetts, Oregon, and Utah.

Further research is still required to implement an environmental measure within NCDOT's highway mobility scoring process. Quantification formulas would need to be developed for all 24 highway mobility specific improvement types (SITs), and the research team recommends that the two remaining highway SITs nested within the highway modernization projects category also receive quantification formulas, so that all highway projects could be ranked and scored subject to an environmental measure.

To aid further research, four "starter" formulas are shown within the *SPOT Process Integration* section specifically Equation 1, Equation 2, Equation 3, and Equation 4. Additionally, Table 7 provides nine different methods that can be used to convert annual average daily traffic (AADT) into vehicle miles traveled (VMT). AADT is a measure that is currently being collected and used within the prioritization process and VMT is a measure that is required to quantify emissions.

This White Paper also presents a process map that demonstrates the modeling and data requirements for emissions quantification, monetization, the establishment of an environmental measure, and where in the prioritization process that measure should be located.

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Introduction

Accounting for emissions in the transportation prioritization process is essential for creating sustainable and environmentally responsible infrastructure. As transportation is a major source of greenhouse gas (GHG) emissions, integrating emissions data into decision-making helps mitigate climate change and improve air quality. By prioritizing low-emission and energy-efficient projects, policymakers can reduce the environmental impact of transportation systems, promote public health, and align with global sustainability goals. Additionally, this approach encourages innovation in cleaner technologies and fosters a long-term shift toward greener transportation networks. Ultimately, it ensures that development is both economically and ecologically sound.

Emissions caused by transportation account for one third of total GHGs in the United States (Environmental Protection Agency, 2024). Emissions are substances released into the atmosphere. When these substances are gasses such as carbon dioxide (CO_2), methane (CH_4), or nitrous oxide (N_2O), they can cause a negative impact to the environment. GHGs are emissions that cause a “greenhouse effect” and heat up the earth's climate (Watts, 2021). The impact of these emissions can be seen all over the world, contributing to global warming, ocean acidification, worsening respiratory disease, and other health issues (Watts, 2021). The average passenger vehicle emits 400 grams of carbon dioxide per mile (EPA, n.d.). That equates to over 135,006 tons of carbon dioxide emissions by North Carolina (NC) drivers per year (Nieves, 2022).

There are several statutory precedents that were developed to reduce emissions and address climate change. According to NC’s Executive Order (EO) No. 80, the state is committed to addressing climate change by reducing GHG emissions to 40 percent below 2005 levels by 2025 (*Climate Change & Clean Transportation, 2023*). Additionally, in 2022, Gov. Roy Cooper signed NC Executive Order No. 246 that expanded on EO 80. EO 246 calls for a “50 percent reduction in economy-wide greenhouse gas emissions by 2030.”

EO 246 also established a transportation-specific goal to increase the total number of registered zero-emission vehicles to 1,250,000 by 2030 and increase the sale of zero-emission vehicles so that 50 percent of all in-state vehicle sales are zero-emission by 2030. EO 246 recognized the reduction of greenhouse gas emissions in the transportation sector as an essential element in the state’s strategy (*Climate Change & Clean Transportation, 2023*). To coincide with this objective, the N.C. Clean Transportation Plan was developed as part of a coordinated strategy for accelerating decarbonization within the transportation sector, (NCDOT, 2023).

The scope of this White Paper will focus on developing an environmental measure that can be included in the scoring process for highway mobility projects and include the accounting of GHGs, criteria pollutants (CPs), or mobile source air toxins (MSATs). Functionally these three terms have similar definitions and implications, all related to pollutants in the air.

Emissions Data Sources and Methodologies

As of September 2024, ten state departments of transportation have developed methodologies to account for greenhouse gas emissions resulting from transportation projects. These agencies typically rely on a combination of publicly available emissions modeling applications, emissions factors, formulas, and statewide transportation models to estimate how the implementation of a highway project would impact emissions.

With the overall objective of documenting guidance that could lead to the implementation of an environmental measure within the highway mobility process, the research team has organized this section of the White Paper into two overarching content areas. First, the research team will discuss key findings that emerged from the review of the ten state DOTs that evaluate emissions. Second, the research team will discuss the methods and data sources that could be used to develop and implement an environmental measure within North Carolina's prioritization process.

Key Findings from Other State Departments of Transportation

Across the United States, ten departments of transportation are currently using either a qualitative or quantitative process to account for the emissions that would result from implementing a transportation project (as referenced in Table 1).[1] Of the approaches available, it is anticipated that NCDOT would prefer to implement a quantitative methodology that supports an environmental measure for project highway scoring. This assumption is based on the data-driven standards of NCDOT's prioritization process and precedents that have been established through the development of other highway and modal measures. For these reasons, quantitative methods are more heavily explored within this White Paper; however, qualitative techniques can still be helpful, and in some instances states that employ qualitative techniques still offer valuable guidance for NCDOT.

The Virginia Department of Transportation (VDOT) uses several scoring process elements that may be transferrable to North Carolina. For example, within VDOT's quantitative scoring process, SMART SCALE, GHG emissions is one of several factors that is used to determine an eligible project's overall score. [2] Emissions considerations are nested within an Environmental Quality criterion, which is one of six criteria used to evaluate eligible transportation projects. VDOT's approach of having multiple criteria used to determine an aggregate project score is similar to NCDOT's scoring process. Thus, its Environmental Quality criterion can shed light on how a similar criterion could potentially be established within NCDOT's prioritization process.

[1]Based on a comprehensive review of the prioritization processes of state departments of transportation. Current as of September 19, 2024.
[2] SMART SCALE is an acronym that encompasses the goals of VDOT's transportation prioritization process (**S**ystem **M**anagement and **A**llocation of **R**esources for **T**ransportation: **S**afety, **C**ongestion, **A**ccessibility, **L**and **U**se, **E**conomic **D**evelopment, and **E**nvironment).

Table 1. State DOTs Evaluating Emissions as Part of Their Prioritization Processes

State	Approach Type	Methodology Snapshot	Scoring Category	Share of Overall Score
CA	Both	CAPTI Metrics	Freight Sustainability and Efficiency	9.1%
DE	*Qualitative	Rating Scale	Environmental Effect/Stewardship	6.6%
MD	Quantitative	Chapter 30 Scoring Methodology	Environmental Stewardship	9%
OR	Both	STIF Discretionary Solicitation Selection Criteria Framework	Environmental Sustainability	20%
VA	Quantitative	SMART SCALE's Custom Formula	Environmental Quality	10%
VT	*Qualitative	VPSP2 Workbook Questionnaire	Environment	10%
WA	*Qualitative	NHFP	Environment and Communities	10%
CO	Quantitative	Multiple Emissions Models	Scoring Guidance Only	–
MA	Both	Evaluation Criteria for the TIP	Component of "Clean Air / Sustainable Communities"	10 out of 134 possible points
**UT	Both	UVision Framework	Environment	5%

*Questions and results are qualitative, but the process still uses a numerical score.
**Utah Department of Transportation no longer considers environmental factors in prioritization.

For VDOT, the primary component of the Environmental Quality criterion is the measure *Air Quality and Energy Environmental Effect*, which estimates the level of benefit that a project is projected to have on air quality and greenhouse gas emissions. The objective of this measure is to recognize projects that are expected to contribute to improvements in air quality and reductions in greenhouse gas emissions. VDOT estimates the emissions of highway vehicles using its Virginia statewide travel demand model and the EPA MOVES model (Cambridge Systematics Inc, 2022).

The Maryland Department of Transportation (MDOT) offers insight into potential methods that could be used to quantify transportation-related emissions. For example, as seen in Figure 1. Annual On-Road Mobile Source Emissions (MDOT, 2023 and
Figure 2, MDOT tracks its mobile emissions from vehicles operating on roadways through the most recent data and version of the EPA MOVES model (MDOT, 2020). MDOT uses VMT, vehicle age, vehicle population, daily temperature, and fuel characteristics to estimate emissions quantities. Several of these variables have data that are available for use in North Carolina.

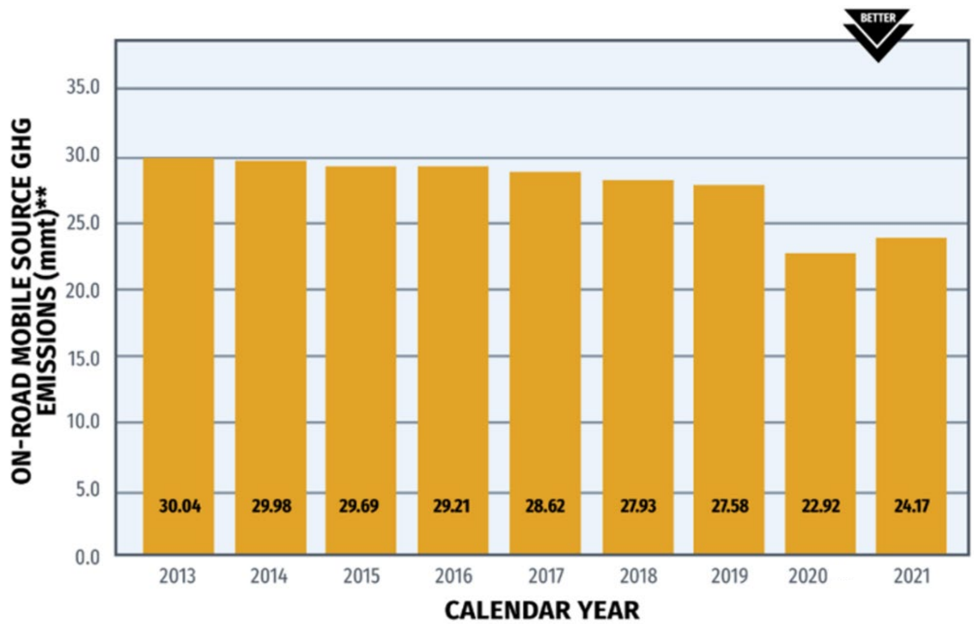

Figure* 1. *Annual On-Road Mobile Source Emissions (MDOT, 2023)

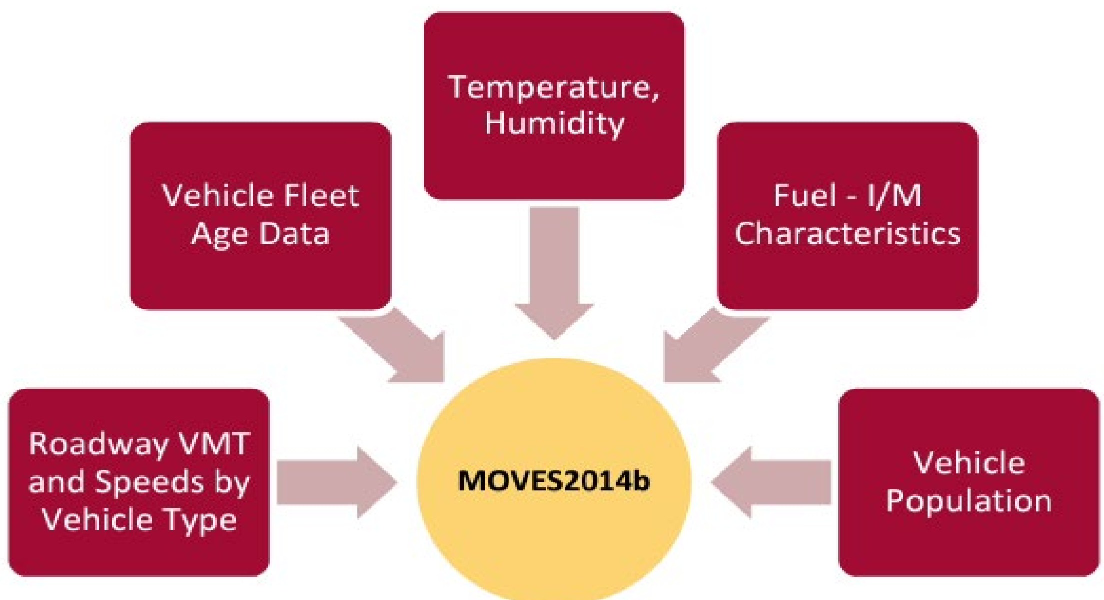

Figure 2. Emissions Calculation Process (MDOT, 2020)

Similarly, the Massachusetts Department of Transportation (MassDOT) also uses MOVES to estimate transportation-related emissions. However, due to the user complexity of the MOVES tool for repeated model runs, MassDOT uses MOVES to create an emissions output table that can then be used as a lookup table for emissions factors. An example of an output table can be seen in Table 2. It shows how variables such as average speed, time of year (month), time of day, vehicle type, and road facility type can be analyzed when estimating emissions quantities in a kilogram per vehicle-mile basis. This process offers promise for emissions quantification that can be scalable to the extent required within NCDOT prioritization.

Table 2. 2025 Rates per Distance Emission Factor for Middlesex County (MassDOT, 2024)

Emission Factor Characteristics					Emission Factors in kilograms/mile						
					Middlesex	2025					
Average Speed ID	Month ID	Time of Day	Vehicle Type ID	Road Type ID	Carbon Monoxide (2)	Oxides of Nitrogen (3)	Sulfure Dioxide (31)	Volatile Organic Compounds (87)	Carbon Dioxide (90)	Particulate Matter 10 (100)	Particulate Matter 2.5 (110)
1	1	1	1	2	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000
1	1	1	1	3	0.0056279190	0.0001329130	0.0000102030	0.0001642780	1.5651338860	0.0000067254	0.0000059737
1	1	1	1	4	0.0056279190	0.0001329130	0.0000102030	0.0001642780	1.5651338860	0.0000067254	0.0000059737
1	1	1	1	5	0.0056279190	0.0001329130	0.0000102030	0.0001642780	1.5651338860	0.0000067254	0.0000059737
1	1	1	2	2	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000
1	1	1	2	3	0.0071390200	0.0041779280	0.0000140232	0.0002928120	2.5676360360	0.0000539707	0.0000494033
1	1	1	2	4	0.0071644550	0.0041955030	0.0000140372	0.0002935620	2.5715167190	0.0000541347	0.0000495540
1	1	1	2	5	0.0071390200	0.0041779280	0.0000140232	0.0002928120	2.5676360360	0.0000539707	0.0000494033
1	1	2	1	2	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000	0.0000000000
1	1	2	1	3	0.0056279190	0.0001329130	0.0000102030	0.0001642780	1.5651338860	0.0000067254	0.0000059737
1	1	2	1	4	0.0056279190	0.0001329130	0.0000102030	0.0001642780	1.5651338860	0.0000067254	0.0000059737

Other states offer practices that could also serve as guideposts for NCDOT. For example, Delaware, Vermont, and Washington state departments of transportation use qualitative project scoring. Their qualitative techniques also offer possibilities to account for environmental outcomes resulting from transportation projects. It stands to reason that if quantitative methodologies become too difficult to implement or obtain buy-in, then qualitative approaches could be used as a “next-best” solution Other state DOTs, including California and Oregon, offer robust quantification approaches; however, their models are state specific.

Available Models and Underlying Capabilities

Upon a review of the state DOTs that account for emissions in their prioritization processes, it became apparent that emissions models were essential for the quantification of emissions resulting from transportation investments. To fully understand what emissions models were available and their capabilities, the research team conducted a comprehensive review of emissions models.

Within the realm of emissions accounting, 43 GHG evaluation tools have been identified (National Academies of Sciences, 2022). These tools primarily fall into five categories: (1) emission factor models, (2) inventory and forecast accounting tools, (3) construction, maintenance, and operations estimation tools, (4) general GHG and VMT reduction strategy analysis tools, and (5) strategy-specific analysis tools. These categories were established by the National Academies of Sciences (2022) and are defined below.

Emission factor models calculate emission rates (such as grams of carbon dioxide (CO_2) per mile) that can be used alongside vehicle activity data to estimate total emissions. The EPA MOVES and California Emission Factor (EMFAC) model focus on tailpipe emission rates and mobile-source inventories, while VISION predicts alternative technology futures. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) tool conducts life-cycle emissions assessments for different vehicle technologies and future scenarios. Additionally, the World Resources Institute offers tools with simplified emission factor data in table format, and other models estimate emissions related to the production of construction materials.

Inventory and forecasting tools are created to help agencies establish a baseline emissions inventory and, in some cases, predict future emissions, either from their own operations or transportation sources. GreenDOT is the only tool specifically tailored for transportation agencies. While some of these tools offer limited capabilities for analyzing strategies, they generally depend on external data for key assumptions like reductions in VMT or the adoption of electric vehicles (EVs).

Tools for estimating emissions from construction, maintenance, and operations help agencies calculate greenhouse gas emissions related to transportation system construction, upkeep, and operations, as well as assess potential mitigation measures. Five transportation-specific tools—Infrastructure Carbon Estimator (ICE), GreenDOT, Greenhouse-Gas Assessment Spreadsheet for Capital Projects (GASCAP), Pavement Life-Cycle Assessment Tool (PaLATE), and LCA Pave—are designed for this purpose (NCHRP, 2022b). Additional resources provide emissions data for construction materials.

GHG and VMT reduction strategy analysis tools are designed to assess various transportation-related GHG reduction strategies. Five tools—VisionEval, GreenSTEP, Energy and Emissions Reduction Policy Analysis Tool (EERPAT), Regional Strategic Planning Model (RSPM), and RPAT—belong to the same model family, sharing common foundations and overlapping functionality. The Trip Reduction Impacts of Mobility Management Strategies (TRIMMS) tool evaluates different travel demand management strategies, while Impacts 2050 is a long-term scenario planning tool that, though not focused solely on GHG, can estimate emissions based on VMT and emission rates. The Senate Bill 1 (SB1) Grant Programs Emissions Calculator is the only tool specifically designed for cross-functional, project-level emissions analysis in transportation.

Strategy-specific analysis tools are designed to assess particular strategies, such as land use scenarios or nonmotorized travel. While these tools often emphasize VMT reduction, GHG emissions can also be estimated by applying emission factors. This category includes tools focused on land use scenario planning, nonmotorized project evaluation, transit operations, intelligent transportation system (ITS) deployment, and alternative vehicle and fuel technologies.

The GHG evaluation tools were fully assessed within the National Cooperative Highway Research Program's Web Resource 1 (National Academies of Sciences, 2022b). As an important note, **this technical assistance request focuses on tools, methods, and data sources that estimate project-specific emissions impacts**. This level of granularity is required to evaluate transportation projects within North Carolina's strategic prioritization process.

After reviewing the publicly available emissions models, a cohort of seven models were determined as viable candidate for use in North Carolina. This is because of their reported abilities to produce emissions factors and rates at the project-level. Each of these candidate models are categorized as emissions factor models. Of the five model categories discussed previously, only emissions factor models offer the granularity to derive emissions by vehicle mile subject to important contextual variables such as vehicle type, vehicle speed, facility type, and land use context. This level of granularity is directly applicable to the methods needed within NCDOT's prioritization process (see Table 3).

Table 3. GHG Analysis Tools by Functionality (National Academies of Sciences, 2022)

GHG Tool	Emission Rates/ Factors	GHG Inventory Development	Agency Facilities and Operations	Construction and Maint. Activities	Highway Network and Operations	Transit Investment and Operations	Nonmotorized Improvements	Pricing Policies	Land Use and Smart Growth	TDM and Public Education	Shared Mobility	Freight Rail and Marine Strategies	Clean Vehicle and Fuel Strategies
Emission Factor Models/Tools													
MOVES	●	●											●
EMFAC	●	●											●
GREET	●												●
VISION	●												●
Mobile Combustion, Version 2.6	●												
Emission Factors from Cross-Sector Tools spreadsheet	●												
Carbon Intensity Factors	●												
Inventory and Forecast Accounting/Support Tools													
GreenDOT		●	●	●	●								●
ClearPath	●	●	●										●
Local Greenhouse Gas Inventory Tool		●											
PATHWAYS	●	●											●
Simplified GHG Emissions Calculator			●										
Tools to Evaluate Agency Construction, Maintenance, and Operations Activities													
FHWA Infrastructure Carbon Estimator		●		●									
PaLATE				●									
GASCAP				●									
Inventory of Carbon and Energy			●	●									
WARM			●	●									
U.S. Environmentally Extended Input-Output Model			●	●									
Smart Location Calculator			●						●				
General GHG, Energy, and VMT Reduction Strategy Analysis Tools													
VisionEval/GreenSTEP/RPAT/RSPM		●			●	●	●	●	●	●		●	●
EERPAT		●			●	●	●	●	●	●		●	●
Impacts 2050						●	●	●	●		●		
TRIMMS						●	●	●	●	●			
SB1 Grant Programs Emissions Calculator					●	●	●					●	
CCAP Transportation Emissions Guidebook Emissions Calculator						●	●	●	●	●			●
CURB	●	●				●	●		●		●		●
Limited Focus/Strategy-Specific Analysis Tools													
Transit Greenhouse Gas Emissions Estimator				●		●							
Envision Tomorrow							●		●				
CommunityViz							●		●				
UrbanFootprint							●		●				
Sketch7									●				
Conserve by Bicycling and Walking Benefits Calculator							●						
AFLEET			●										●
HDVEC			●	●									●
Diesel Emissions Quantifier			●	●									●
MA3T													●
Other Tools													
INVEST													
Greenhouse Gas Equivalencies Calculator	●												

After isolating the cohort of seven candidate models for emissions accounting, the research team conducted a review to determine which models would be most appropriate for North Carolina's prioritization process. Key findings from that review are discussed on the following page.

MOVES (Environmental Protection Agency)

EPA's Motor Vehicle Emission Simulator (MOVES) is a powerful tool designed to estimate emissions from on-road vehicles and mobile sources in the United States. It calculates emissions of various pollutants and GHGs from different vehicle types under a wide range of operating conditions. MOVES is the EPA's primary tool for estimating emissions from on-road vehicles and mobile sources such as cars, trucks, motorcycles, and buses. It calculates emissions of pollutants such as (but not limited to): carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x), particulate matter (PM), volatile organic compounds (VOCs), and sulfur dioxide (SO_2).

MOVES allows users to estimate emissions at different geographic scales, ranging from national to local levels. It also offers flexibility in temporal scales, enabling emissions estimates over short periods (such as hours or days) or longer periods (like months or years). The model produces estimates of total emissions from mobile sources, which can be broken down by pollutant, vehicle category, and operational mode (such as idling or cruising). This granularity allows for a more detailed understanding of where emissions are coming from and under what conditions.

MOVES is widely used in applications such as air quality modeling, developing State Implementation Plans (SIPs) to meet National Ambient Air Quality Standards (NAAQS), conducting transportation conformity assessments, and supporting climate action plans aimed at reducing greenhouse gas emissions from transportation sources.

According to FHWA's Greenhouse Gas Handbook (2013), MOVES is EPA's preferred tool for developing on-road GHG inventories at the state and local level. It is also described as the "most robust ability to address all of the factors that influence GHG emissions" (FHWA, 2013). MOVES and EMFAC can account for effects of changes in vehicle travel and congestion and speeds, while EERPAT is typically used to understand land use, transportation demand, vehicle technology, fuels, and price changes (FHWA, 2013). Also with EERPAT it is claimed to be relatively well-suited to statewide transportation GHG analysis, but the authors admit that there are a large number of model inputs and some may be difficult to obtain and that the model's VMT estimates are not as accurate as a network-based model (FHWA, 2013). The limitation of MOVES focuses on its ability to forecast since it could be difficult due to emissions often being driven by factors that are external to a state or region (FHWA, 2013).

EMFAC (California Air Resources Board)

The EMFAC (EMission FACtor) model is a tool developed by the California Air Resources Board (CARB) to estimate emissions from on-road vehicles in California. It provides detailed information on pollutant emissions from various types of vehicles, including passenger cars, trucks, buses, and motorcycles, under different operating conditions. EMFAC calculates emission factors, which represent the amount of pollutants emitted per unit of vehicle activity (e.g., grams of pollutants per mile driven). These factors are determined based on real-world data such as vehicle type, age, fuel type, and operating conditions. EMFAC operates at different geographic levels (state, regional, county) and for different time periods (historical, current, and future years). A key drawback of the EMFAC model is that it is specifically tailored for California and that its model outputs specifically pertain to California geographies.

GREET (Argonne National Labs)

The GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) model developed by the Argonne National Laboratory is a tool used to evaluate the environmental impacts of different transportation fuels and vehicle technologies. GREET is different from other models such as MOVES, EMFAC and EERPAT, because it estimates energy use and emissions associated with each stage of the fuel life cycle, often referred to as a "well-to-wheels" analysis. It is used to evaluate fuel and vehicle technology strategies that relies on user-input fuel mix and inventory results (FHWA, 2013). A key drawback of the GREET tool is its limited accessibility. The research team was unable to access it due to the tool being locked behind a registration portal online (Argonne National Laboratory, 2024). Another limitation of the model is its units of grams of CO_2 equivalent per mile (gCO_2e/mi) that limit the user to a predetermined fuel economy (FHWA, 2013).

VISION (Argonne National Labs)

The VISION emissions tool developed by the U.S. Department of Energy's Argonne National Laboratory is designed to estimate the future impacts of different vehicle and fuel technologies on energy use, GHGs, and petroleum consumption in the transportation sector. It helps policymakers, researchers, and industry experts evaluate the potential long-term effects of alternative technologies and policies. The research team was unable to access it due to the tool being locked behind a registration portal online (Argonne National Laboratory, 2024).

Mobile Combustion (WRI)

The Mobile Combustion emissions tool developed by the World Resources Institute (WRI) is designed to help organizations calculate GHG emissions from the combustion of fuel in mobile sources, such as vehicles, trains, ships, and aircraft. It supports companies and governments in estimating emissions from transportation-related activities. The tool uses emission factors to estimate GHGs from mobile combustion sources. These emission factors represent the amount of CO_2, CH_4, and N_2O emitted per unit of fuel consumed. The tool includes default emission factors based on fuel type, vehicle type, and engine technology. A primary drawback of this tool is that it is highly dependent on user-input which increases the time and complexity of using the model.

Emissions Factors from Cross-Sector Tools Spreadsheet (WRI)

The Emissions Factors from Cross-Sector Tools Spreadsheet developed by the World Resources Institute (WRI) is a simplified tool designed to help organizations estimate GHG emissions across various sectors, including transportation, energy, and industry. It provides a set of standardized emission factors that can be applied to activity data to calculate GHGs. The spreadsheet contains a comprehensive set of emission factors for different sectors and activities. These emission factors represent the quantity of GHGs emitted per unit of activity or fuel consumed. It includes emission factors for different modes of transportation (e.g., cars, trucks, ships, airplanes), categorized by fuel type. A drawback of this tool is that it has not remained updated over time. For example, fuel economy values may not reflect the latest U.S. standards or local conditions (National Academies of Sciences, 2022b).

Recommendations From Review of Emissions Factor Models

After a review of the emissions factor models, the EPA MOVES model seems to offer the greatest viability within North Carolina's prioritization process. It's primary advantages include being able to estimate emissions at a high-level of granularity (emissions per vehicle mile traveled) while accounting for several context-specific variables (type of vehicle, speed of vehicle, type of highway facility, among other variables). This would allow for emissions quantification to occur at the project level, such that, if a new project were implemented, the MOVES model could help quantify the emissions associated with that project. Another advantage of the MOVES model is that it is capable of estimating emissions quantities on a per-mile basis for all pollutant categories included within USDOT's BCA guidance documentation (e.g. NO_x, SO_2, $PM_{2.5}$, and CO_2,). The social costs of these emissions can then be monetized and included within a benefit-cost analysis framework within the prioritization process (more information about monetization is discussed in the "Emissions Monetization Methods" section of this White Paper). Whether using emissions quantities or costs, estimated to result from highway mobility projects, the MOVES model can be used as the tool to enable emission quantification.

Emissions Monetization Methods

USDOT's BCA Guidance provides a standardized framework for assessing the economic efficiency of transportation projects, including highways. One key component is the monetization of air emissions costs, which allows for the inclusion of environmental impacts in decision-making. By following USDOT guidelines, analysts can quantify the economic costs of air pollutants such as nitrogen oxides (NO_x), sulfur oxides (SO_x) particulate matter ($PM_{2.5}$), and carbon dioxide (CO_2), using emissions cost factors such as the social cost of carbon (SCC) and health cost estimates.

USDOT provides standard values for the damage costs of emissions by metric ton. Those values can be converted into costs per gram. Emissions in costs per gram align with the unit of measure typically provided in the EPA MOVES model output. For example, grams of emissions released per vehicle mile (based on specifications identified through MOVES model parameters, e.g. vehicle type, facility type, time of day, air temperature, etc.) can be multiplied by social cost of emissions per gram to derive the monetized cost of emissions.

For example, if a highway project resulted in 1,000 vehicles traveling an additional 100 miles in 2024 (using the 7th speed grouping at 6pm), emissions costs could be calculated as follows:

= 1,000 x (100 x ((NO_x emissions in grams x $0.02) + ($SO_x$ emissions in grams x $0.05) + ($PM_{2.5}$ emissions in grams x $0.96) + ($CO_2$ emissions in grams x $0.00023)))
= 1,000 x (100 x ((0.729 x $0.02) + (0.002 x $0.05) + (0.014 x $0.96) + (353.806 x $0.00023))
= ***a societal cost of $10,949.54 in 2024***

Table 4. Damage Costs for Emissions by Metric Ton and by Gram

Year	Damage Costs for Emissions per Metric Ton				Damage Costs for Emissions per gram			
	NOx	SOx	$PM_{2.5}$	CO_2	NOx	SOx	$PM_{2.5}$	CO_2
2023	$19,800	$52,900	$951,000	$228	$0.02	$0.05	$0.95	$0.00023
2024	$20,100	$53,800	$963,200	$233	$0.02	$0.05	$0.96	$0.00023
2025	$20,300	$54,800	$975,500	$237	$0.02	$0.05	$0.98	$0.00024
2026	$20,600	$56,100	$993,500	$241	$0.02	$0.06	$0.99	$0.00024
2027	$21,000	$57,400	$1,011,900	$245	$0.02	$0.06	$1.01	$0.00025
2028	$21,300	$58,700	$1,030,600	$250	$0.02	$0.06	$1.03	$0.00025
2029	$21,700	$60,100	$1,049,600	$253	$0.02	$0.06	$1.05	$0.00025
2030	$22,000	$61,500	$1,069,000	$257	$0.02	$0.06	$1.07	$0.00026
2031	$22,000	$61,500	$1,069,000	$262	$0.02	$0.06	$1.07	$0.00026
2032	$22,000	$61,500	$1,069,000	$265	$0.02	$0.06	$1.07	$0.00027
2033	$22,000	$61,500	$1,069,000	$270	$0.02	$0.06	$1.07	$0.00027
2034	$22,000	$61,500	$1,069,000	$274	$0.02	$0.06	$1.07	$0.00027
2035	$22,000	$61,500	$1,069,000	$278	$0.02	$0.06	$1.07	$0.00028
2036	$22,000	$61,500	$1,069,000	$282	$0.02	$0.06	$1.07	$0.00028
2037	$22,000	$61,500	$1,069,000	$287	$0.02	$0.06	$1.07	$0.00029
2038	$22,000	$61,500	$1,069,000	$290	$0.02	$0.06	$1.07	$0.00029
2039	$22,000	$61,500	$1,069,000	$294	$0.02	$0.06	$1.07	$0.00029
2040	$22,000	$61,500	$1,069,000	$299	$0.02	$0.06	$1.07	$0.00030
2041	$22,000	$61,500	$1,069,000	$303	$0.02	$0.06	$1.07	$0.00030
2042	$22,000	$61,500	$1,069,000	$308	$0.02	$0.06	$1.07	$0.00031
2043	$22,000	$61,500	$1,069,000	$312	$0.02	$0.06	$1.07	$0.00031
2044	$22,000	$61,500	$1,069,000	$317	$0.02	$0.06	$1.07	$0.00032
2045	$22,000	$61,500	$1,069,000	$321	$0.02	$0.06	$1.07	$0.00032
2046	$22,000	$61,500	$1,069,000	$326	$0.02	$0.06	$1.07	$0.00033
2047	$22,000	$61,500	$1,069,000	$331	$0.02	$0.06	$1.07	$0.00033
2048	$22,000	$61,500	$1,069,000	$336	$0.02	$0.06	$1.07	$0.00034
2049	$22,000	$61,500	$1,069,000	$340	$0.02	$0.06	$1.07	$0.00034
2050	$22,000	$61,500	$1,069,000	$345	$0.02	$0.06	$1.07	$0.00035
2051	$22,000	$61,500	$1,069,000	$349	$0.02	$0.06	$1.07	$0.00035
2052	$22,000	$61,500	$1,069,000	$353	$0.02	$0.06	$1.07	$0.00035
2053	$22,000	$61,500	$1,069,000	$357	$0.02	$0.06	$1.07	$0.00036

Source: Adapted from USDOT BCA Guidance (2024)

Once these emissions are quantified and monetized, they can be integrated into a BCA to provide a more comprehensive evaluation of the project's total benefits and costs. In the BCA, emissions costs are treated as negative externalities, or costs borne by society, which subtract from the overall net benefits of the project. By incorporating emissions costs, the analysis ensures that projects with significant environmental impacts reflect their true social costs, improving the accuracy of project evaluation and fostering more sustainable decision-making.

When considering the integration of an environmental measure into NCDOT's prioritization process, emissions quantification will be essential. Emissions quantification is likely to embody two forms: (1) the quantification of emissions resulting from a transportation project, or (2) the quantification and monetization of societal emissions costs that result from a transportation project. Both options offer viable opportunities for emissions accounting and the establishment of an environmental measure for the SPOT process.

SPOT Process Integration

As NCDOT considers the adoption of an environmental measure, a couple of primary considerations would need to be addressed. First, what are the best methods to use EPA MOVES (or another emissions factor model) to estimate emissions resulting from specific improvement types (SITs)? Second, what are the best ways to include an environmental measure within the prioritization process?

Methods for Emissions Quantification and SPOT Process Integration

The EPA MOVES tool acts like a key that unlocks the potential to quantify transportation-related emissions in a standardized and nationally vetted process. However, the model does come with its limitations. Depending on the inputs selected, one model run can last anywhere from 10 minutes to over an hour, which greatly limits its ability to be used for the hundreds or thousands of North Carolina highway projects that compete against each other for projecting funding each prioritization cycle.

Fortunately, there is an approach that enables emissions factors to be extracted from the model and stored within a lookup table in an excel workbook or other scratch tools. This lookup table can then be referenced, so that it can handle hundreds or thousands of emissions quantification commands without requiring individual model runs. MassDOT (2020) uses this approach to assess the air quality impacts of transportation projects included in its State Transportation Improvement Program (STIP) and as part of its Congestion Mitigation and Air Quality (CMAQ) process.

To test this process, the research team conducted three model runs using the latest EPA MOVES.[3] These runs were done in default scale with a focus on counties including Wake (urban), Johnston (suburban), and Brunswick (rural). To help choose counties based on area description, the research team reviewed Rural Center's County Data (n.d.). Table 4, Table 5, and Table 6 show the quantity of emissions that are released on a per-mile basis in terms of grams per vehicle mile in select counties. These emissions quantities are differentiated by vehicle type, speed, time of day, month, and road type.[4] Similar lookup tables can be developed for all individual North Carolina counties.

For an environmental measure to be both quantitative and scalable within NCDOT's prioritization process, it is anticipated that a lookup table that interfaces with SPOT's existing highways master sheet would need to be established. That way emissions quantification formulas could quickly reference the appropriate emissions values.

Table 5. Emissions Factor Characteristics for an Urban County

Emission Factor Characteristics					Emission Factors in grams per vehicle-mile			
					Wake County 2024			
Average Speed ID	Month ID	Hour ID	Vehicle Type ID	Road Type ID	Oxides of Nitrogen (NO_x)	Sulfure Dioxide (SO_2)	Carbon Dioxide (CO_2)	Particulate Matter 2.5 ($PM_{2.5}$)
0	1	18	11	1	0	0	0	0
0	1	18	21	1	0.183842	0.0141354	2649.9	0.0205532
0	1	18	31	1	0.685256	0.0177827	3366.56	0.0417778
1	1	18	31	2	0.224994	0.00691616	1294.5	0.00869739
1	1	18	21	2	0.534441	0.00833978	1563.53	0.0185449
1	1	18	11	2	1.30269	0.0102259	1935.54	0.0456624
2	1	18	31	2	0.181419	0.00400042	748.759	0.00521726
2	1	18	21	2	0.375568	0.0046269	867.444	0.0111589
2	1	18	11	2	0.83647	0.00574391	1087.71	0.0283901
3	1	18	31	2	0.15344	0.00259074	484.908	0.00327308
3	1	18	21	2	0.289427	0.00278732	522.567	0.00720308
3	1	18	11	2	0.593792	0.00351117	665.326	0.0182275
4	1	18	31	2	0.132129	0.00220678	413.733	0.00222994
4	1	18	21	2	0.247735	0.0022141	414.414	0.00537562
4	1	18	11	2	0.494383	0.00278296	527.493	0.0118854
5	1	18	31	2	0.113036	0.00184117	345.191	0.00180409
5	1	18	21	2	0.206365	0.00196379	367.563	0.00410879
5	1	18	11	2	0.494239	0.0023108	437.945	0.0127478
6	1	18	31	2	0.110975	0.00164139	307.735	0.00177471
6	1	18	21	2	0.197791	0.00185401	347.015	0.00375834
6	1	18	11	2	0.571302	0.00207164	392.675	0.0130414
7	1	18	31	2	0.110801	0.0015116	283.403	0.00177936
7	1	18	21	2	0.194244	0.00178638	334.357	0.00357683
7	1	18	11	2	0.630679	0.00191891	363.78	0.0131485
8	1	18	31	2	0.113211	0.00145383	272.572	0.00178046
8	1	18	21	2	0.199121	0.00185289	346.805	0.00353218
8	1	18	11	2	0.728599	0.0018662	353.806	0.0142913

Source: EPA MOVES Analysis by ITRE, 2024

**NOx, SO_2, CO_2, and $PM_{2.5}$ are identified as pollutant IDs (3), (31), (90), and (110) respectively within the MOVES output table.*

[3] The emissions rates script in the MOVES Post Processing menu takes MOVES Inventory output and divides by VMT to estimate emission rates in units of mass per distance (e.g., grams/mile).

[4] For ease of understanding, dayID, temperature, and humidity were omitted from HeidiSQL's output tables (a software that comes with MOVES).

Table 6. Emissions Factor Characteristics for a Suburban County

Emission Factor Characteristics					Emission Factors in grams per vehicle-mile Johnston County 2024			
Average Speed ID	Month ID	Hour ID	Vehicle Type ID	Road Type ID	Oxides of Nitrogen (NO_X)	Sulfure Dioxide (SO_2)	Carbon Dioxide (CO_2)	Particulate Matter 2.5 ($PM_{2.5}$)
0	1	18	11	1	0	0	0	0
0	1	18	21	1	0.183352	0.0141354	2649.9	0.0205532
0	1	18	31	1	0.683826	0.0177827	3366.56	0.0417778
1	1	18	31	2	0.224395	0.00691616	1294.5	0.00869739
1	1	18	21	2	0.533214	0.00833978	1563.53	0.0185449
1	1	18	11	2	1.29922	0.0102259	1935.54	0.0456624
2	1	18	31	2	0.180936	0.00400042	748.759	0.00521726
2	1	18	21	2	0.374679	0.0046269	867.444	0.0111589
2	1	18	11	2	0.834238	0.00574391	1087.71	0.0283901
3	1	18	31	2	0.153031	0.00259074	484.908	0.00327308
3	1	18	21	2	0.288724	0.00278732	522.567	0.00720308
3	1	18	11	2	0.592208	0.00351118	665.326	0.0182275
4	1	18	31	2	0.131777	0.00220678	413.733	0.00222994
4	1	18	21	2	0.24713	0.0022141	414.414	0.00537561
4	1	18	11	2	0.493064	0.00278296	527.493	0.0118854
5	1	18	31	2	0.112735	0.00184117	345.191	0.00180409
5	1	18	21	2	0.205855	0.00196379	367.563	0.00410879
5	1	18	11	2	0.49292	0.0023108	437.945	0.0127478
6	1	18	31	2	0.110679	0.00164139	307.735	0.00177471
6	1	18	21	2	0.197298	0.00185401	347.015	0.00375834
6	1	18	11	2	0.569778	0.00207164	392.675	0.0130414
7	1	18	31	2	0.110506	0.0015116	283.403	0.00177936
7	1	18	21	2	0.193756	0.00178638	334.357	0.00357683
7	1	18	11	2	0.628997	0.00191891	363.78	0.0131485
8	1	18	31	2	0.112909	0.00145383	272.572	0.00178046

Source: EPA MOVES Analysis by ITRE, 2024
**NOx, SO_2, CO_2, and $PM_{2.5}$ are identified as pollutant IDs (3), (31), (90), and (110) respectively within the MOVES output table.*

Table 7. Emissions Factor Characteristics for a Rural County

Emission Factor Characteristics					Emission Factors in grams per vehicle-mile Brunswick County 2024			
Average Speed ID	Month ID	Hour ID	Vehicle Type ID	Road Type ID	Oxides of Nitrogen (NO_X)	Sulfure Dioxide (SO_2)	Carbon Dioxide (CO_2)	Particulate Matter 2.5 ($PM_{2.5}$)
0	1	18	11	1	0	0	0	0
0	1	18	21	1	0.1846	0.0141354	2649.9	0.0205532
0	1	18	31	1	0.679241	0.0177827	3366.56	0.0417778
1	1	18	31	2	0.225402	0.00691616	1294.5	0.00869738
1	1	18	21	2	0.530463	0.00833978	1563.53	0.0185449
1	1	18	11	2	1.26256	0.0102259	1935.54	0.0456624
2	1	18	31	2	0.18245	0.00400042	748.759	0.00521726
2	1	18	21	2	0.373739	0.0046269	867.444	0.0111589
2	1	18	11	2	0.810697	0.00574391	1087.71	0.0283901
3	1	18	31	2	0.154651	0.00259074	484.908	0.00327308
3	1	18	21	2	0.288586	0.00278732	522.567	0.00720308
3	1	18	11	2	0.575497	0.00351117	665.326	0.0182275
4	1	18	31	2	0.133149	0.00220678	413.733	0.00222994
4	1	18	21	2	0.247057	0.0022141	414.414	0.00537561
4	1	18	11	2	0.479151	0.00278296	527.493	0.0118854
5	1	18	31	2	0.113917	0.00184117	345.191	0.00180409
5	1	18	21	2	0.205885	0.00196379	367.563	0.00410878
5	1	18	11	2	0.479011	0.0023108	437.945	0.0127478
6	1	18	31	2	0.111968	0.00164139	307.735	0.00177471
6	1	18	21	2	0.197496	0.00185401	347.015	0.00375834
6	1	18	11	2	0.5537	0.00207164	392.675	0.0130414
7	1	18	31	2	0.111891	0.0015116	283.403	0.00177936
7	1	18	21	2	0.194077	0.00178638	334.357	0.00357683
7	1	18	11	2	0.611247	0.00191891	363.78	0.0131485
8	1	18	31	2	0.114431	0.00145383	272.572	0.00178046

Source: EPA MOVES Analysis by ITRE, 2024
**NOx, SO_2, CO_2, and $PM_{2.5}$ are identified as pollutant IDs (3), (31), (90), and (110) respectively within the MOVES output table.*

Considering Existing Data and SPOT Processes for Emissions Quantification

Quantifying emissions requires an understanding of highway facility usage. In an ideal world, transportation agencies would have a validated record of how much fuel vehicles expend on their roadways and the associated levels of emissions released. In reality, emissions are difficult to measure, so models are required to derive this information.

Emissions can be estimated in the most basic form by taking the average level of emissions per passenger vehicle mile, multiplying that by vehicle miles traveled on a given segment, and then multiplying that times the number of vehicles on that segment. This equation is shown in Equation 1. The part of the equation shown in *italics* is information that can be extracted from EPA MOVES, the part in **bold** can be determined using data currently used as part of the SPOT Process. In Equation 1, the emissions per mile and VMT per segment factors could be derived from a statewide average of all vehicles, while the number of vehicles could be sourced from NCDOT annual average daily traffic estimates, which are currently being used within the highway scoring process. In Equation 2, additional precision is provided by accounting for a split between trucks and automobiles. In Equation 3 and Equation 4, further precision is added by accounting for emissions based on vehicle speed and average daily temperature, which can be accounted for using EPA MOVES model emissions factors. As an important note, VMT per segment component of the equation could be derived using AADT combined with a number of extrapolation techniques. These techniques are discussed in Table 8. Each of these methods offers different levels of precision and complexity, and the choice of method depends on the quality of available data, the scale of the study area, and the specific needs of the analysis.

Equation 1. Statewide Average

[*Emissions per Mile*] x [VMT per segment] x **[No. of vehicles (AADT)]**

Equation 2. Stratification Based on Vehicle Type Average

([*Emissions per Mile Auto*] x [VMT per segment] x **[AADT Auto])** + ([*Emissions per Mile Truck*] x [VMT per segment] x [AADT Truck])

Equation 3. Further Precision Based on Vehicle Speed

([*Emissions per Mile Auto*] x [VMT per segment] x **[AADT Auto]** x [*Emissions by Auto Speed*]) + ([*Emissions per Mile Truck*] x [VMT per segment] x **[AADT Truck]** x [*Emissions by Truck Speed*])

Equation 4. Further Precision Based on Air Temperature

([*Emissions per Mile Auto*] x [VMT per segment] x **[AADT Auto]** x [*Emissions by Auto Speed*] x [*Emissions by Daily Temperature*]) + ([*Emissions per Mile Truck*] x [VMT per segment] x **[AADT Truck]** x [*Emissions by Truck Speed*] x [*Emissions by Daily Temperature*])

Table 8. Methods for Deriving Vehicle Miles Traveled for a Highway Network

Method	Explanation
AADT-Based Formula Method	This method calculates VMT by multiplying AADT (the average daily traffic count on a roadway) by the length of the roadway segment and then multiplying by 365 (for the days in a year). It provides a straightforward estimate but assumes traffic volume is relatively consistent throughout the year. | *Formula: VMT = AADT × Length of Roadway (miles) × 365*
Traffic Monitoring and Expansion Factors	This method refines the AADT estimate by incorporating expansion factors (seasonal, daily, or hourly). These factors adjust for daily variations in traffic flow, such as higher volumes during weekdays or specific seasons. Expansion factors can be derived from long-term continuous count stations or historical data. | *Formula: VMT=Hourly / Seasonal Volume × Length of Roadway (miles) × Expansion Factors*
State or Local Traffic Models	Many states or regions use transportation models that simulate traffic conditions based on land use, population, employment data, and other socio-economic factors. These models take AADT data as input and combine it with travel demand forecasting tools to estimate more accurate VMT for different roadway segments
GIS-Based Network Models	Geographic Information System (GIS) models can integrate AADT data with spatial roadway networks to estimate VMT. These models account for the total roadway length and traffic flow on various segments, and they can analyze VMT across a network by considering traffic patterns in different areas.
Continuous Count Stations and Short-Term Traffic Counts	Continuous traffic counting stations collect real-time data that can be used to estimate VMT. In areas without continuous stations, short-term traffic counts (e.g., a few days or a week) can be extrapolated using factors derived from nearby continuous stations. These methods provide more localized estimates but require consistent monitoring infrastructure.
Mobile Device and GPS Data	Recent advancements allow for the use of GPS, mobile devices, and telematics data from connected vehicles to estimate traffic flow and VMT. These sources can provide highly granular data on traffic patterns and offer real-time insights into roadway usage. This data can be integrated with AADT for more accurate VMT estimation, especially in areas with fluctuating traffic.
Probe Data and Big Data Analytics	With the growing availability of probe data (e.g., from navigation apps like Google Maps, Waze, or commercial fleet tracking), large datasets can be processed to estimate VMT. These datasets capture dynamic traffic conditions and patterns in real time and can be correlated with traditional AADT data.
Travel Demand Forecasting Models	Travel demand models, typically used in metropolitan planning organizations (MPOs), combine land use data with observed travel survey data to estimate mathematical models that forecast travel demand for the modeled region. These models provide VMT estimates at various scales (e.g. various geographic scales and across various roadway classifications). These models are the principal analytical tool supporting long-range planning, policy decisions and air quality conformity determination.
Combination of AADT and Functional Classification	AADT data can be used in conjunction with the functional classification of the road (e.g., interstate, arterial, collector roads) to estimate VMT. Roads with higher functional classification (like interstates and multilane highways) often have higher traffic volumes. By adjusting AADT based on road type, more accurate VMT can be calculated.

Project Eligibility	Type (Based on SIT)	Statewide Mobility Scoring	Regional Impact Scoring	Division Needs Scoring
Statewide Mobility	Segment	NCSTM	NCSTM	CALC
	Int/Int/SS/Ops	CMT	CMT	CMT
	Other	CALC	CALC	CALC
Regional Impact	Segment		NCSTM	CALC
	Int/Int/SS/Ops		CMT	CMT
	Other		CALC	CALC
Division Needs	Segment			CALC
	Int/Int/SS/Ops			CMT
	Other			CALC

Figure 3. Travel Time Savings Methods (NCDOT, 2019)

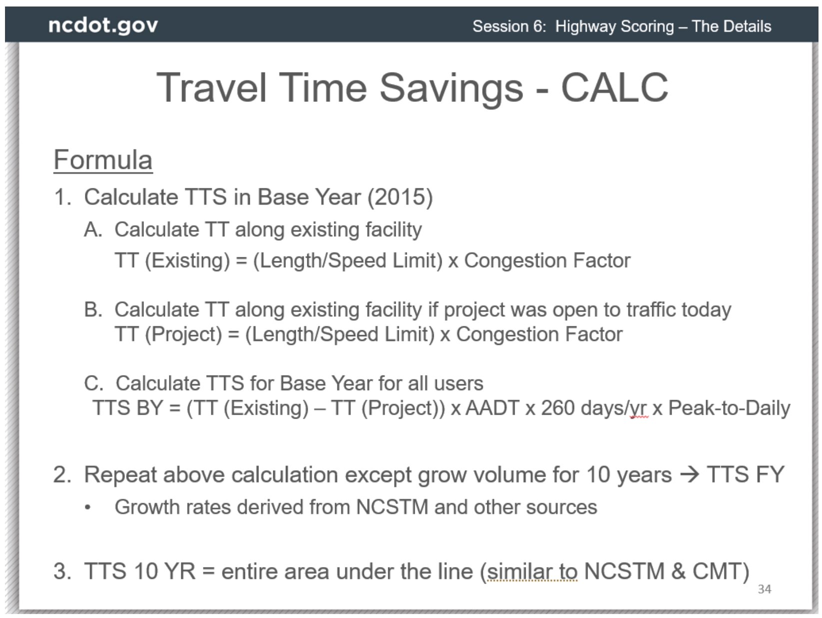

Figure 4. Travel Time Savings Calculations (NCDOT, 2019)

Determining emissions quantification formulas requires further research and is outside the scope of this study. However, the research team recommends evaluating Equation 1, Equation 2, Equation 3, Equation 4 and Table 8 as starting points to understand the types of data and methods required to build emissions formulas.[5] There are two methods that standout as the most viable options for deriving VMT for a highway projects, which are highlighted in Table 8 (note, deriving VMT is a key step in the quantification of emissions for highway projects). These methods include (1) using an AADT-Based Formula to convert AADT to VMT or (2) using a travel demand model to forecast VMT in a modeled region. The North Carolina Statewide Travel Model (NCSTM) is a travel demand model that is currently used to estimate travel times savings values that are used as part of North Carolina's highway project scoring criteria. The NCSTM is used to estimate travel time savings for statewide and regional highway projects (see Figure 3), and it is anticipated that the NCSTM could also be a viable model to develop VMT estimates for highway segments before and after highway project implementation.

An AADT-based formula conversion could also be a viable option for estimating VMT. NCDOT has 48,817 AADT stations that provide traffic data history from 2002 to 2023 (NCDOT, 2023).

[5] Once emissions have been quantified, social costs can be valued using standard monetization factors found within USDOT BCA guidance.

These stations collect AADT data which are used to calculate travel time savings for the base year for all traffic users (see Figure 4). It is anticipated that an AADT-based formula similar to the one shown in Table 8 could be used to develop VMT estimates for highway segments before and after highway project implementation.

There are 26 highway specific improvement types (SITs) that should be considered when developing an environmental measure for emissions quantification (see Table 9). Of these SITs, 24 of them fall within the highway mobility projects category. Highway mobility projects include widening, intersection/interchange improvements, access management, and other capacity additions. Two SITs fall within the highway modernization projects category, which are outside the scope of this project. Highway modernization projects include the modernization of roadways and the upgrade of freeways to interstate standards.

When considering the development of an environmental measure that evaluates the change in emissions, it's important to understand the base unit of measure and how quantification links to that measure. For example, this White Paper provides documentation on considerations for quantifying emissions and their associated societal costs for every vehicle mile of travel. Emissions released by pollutant category are quantified in grams, which can be modeled using EPA MOVES (note, emissions vary based on vehicle type, temperature, vehicle speed, and other variables also available through MOVES). Meanwhile, estimates of VMT could be developed using the NCSTM or an AADT-based formula conversion. These methods account for emissions quantification for highway project SITs that are associated with highway segments that use the NCSTM or AADT data for travel time savings derivations (SITs 1-6, 11-15, 18, and 21-26). SITs associated with intersections or other point projects would require a different quantification methodology based on delay, which will be evaluated in a follow-up project (SITs 7-10 and 19-21).

Recommendations for an Environmental Measure within the SPOT Process

The scope of this White Paper focuses on evaluating options for including an environmental measure within the highway mobility projects category (see Figure 3). Within the Highway Mobility projects category there are **two primary opportunities for the inclusion of an environmental measure**.

Criteria	Measure Description	Statewide Mobility (100%)	Regional Impact (70%)	Division Needs (50%)
Congestion	[Volume] and [Volume/Capacity]	30%	20%	15%
Benefit/Cost	[10-year Travel Time Savings benefit] + [10-year Safety Benefit] / [Cost to NCDOT]	25%	20%	15%
Safety	SEG: Crash Density, Crash Severity, Crash Rate, Safety Benefits INT: Crash Frequency, Crash Severity, Safety Benefits	10%	10%	10%
Freight	[Truck Volumes] and [Truck Percentage]	25%	10%	5%
Economic Competitiveness	TREDIS Model Output: [% Change in Long-Term Jobs] and [% Change in County Economy over 10 years]	10%	-	-
Accessibility / Connectivity	[Measurement of county economic distress indicators] and [degree the project upgrades mobility of the roadway]	-	10%	5%
Environment	[10-year quantity of emissions resulting from project] – [quantity of emissions in base case scenario]			

Figure 5. Highway Mobility Projects (adapted from NCDOT, 2023)

The first involves creating **a standalone "environment" criterion** that will join the six other criteria within the Highway Mobility projects category. To be consistent with the Benefit/Cost criteria, the research team recommends deriving the quantity of emissions that would result from an implemented project over a 10-year period and comparing that to an estimated level of emissions that would have occurred if the project were not implemented.

Table 9. Highway Specific Improvement Types and Associated Methods (adapted from NCDOT, 2019 and 2024)

SIT	Description	Scoring Category (Mobility or Modernize)	Segment or Point Type	Requires New ROW	Travel Time Savings Method	Method for Env. Measure Discussed in White Paper
1	Widen Existing Roadway	Mobility	Existing Segment	Yes	NCSTM	Yes
2	Upgrade Arterial to Freeway/Expressway	Mobility	Existing Segment	Yes	NCSTM	Yes
3	Upgrade Expressway to Freeway	Mobility	Existing Segment	No	NCSTM	Yes
4	Upgrade Arterial to Superstreet	Mobility	Existing Segment	Yes	NCSTM	Yes
5	Construct Roadway on New Location	Mobility	New Segment	Yes	NCSTM	Yes
6	Widen Existing Roadway (Part new location)	Mobility	New Segment	Yes	NCSTM	Yes
7	Upgrade at-grade intersection to Interchange or Grade Separation	Mobility	Existing Point(s)	Yes	CMT	Further Research Required
8	Improve Interchange	Mobility	Existing Point(s)	No	CMT	Further Research Required
9	Convert Grade Separation to Interchange	Mobility	Existing Point(s)	Yes	CMT	Further Research Required
10	Improve Intersection	Mobility	Existing Point(s)	Yes	CMT	Further Research Required
11	Access Management	Mobility	Existing Segment	Yes	NCSTM	Yes
12	Ramp Metering	Mobility	Existing Segment	No	NCSTM	Yes
13	Citywide Signal System	Mobility	Other	No	CALC	Yes
14	Closed Loop Signal System	Mobility	Other	No	CALC	Yes
15	Install Cameras and DMS	Mobility	Other	No	CALC	Yes

SIT	Description	Scoring Category (Mobility or Modernize)	Segment or Point Type	Requires New ROW	Travel Time Savings Method	Method for Env. Measure Discussed in White Paper
16	*Modernize Roadway*	*Modernize*	*Existing Segment*	*Sometimes*	NCSTM	N/A – outside of project scope
17	*Upgrade Freeway to Interstate Standards*	*Modernize*	*Existing Segment*	*No*	NCSTM	N/A – outside of project scope
18	Widen Existing or construct New Local (non-state) Road	Mobility	Existing Segment	Yes	NCSTM	Yes
19	Improve Intersection on local (non-state) road	Mobility	Existing Point(s)	Yes	CMT	Further Research Required
20	Convert Grade Separation to Interchange to relieve an existing interchange	Mobility	Existing Point(s)	Yes	CMT	Further Research Required
21	Realign Multiple Intersections	Mobility	Existing Point(s)	Yes	CMT	Yes
22	Construct Auxiliary Lanes or Other Operational Improvements	Mobility	Existing Segment	No	NCSTM	Yes
23	Improve Highway-Railroad Crossing	Mobility	Existing Point(s)	Sometimes	NCSTM	Yes
24	Implement Road Diet to Improve Safety	Mobility	Existing Segment	No	NCSTM	Yes
25	Improve Multiple Intersections along a corridor	Mobility	Existing Point(s)	Yes	NCSTM	Yes
26	Upgrade Roadway	Mobility	Existing Segment	Yes	NCSTM	Yes

The second opportunity involves creating an **"environmental" element that can be added to the numerator of the benefit/cost criterion** (see Figure 3). Similar to the quantification methodology recommended with a standalone criterion, an environmental element should also derive the quantity of emissions that would result from an implemented project over a 10-year period. However, this method would require monetizing the social costs of emissions, so that a benefit or disbenefit in the form of a dollar value, can be applied appropriately within the BCA equation.

To demonstrate how an environmental measure could be integrated into the highway mobility scoring process, a process map is shown in Figure 4. The process map demonstrates the modeling and data requirements for emissions quantification, monetization, the establishment of an environmental measure, and where in the prioritization process that measure should be located.

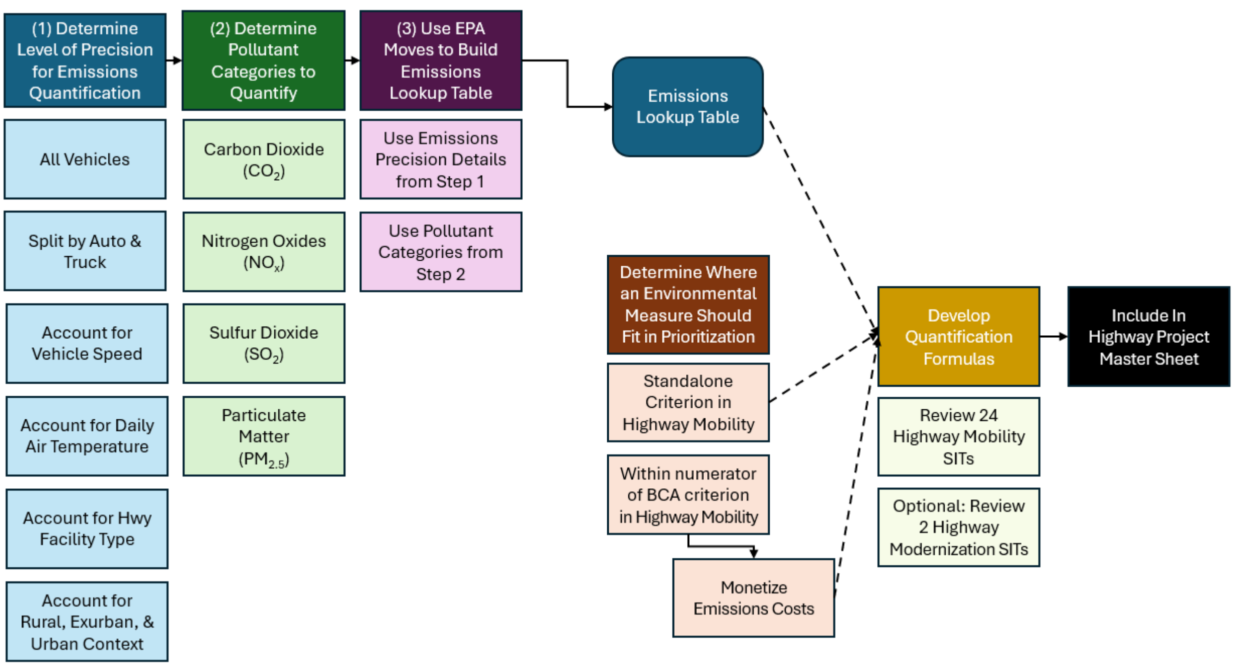

Figure 6. Environmental Measure Process Map

Conclusions

At least two viable options are available for integrating an environmental measure into NCDOT's prioritization process. These options include (1) creating a standalone criterion that will stand among the six other criteria within the Highway Mobility projects category, or (2) creating an element that can be added to the numerator of the benefit/cost criterion. To enable emissions quantification, the research team recommends using the EPA MOVES model to generate an *emissions factors lookup table* that can be referenced within the SPOT Office's highways master spreadsheet. This lookup table should contain emissions per mile factors for carbon dioxide (CO_2), nitrous oxide (NO_x), sulfur dioxide (SO_2), and particulate matter ($PM_{2.5}$) that vary by vehicle type (truck vs. automobile), facility type, and land use context (rural, suburban, urban).

Further research is still required to implement an environmental measure within NCDOT's highway mobility scoring process. Quantification formulas need to be developed for all 24 highway mobility SITs, and the research team recommends that the two remaining highway SITs nested within highway modernization projects category also receive quantification formulas, so that that all highway projects could be ranked and scored subject to an environmental measure. To aid further research, this White Paper presents a process map that shows how emissions can be quantified, how an environmental measure can be developed, and where in the prioritization process that measure can be included. Additionally Equation 1, Equation 2, Equation 3, Equation 4, and Figure 4 provide "starter" formulas and AADT conversion methodologies that can be used to kick-start the process.

In summary, this White Paper was developed to help guide the development of an environmental measure that would be applicable to the largest share of highway SITs, highway segments (SITs 1-6, 11-15, 18, and 21-26). A follow-up project will be undertaken to evaluate developing emissions quantification methods for point projects (SITs 7-10 and 19-21).

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