Appendix B. Greenhouse Gas Evaluation Tools

- B.1 Overview of Tools
- B.2 Tool Assessment

B.1 Overview of Tools

Table B.1 lists 43 greenhouse gas (GHG) evaluation tools identified at the time this guide was written. The table identifies the creator, year of inception and/or last update, and availability (free or at cost), and provides a brief description of the tool and its relevance. Table B.2 identifies which functions the tool is designed to perform, including which specific transportation GHG strategies can be analyzed. Following this overview, Section B.2 provides a more detailed evaluation of tools that are most relevant to GHG evaluation for State departments of transportation (DOTs).

In these tables, the tools are grouped into the following general categories according to their primary purpose:

- **Emission factor models—**These models provide emission rates (e.g., grams carbon dioxide (CO_2) per mile) that can be applied to estimates of vehicle activity to estimate total emissions. Motor Vehicle Emission Simulator (MOVES) and the California Emission Factor (EMFAC) model provide tailpipe emission rates and mobile-source inventories, while VISION evaluates alternative technology futures and Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) provides life-cycle emissions assessment for different vehicle technologies and futures. Two tools from the World Resources Institute provide simplified data (tables of emission factors). There also are models that provide emissions rates for the production of various construction materials.

- Inventory and forecast accounting/support tools—These are designed to help an agency build a baseline inventory and possibly a baseline forecast of emissions, either from its own activities, or from transportation sources. GreenDOT is the only tool specifically designed for transportation agencies. Some of these tools also have limited strategy analysis capabilities, although they typically require external inputs for key assumptions such as vehicle miles traveled (VMT) reductions or electric vehicle (EV) market penetration.
- Tools to evaluate agency construction, maintenance, and operations activities—These are designed to assist an agency in estimating GHG emissions associated with transportation system construction, maintenance, and operations activities, and to identify and evaluate mitigation measures for these activities. Four tools, Infrastructure Carbon Estimator (ICE), GreenDOT, Greenhouse-Gas Assessment Spreadsheet for Capital Projects (GASCAP), and Pavement Life-Cycle Assessment Tool (PaLATE) are transportation-specific, while other resources are available to assist with emissions accounting (e.g., emission factors for materials used in construction). The Federal Highway Administration (FHWA) LCAPave tool scheduled for release in 2021 will provide an updated pavement life-cycle assessment tool.
- General GHG and VMT reduction strategy analysis tools—These are designed to evaluate multiple types of transportation GHG reduction strategies. Five of the tools in this category—VisionEval, GreenSTEP, Energy and Emissions Reduction Policy Analysis Tool (EERPAT), Regional Strategic Planning Model (RSPM), and RPAT—are all part of the same family of models and have similar underpinnings and considerable overlap in functionality. Trip Reduction Impacts of Mobility Management Strategies (TRIMMS) evaluates multiple travel demand management strategies. Impacts 2050 is a long-range scenario planning tool not focused specifically on GHG, but GHG could be estimated from VMT and emission rates. The Senate Bill 1 (SB1) Grant Programs Emissions Calculator is the only cross-functional tool designed for transportation project-level emissions analysis.
- Limited focus/strategy-specific analysis tools—These are designed to evaluate a specific type of strategy (e.g., land use scenarios or nonmotorized travel). These tools often focus on VMT reduction but GHG emissions can be estimated by applying emission factors. This category includes a number of tools focused on land use scenario planning, as well as tools for nonmotorized project evaluation, transit operations, intelligent transportation system (ITS) deployment, and alternative vehicle and fuel technologies.
- Other tools—Tools that do not fit into any of the above categories, including the Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) tool to support DOT agencywide sustainability assessment, and an Environmental Protection Agency (EPA) tool to support communications of GHG impacts.

The tools do not always fit neatly into a single category. For example, the MOVES model can produce emission rates as well as an overall inventory for mobile sources. The ICLEI ClearPath tool is an accounting framework that includes emission factors and can include user-defined strategy analysis modules. The tools for agency construction, maintenance, and operations would be useful to inform an agencywide carbon footprint/inventory. The columns of Table B.2 identify cases in which tools have multiple functionalities that cut across these broad categories.

Some of the tools included are developed with the primary audience being a municipality. These are included here for two reasons. First, some of the methods and data also may be relevant to State DOTs (e.g., the issues involved in inventorying emissions from municipal and State fleets are similar). Second, some DOTs may see it as part of their role to provide technical assistance to municipalities who wish to estimate GHG emissions and evaluate transportation mitigation strategies. This review provides an overview of some of the tools and methods commonly in use at the municipal level.

Despite the large number of tools, most of them have a very specific focus. In particular, there are a limited number of tools with strategy analysis capabilities. In the “general strategy analysis tools” category, only one robust set of tools (the VisionEval family) is available that is designed specifically for broad-based GHG strategy analysis, and even these tools have limitations (e.g., not designed for project-specific evaluation). Therefore, the universe of tools may still be missing significant functionalities to support State DOTs’ GHG analysis activities, such as relatively simple project evaluation tools, and tools that include policy levers that DOTs and other State agencies can directly influence (e.g., EV infrastructure).

Additional proprietary tools may exist that are not included in this review. These are typically owned by corporations or nonprofit entities and customized for application for individual clients.

FHWA is also expected to release a more detailed pavement life-cycle assessment tool in 2021.

Table B.1 Transportation GHG Analysis Tools

Click here to download Table B.1

Table B.2 GHG Analysis Tools by Functionality

Click here to download Table B.2

B.2 Tool Assessment

This section provides a more detailed overview of tools most relevant to State DOT emissions inventory and strategy assessment. The following information is provided:

- Developer/sponsor agency.
- Year of inception/latest update.
- Availability (free, cost, etc.).
- Platform.
- Description.
- Level of effort, using the following general guidance:
  - Low = <1 week of staff time.
  - Medium = 1 week to 1 month of staff time.
  - High = >1 month of staff time.
- Input data requirements (an overview, not a comprehensive listing).
- Functions performed.
- Strengths.
- Limitations.
- Sample applications.
- References/links.

The tools described below include:

- MOVES
- EMFAC
- GREET
- VISION
- Mobile Combustion, Version 2.6
- Emission Factors from Cross-Sector Tools
- GreenDOT
- Infrastructure Carbon Estimator
- Pavement Lifecycle Assessment Tool

- GASCAP
- Waste Reduction Model (WARM)
- VisionEval
- EERPAT
- SB1 Grant Programs Emissions Calculator
- CMAQ Emissions Calculator Toolkit
- Impacts 2050
- Transit Greenhouse Gas Emissions Estimator
- AFLEET
- HDVEC
- Diesel Emissions Quantifier
- MA3T
- INVEST

B.2.1 Motor Vehicle Emission Simulator (MOVES)

Developer/Sponsor Agency: U.S. Environmental Protection Agency.

Year of Inception/Latest Update: 2015.

Availability: Free/public.

Platform: Downloadable JAVA-based Windows software with outputs stored in MySQL databases.

Description: MOVES is the U.S. Environmental Protection Agency's Motor Vehicle Emission Simulator. It is used to create emission factors or emission inventories for both on-road motor vehicles and nonroad equipment. The purpose of MOVES is to provide an accurate estimate of emissions from cars, trucks, and nonhighway mobile sources under a wide range of user-defined conditions.

Level of Effort: High for initial setup, low to medium for additional policy testing/runs.

Input Data Requirements: The MOVES model includes a default database that summarizes emission relevant information for the entire United States. The MOVES team continually works to improve

this database, but, for many uses, up-to-date local inputs will be more appropriate, especially for analyses supporting State Implementation Plans and conformity determinations.

Functions Performed: Estimation of emissions and energy use from a variety of sources, including cars, trucks, and nonhighway mobile sources. Estimates can be formulated for specific time periods, geographic boundaries, vehicle types, and road types. Specific pollutants and processes can be chosen as well.

Strengths: Developed to allow customization for local areas. Can be easily updated with new information/data. User-friendly graphical user interface (GUI).

Limitations:

Sample Applications:

References/links:

https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves#manuals

https://www.fhwa.dot.gov/Environment/air_quality/conformity/training/webinar_introductiontomoves.pdf

B.2.2 EMFAC

Developer/Sponsor Agency: California Air Resources Board (CARB).

Year of Inception/Latest Update: 2017 (update).

Availability: Free/public.

Platform: Online database (downloads to Microsoft Excel CSV).

Description: CARB-developed emissions models used to assess emission from on-road vehicles, including cars, trucks, and buses in California. The most recent approved version (by the EPA) is

EMFAC2017.

Level of Effort: Low.

Input Data Requirements: Select data type (emissions or emissions rates), geography, temporal window, and vehicle/fuel characteristics from dropdown menu.

Functions Performed: Produces emission estimates from on-road vehicles, including cars, trucks, and buses in California.

Strengths: Simple user interface that exports estimates directly to Excel.

Limitations: EMFAC can only be used within California, and thus results will be highly influenced by California-specific conditions.

Sample Applications: EPA approves EMFAC for use in State Implementation Plan and transportation conformity analyses. EMFAC and MOVES were used in a study by Sonoma Technologies and the Washington State DOT to assess the potential for transportation projects to create particulate matter hot spots.

References/links:

https://ww2.arb.ca.gov/our-work/programs/mobile-source-emissions-inventory/msei-modeling-tools

https://journals.sagepub.com/doi/pdf/10.3141/2570-02

B.2.3 Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)

Developer/Sponsor Agency: Argonne National Labs.

Year of Inception/Latest Update: 2019 (update).

Availability: Free/public.

Platform: Offered in both a downloadable software ("GREET.net") and as a spreadsheet tool ("GREET Excel"). The spreadsheet tool includes submodels named Fuel-Cycle Model (GREET 1, contains data on fuel cycles and vehicle operations) and Vehicle-Cycle Model (GREET 2, evaluates the energy and emission effects associated with vehicle material recovery and production, vehicle component fabrication, vehicle assembly, and vehicle disposal/recycling).

Description: Calculates resource consumption (energy), fossil fuel use, natural gas, and water. Also provides all emissions of GHG (and their CO_2-equivalent) along with other pollutants for a given vehicle and fuel system.

Level of Effort: Low.

Input Data Requirements: The number and types of vehicles in a fleet.

Functions Performed: GREET provides life-cycle energy consumption rates and emission factors for a wide variety of vehicle and fuel technologies. Users can override default input parameters. GREET has been expanded to include air, marine, and rail as well as on-road vehicles. GREET includes additional tools—the GREET Fleet Footprint Calculator (2012) and a Travel Carbon Calculator.

Strengths: Compared to MOVES or EMFAC, provides life-cycle emission factors, not just tailpipe, and can be tailored to over 100 different fuel paths, and almost any available vehicle technology type, to examine GHG emissions from alternative fuel vehicles.

Limitations:

Sample Applications: Sample applications include life-cycle analyses of various transportation fuels and vehicle systems, as well as well-to-wheel analyses.

References/links:

https://greet.es.anl.gov/index.php

https://greet.es.anl.gov/workshops

B.2.4 VISION

Developer/Sponsor Agency: Argonne National Labs.

Year of Inception/Latest Update: 2019 (update).

Availability: Free/public.

Platform: Spreadsheet model.

Description: Model designed to provide estimates of the potential energy use, oil use, and carbon emission impacts of advanced light-duty and heavy-duty vehicle technologies and alternative fuels through the year 2050, and in some cases 2100.

Level of Effort: Medium.

Input Data Requirements: Major input parameters include: Car technology market penetration and fuel economy ratio; Light-truck technology market penetration and fuel economy ratio; Light-truck share of total light-duty vehicles (LDV) market; fuel type (including hydrogen and ethanol via multiple production pathways) and price; VMT, including growth rate and elasticity to the cost of driving; Flex-Fuel Vehicle VMT share by E85 and all-electric range for new Plug-In Hybrid Electric Vehicle; heavy-truck fuel economy, technology market share, and alternative fuel usage; and light-vehicle cost.

Functions Performed: Can output energy use by fuel type; full fuel cycle carbon emissions; full fuel cycle GHG emissions; fuel expenditures; light vehicle miles per gasoline gallon equivalent; energy consumed while producing feedstock for end-use fuels, and energy consumed in producing end-use fuels.

Strengths: Useful for future scenario analysis of alternative fuel and vehicle technologies, considering fleet turnover.

Limitations:

Sample Applications: U.S. DOT/National Highway Traffic Safety Administration used VISION to determine how to reduce LDV fuel use by 5% in 2010. U.S. Department of Energy (DOE) used VISION to determine the impact of various forms of rebates and feebates on oil use and associated Government expenditures through 2020.

References/links:

https://www.anl.gov/es/vision-model

B.2.5 Mobile Combustion, Version 2.6

Developer/Sponsor Agency: World Resources Institute.

Year of Inception/Latest Update: 2017 (update).

Availability: Free/public.

Platform: Spreadsheet model.

Description: This tool calculates the CO_2, CH_4 and N_2O emissions from various transportation sources using activity data input by the user. Uses default emissions factors calculated by UK Department for Environment, Food, and Rural Affairs (DEFRA), U.S. EPA, and the United Nations Intergovernmental Panel on Climate Change (IPCC) (2006), but customized emissions factors can be added if known.

Level of Effort: Medium.

Input Data Requirements: Fuel use and distance-traveled data are both necessary for a complete emissions picture, although the model can use fuel economy data to convert between the two data types if necessary.

Functions Performed: Calculates CO_2, CH_4, and N_2O emissions from fleets, public transport, and mobile machinery.

Strengths: Useful rough calculation tool to give an idea of Scope 1 and Scope 3 emissions from transportation activities.

Limitations: The use of EPA or IPCC data does give some structure to results, but it will be highly dependent on quality of user inputs. Not applicable for private vehicles.

Sample Applications: The Inter-American Development Bank used this tool to calculate emissions from fuel consumption by tugboat fleets.

References/links:

https://ghgprotocol.org/sites/default/files/Transport_Tool_v2_6.xlsx

https://publications.iadb.org/publications/english/document/Greenhouse-Gas-Assessment-Emissions-Methodology.pdf

B.2.6 Emission Factors from Cross-Sector Tools

Developer/Sponsor Agency: World Resources Institute.

Year of Inception/Latest Update: 2017 (update).

Availability: Free/public.

Platform: Spreadsheet model.

Description: This Excel document provides standardized CO_2, CH_4, and N_2O emissions values for purchased energy and transportation sources per unit of fuel (e.g., kg/gallon) and per distance traveled (e.g., g/mile).

Level of Effort: Low.

Input Data Requirements: None.

Functions Performed: Provides emissions factors for CO2, CH4 and N_2O per unit of fuel (e.g., kg/gallon) and per distance traveled (e.g., g/mile), as well as for freight transportation and public transportation.

Strengths: A quick way to look up emission factors by fuel type or per mile by vehicle type, age, etc., to apply to specific vehicle fleets with known characteristics.

Limitations: Fuel economy values may not reflect the latest U.S. standards or local conditions.

Sample Applications:

References/links:

https://ghgprotocol.org/sites/default/files/Emission_Factors_from_Cross_Sector_Tools_March_2017.xlsx

B.2.7 GreenDOT

Developer/Sponsor Agency: National Cooperative Highway Research Program/ICF international.

Year of Inception/Latest Update: 2010.

Availability: Free.

Platform: Microsoft Excel.

Description: GreenDOT calculates CO_2 emissions from the operations, construction, and maintenance activities of State DOTs. GreenDOT is designed to calculate emissions for geographical areas ranging from a single project to an entire State and over time periods ranging from one day to several years. The two most likely uses of the tool are to

1. Calculate annual agencywide emissions.
2. Calculate emissions related to a specific project, covering a period of days or years.

The tool consists of four modules, which calculate emissions from on-road vehicles, off-road equipment, electricity used in transportation facilities, and construction.

Level of Effort: Medium

Input Data Requirements:

- Major materials and those that might be substituted.
- On-road fleet in fuel use or VMT.
- Nonroad equipment in fuel consumed or run time.

Functions Performed: The tool can footprint the activities of a DOT or a project and can test mitigation strategies, including congestion management.

Strengths: The user can edit assumptions. The emission factors are transparent and can be used as defaults or can be populated with unique numbers.

Limitations: Needs updated emission factors as well as other GHGs.

Sample Applications: Project footprinting and agency operations footprinting. The GreenDOT tool was used for a comprehensive evaluation of strategies for State DOTs to reduce CO_2 emissions from their construction, operations, and management practices.

References/links:

https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2621

http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(58)_GreenDOTv1-5b.xls

B.2.8 Infrastructure Carbon Estimator

Developer/Sponsor Agency: Federal Highway Administration and State DOTs.

Year of Inception/Latest Update: 2014/2020.

Availability: Free/public.

Platform: Microsoft Excel.

Description: The Estimator allows users to create "ballpark" estimates of energy and GHG emissions using *limited* data inputs. This approach allows the tool to be used in transportation planning processes before details about specific facility dimensions, materials, and construction practices are known. The User's Guide component of this document provides a step-by-step guide to using the tool. Detailed instructions and explanations of key input parameters also are provided in the tool itself.

Level of Effort: Low for initial setup, Low for outputs and modifications.

Input Data Requirements: Project inputs such as project facility type; new, refurbished, or expansion; pavement types and lengths; parking; bridge structures; and rail, bus, bicycle, and pedestrian facilities. Mitigation inputs such as users of the system, vehicle types, and fuels; vegetation sequestration; alternative snow removal strategies; material substitutions; and preventative maintenance.

Functions Performed: Calculates a rough-scale GHG inventory for the project and shows the mitigation potential of preset reduction strategies. Calculates detour emissions and vehicle emissions reductions from reduced friction on pavements.

Strengths: Helps agencies that are beginning to look at GHG emissions in projects get to some rough answers of what the GHG footprint of a project is and some stock mitigation strategies and their potential to reduce emissions. Looks at the entire life-cycle of the facility.

Limitations: Does not differentiate between major material types such as asphalt versus concrete pavements or concrete versus steel for bridges. Material types are an index of all materials in ratios from national averages. Mitigation strategies are based on national norms as well. Specific project details are not included and could be substantially off when materials are selected and mitigation details are discussed, such as pavement mixes with cement alternatives.

Sample Applications: Can be used in early estimations of proposed facilities before the engineering phase.

References/links:

http://www.dot.state.mn.us/sustainability/ghg-analysis.html

B.2.9 Pavement Lifecycle Assessment Tool PaLATE

Developer/Sponsor Agency: University of California, Berkeley.

Year of Inception/Latest Update: 2013.

Availability: Free/public.

Platform: Microsoft Excel.

Description: Spreadsheet-based tool which calculates environmental and economic effects of pavement and road construction. Users input initial designs, initial construction material, maintenance material and processes, equipment, and cost for a project. Tool provides outputs of energy consumption, CO_2 emissions, and other pollutant emissions and resource consumption.

Level of Effort: Medium.

Input Data Requirements: Roadway design specifications, materials specifications, material transportation distances and modes, on-site and off-site construction equipment and activity, life-cycle economic costs.

Functions Performed: A tool for performing detailed calculations of GHG emissions from various pavement and road construction approaches. Provides net present value of the life-cycle costs of the pavement type.

Strengths: Deep detail on material substitutions and construction practices. Helps a design team determine the lowest embodied emissions of the pavement it chooses and alternatives to it. Also provides leachate data on pavement types.

Limitations: Can be a heavy tool for beginning users. Factors need to be updated. Note that the FHWA LCAPave tool scheduled for release in 2021 will provide an updated pavement life-cycle assessment tool.

Sample Applications: Footprinting pavement design and construction and differing strategies.

References/links:

http://faculty.ce.berkeley.edu/horvath/palate.html

https://rmrc.wisc.edu/palate/

B.2.10 GASCAP

Developer/Sponsor Agency: Rutgers/Vorhees Transportation Center.

Year of Inception/Latest Update: 2014

Availability: Free.

Platform: Microsoft Excel.

Description: GASCAP provides estimates of life-cycle GHG emissions for many of the different components of a transportation construction project, as well as for maintenance activities. It is designed to be both user-friendly and flexible, allowing the user to specify inputs for a variety of different modules. GASCAP provides life-cycle emissions estimates for the major GHGs. These include CO_2, methane, nitrous oxide, sulfur hexafluoride, and black carbon. The primary modules within GASCAP provide estimates of embodied emissions associated with a wide range of materials, construction equipment used on a project site, emissions associated with project mobilization, traffic disruption based on how the project is staged, and life-cycle maintenance over the lifetime of the project. Other modules include procedures for using recycled materials, induced travel effects, and rail capital projects. A future upgrade will include the effects of pavement deterioration on the GHG emissions of road users.

Level of Effort: Low to medium.

Input Data Requirements:

- Construction:
  - Materials.
  - Nonroad Equipment.
  - Recyclables.
  - Staging.
  - Traffic Disruption.
  - Life-Cycle Maintenance-Materials.
  - Lighting.
  - Rail Modifier for Rail Specific Projects.
- Induced Travel.
- Maintenance Department Module.

Functions Performed: Life-cycle of the facility emissions with induced travel estimates.

Strengths: Detailed and able to select most accurate emissions factors. Upstream and downstream emissions included.

Limitations: Requires some time commitment to populate the tool.

Sample Applications: Use during environmental assessment or preliminary design to explore alternatives.

References/links:

http://vtc.rutgers.edu/gascap/

B.2.11 Waste Reduction Model (WARM)

Developer/Sponsor Agency: U.S. Environmental Protection Agency.

Year of Inception/Latest Update: 2019.

Availability: Free/public.

Platform: Online database or Microsoft Excel.

Description: WARM is a tool that calculates and totals the GHG emissions, energy savings, and economic impacts of baseline and alternative waste management practices, including source reduction, recycling, combustion, composting, anaerobic digestion, and landfilling. The model calculates emissions, energy units, and economic factors across a wide range of material types commonly found in municipal solid waste in the following categories:

- Metric tons of CO_2 equivalent.
- Energy units (millions of British Thermal Units).
- Labor hours.
- Wages ($).
- Taxes ($).

Level of Effort: Low.

Input Data Requirements:

- Materials and tonnage.
- Disposal or recovery fates.

Functions Performed: WARM helps solid waste planners and organizations track and voluntarily report GHG emissions reductions, energy savings, and economic impacts from six different waste management practices, including source reduction, recycling, composting, anaerobic digestion, combustion, and landfilling.

Strengths: Very good for material embodied emissions and recycling strategies.

Limitations: Does not go beyond materials and recovery methods.

Sample Applications: Looking at demolition materials and their best fate.

References/links:

https://www.epa.gov/warm/basic-information-about-waste-reduction-model-warm

B.2.12 VisionEval

Developer/Sponsor Agency: Oregon DOT and FHWA.

Year of Inception/Latest Update: Ongoing.

Availability: Free/public.

Platform: R-based open-source software.

Description: VisionEval is a programming framework of disaggregate strategic planning model elements that include GHG emissions functionality. VisionEval includes code that is common to four other tools listed here—GreenSTEP, EERPAT, RPAT, and RSPM.

Level of Effort: High for initial setup, lower for future runs.

Input Data Requirements: Depends on which specific strategic planning models are used.

Functions Performed: Can support a broad array of potential tool uses and enable pooled enhancements expanding the types of outcomes measured or refine the specificity of transportation and land use solutions considered. Merges the essential functionalities of all the programs in the GreenSTEP family of tools into one model. Functions include GHG inventory development, highway network and operations, transit investment and operations, nonmotorized improvements, pricing policies, land use and smart growth, TDM and public education, freight rail and marine strategies, and clean vehicle and fuel strategies.

Strengths: FHWA has an effort underway to improve access and documentation for the VisionEval model, which should make it a more widely usable framework for scenario modeling and policy analysis addressing GHG and other outcomes, incorporating the functionality of the other VisionEval family tools listed here.

Limitations: Policy-level model, not suited for project-level or detailed geographic assessment.

Sample Applications: Oregon DOT and the Corvallis Area MPO used VisionEval (in this case, specifically both RPAT and RSPM) to test hundreds of scenarios for policies on land use, parking, mode choice, and transportation options.

References/links:

https://visioneval.org/

https://visioneval.org/assets/refs/2016_RPAT_Case_Study_ODOT.pdf

B.2.13 EERPAT

Developer/Sponsor Agency: Federal Highway Administration.

Year of Inception/Latest Update: 2016.

Availability: Free/public.

Platform: Programming in R, with a GUI interface. Data input through CSV files.

Description: Based on the GreenSTEP model (part of the VisionEval framework), but with a GUI and designed to serve all 50 States and published by FHWA. EERPAT uses disaggregate household-level analysis to create an integrated, State-level modeling system. It is designed specifically to evaluate strategies for reducing transportation energy consumption and GHG emissions.

Level of Effort: High for initial setup, low to medium for additional policy testing/runs.

Input Data Requirements: Baseline data for State, by MPO region and/or county, including freeway and arterial lane miles, population density, urban and rural population splits, population forecasts by age group, transit revenue miles, truck and bus VMT splits, vehicle age distributions. Data for calibration, including income, vehicle ownership, VMT, motor fuel use. Additional data requirements for each strategy vary.

Functions Performed: GHG inventory development, highway network and operations, transit investment and operations, nonmotorized improvements, pricing policies, land use and smart growth, TDM and public education, freight rail and marine strategies, clean vehicle and fuel strategies.

Strengths: Microsimulation of individual household choices supports robust analysis of policies affecting travel time and cost, considering how households with different characteristics respond differently. Household travel budgets support inclusion of induced demand factors as a result of travel time and cost changes. Provides for consideration of life-cycle emission factors by fuel type and considers fleet age/composition and turnover effects.

Limitations: Requires user-input market share assumptions for some strategies such as EVs and bicycle travel, although the model constrains travel based on distance/range limitations. Strategy evaluation methods vary in their robustness. Policy-level model not suited for project-level or detailed geographic assessment.

Sample Applications: Maryland, Vermont, and Washington State DOTs; Massachusetts DOT (MassDOT, 2015).

References/links:

https://fhwaapps.fhwa.dot.gov/planworks/Applications/Show/greenhouse-gas-emissions

B.2.14 SB1 Grant Programs Emissions Calculator

Developer/Sponsor Agency: Caltrans.

Year of Inception/Latest Update: 2017 (update).

Availability: Free/public.

Platform: Spreadsheet tool.

Description: Spreadsheet-based emissions calculator for evaluating project emissions using input data on VMT, service miles, ton miles, and speeds.

Level of Effort: Low if input data requirements are easily obtained, medium-high otherwise.

Input Data Requirements: Project information, VMT (before and after), trip lengths, service-miles, ton-miles, average speed, and fuel consumption.

Functions Performed: The model estimates emissions from changes in VMT, service-miles, ton-miles, and speeds in terms of CO, CO_2, NO_x, PM_{10}, $PM_{2.5}$, SOx, and volatile organic compounds.

Strengths: One of the only tools identified that focuses on transportation-project-specific emissions evaluation for multiple project types.

Limitations: Requires user inputs of data such as VMT changes, so it is not a true forecasting tool.

Sample Applications:

References/links:

https://dot.ca.gov/programs/transportation-planning/economics-data-management/transportation-economics

B.2.15 CMAQ Emissions Calculator Toolkit

Developer/Sponsor Agency: FHWA.

Year of Inception/Latest Update: 2019 (update).

Availability: Free/public.

Platform: Spreadsheet tool.

Description: Excel tools to assist in calculating emissions reductions from CMAQ projects, including bicycle/pedestrian, transit service and technology, carpooling and vanpooling, alternative fuels and vehicles, and congestion reduction and traffic flow improvements.

Level of Effort: Depends on type of project modeled, but generally medium-low if input data requirements are easily obtained, medium-high otherwise.

Input Data Requirements: Data requirements depend on the type of project evaluated. For example, for a transit bus service evaluation, the user would need to input allocations of fuel types and bus model years, service duration, bus VMT, number of trips, and average trip distance.

Functions Performed: This toolkit can estimate air quality and GHG emissions changes from a number of different project types, including bicycle and pedestrian improvements, transit bus service and fleet expansion, transit bus retrofits and replacement, carpooling/vanpooling, alternative fuels/vehicles, and congestion reduction/traffic flow improvements.

Strengths: This is one of the only prepackaged tools available for estimating project-level GHGs.

Limitations: Requires user inputs of data such as VMT changes, so it is not a true forecasting tool.

Sample Applications: The FHWA provides a number of examples of potential applications on its website. For example, the Bicycle/Pedestrian Improvement tool can be used to determine the emissions benefits of installing a midblock crossing on a busy arterial road, or the installation of a protected bicycle lane.

References/links:

https://www.fhwa.dot.gov/environment/air_quality/cmaq/toolkit/

B.2.16 Impacts 2050

Developer/Sponsor Agency: NCHRP

Year of Inception/Latest Update: 2014

Availability: Free/public.

Platform: Spreadsheet tool.

Description: Part of *NCHRP Report 750, Vol. 6*, Impacts 2050 is a spreadsheet tool focused on demographic scenario analysis to determine the impacts of sociodemographic factors in future travel demand. Impacts 2050 integrates two elements: 1) a system dynamics model that represents regional links between population, land use, employment, transport supply, and travel behavior; and 2) scenarios representing visions of possible futures.

Level of Effort: Low to medium.

Input Data Requirements: Four sets of data must be specified to define the year 2000 base conditions for the simulation region:

- Demographic data.
- Employment data.
- Land-use data.
- Transport supply data.

Functions Performed: Summarizes the simulated change in the sociodemographic characteristics of the region's population over the forecast period and predicted changes in travel behavior.

Impacts 2050 is designed to address a wide range of "what if" questions that a region may confront.

- Sociodemographic questions, e.g.: What happens if the birth rate increases?
- Travel behavior questions, e.g.: What happens if the price of fuel doubles?
- Employment questions, e.g.: What if technological changes lead to increased job creation rates?
- Land-use questions, e.g.: What if there was a large shift in preference toward urban locations?
- Transport supply questions, e.g.: What would happen if no new roads were built in the next 30 years, but population growth continues?

Strengths: Useful for considering factors such as changes in vehicle occupancy from shared mobility that may not be considered in other tools.

Limitations: This is not a forecasting tool as it focuses on the breadth of scope and flexibility of assumptions, rather than on short-term accuracy and spatial detail.

Sample Applications: In *NCHRP Report 750*, *Vol. 6*, an analysis of five different metro regions (Atlanta, Boston, Detroit, Houston, and Seattle) is conducted using Impacts 2050 to consider disruptive sociodemographic changes on travel patterns and behavior.

References/links:

https://www.nap.edu/read/22321/chapter/7

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_750-v6_usersguide.pdf

B.2.17 Transit Greenhouse Gas Emissions Estimator

Developer/Sponsor Agency: Federal Transit Administration.

Year of Inception/Latest Update: 2016.

Availability: Free/public.

Platform: Microsoft Excel

Description: The Transit Greenhouse Gas (GHG) Emissions Estimator is a spreadsheet tool that allows users to estimate the partial life-cycle GHG emissions generated from the construction, operations, and maintenance phases of projects across select transit modes. The tool was developed in connection with the Greenhouse Gas Emissions from Transit Projects Programmatic Assessment. The tool provides a resource to generate coarse but informative estimates of GHG emissions using limited project information and can be used for a broad range of transit projects.

Level of Effort: Low for initial setup, Low for outputs and modifications.

Input Data Requirements:

- Construction: # of parking spots—garage or surface; # of trees removed.
  Transit Mode: Miles of alignment or track by underground, at grade, elevated, with catenary; number of stations by underground, elevated, or at grade.
- Operations of Transit: Transit mode by heavy rail, light rail, streetcar, commuter rail, bus/dr bus, vanpool, school bus; fuel source; annual VMT.
- Displaced Emissions: Mode that transit displaces; fuel source; annual VMT.
- Facility Operations: Mode the facility is associated with; building type—station or maintenance/storage; square footage.

Functions Performed: GHG emissions totals in metric tons; upstream construction emissions; downstream construction emissions; operations downstream; maintenance; displaced emissions.

Strengths: This tool is intended to provide "coarse" scale estimates that can support decision-making.

Limitations: If precise calculations are needed, this tool does not have project-specific values for materials.

Sample applications: Can be used in early estimations of proposed facilities before the engineering phase. Can estimate the life-cycle emissions of a facility or part of a system.

References/links:

https://www.transit.dot.gov/regulations-and-guidance/environmental-programs/ftas-transit-greenhouse-gas-emissions-estimator

B.2.18 Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET)

Developer/Sponsor Agency: Argonne National Labs.

Year of Inception/Latest Update: 2018.

Availability: Free/public with registration.

Platform: Microsoft Excel.

Description: This tool examines both the environmental and economic costs and benefits of alternative fuel and advanced vehicles. It was developed for Clean Cities stakeholders to estimate petroleum use, GHG emissions, air pollutant emissions, and cost of ownership of light-duty and heavy-duty vehicles using simple spreadsheet inputs.

The tool uses data from Argonne's GREET fuel-cycle model to generate necessary well-to-wheels petroleum use and GHG emission coefficients for key fuel production pathways and vehicle types. In addition, MOVES and certification data are used to estimate tailpipe air pollutant emissions. Various sources are used to provide default cost data, including the Clean Cities Alternative Fuel Price Report and American Recovery and Reinvestment Act awards.

Level of Effort: Low for initial setup, varies based on number of inputs.

Input Data Requirements: primary vehicle location (State and county); vehicle type; vehicle fuel type; number of vehicles; annual vehicle mileage; fuel economy; vehicle purchase price; public or private fuel station pricing; fuel and diesel emission fluid price.

Functions Performed: Estimate petroleum use, GHG emissions, air pollutant emissions, and costs of ownership for light-duty and heavy-duty vehicles. Includes simple payback calculator; total cost of ownership calculator; fleet footprint calculator; idle reduction calculator.

Strengths: Simple tool for life-cycle fleet assessment.

Limitations: Only for fleet use.

Sample applications: Can be used for construction or operations and maintenance estimates or construction and operations and maintenance actuals. Good for planning to test differences in fuel types or vehicle types.

References/links:

https://greet.es.anl.gov/afleet_tool

B.2.19 Heavy-Duty Vehicle Emissions Calculator (HDVEC)

Developer/Sponsor Agency: Argonne National Labs.

Year of Inception/Latest Update: 2018.

Availability: Free/public with registration.

Platform: Web-based tool with Microsoft Excel export ability.

Description: The Heavy-Duty Vehicle Emissions Calculator (HDVEC) was developed to estimate the vehicle operation nitrogen oxide and particulate matter, as well as the well-to-wheel GHGs of commercially available alternative fuel medium- and heavy-duty vehicles. This tool is designed to aid fleets and decision-makers in comparing vehicle technologies for emission reductions and considering allocation of funding. The tool uses emissions data from both the EPA's MOVES and Argonne's GREET models.

Level of Effort: Low for initial setup, varies based on input scale.

Input Data Requirements: Project state; vehicle type; number of vehicles; vehicle lifetime; annual vehicle mileage; engine details; mitigation dollars by fuel type available; fuel type, including electricity and grid mix.

Functions Performed: Environmental mitigation with scrappage (new alternative fuel versus new diesel, plus additional benefit from early retirement of scrapped vehicle); environmental mitigation w/ repower (engine replacement) (vehicle after repower versus diesel vehicle before repower); clean vehicle replacement (new alternative fuel versus new diesel).

Strengths: Mitigation estimation and comparing heavy-duty-vehicle fuels. Estimates cost per mitigation benefit. Results can be exported to Microsoft Excel.

Limitations: Only for heavy-duty fleet use. High-level estimates.

Sample Applications: Can be used for construction or operations and maintenance estimates or construction and operations and maintenance actuals. Good for planning to test differences in fuel types or vehicle types.

References/links:

https://afleet-web.es.anl.gov/hdv-emissions-calculator/

B.2.20 Diesel Emissions Quantifier

Developer/Sponsor Agency: U.S. Environmental Protection Agency.

Year of Inception/Latest Update: 2019.

Availability: Free/public.

Platform: Web-based. Requires login.

Description: Evaluates clean diesel projects and upgrade options for medium-heavy and heavy-duty diesel engines. Estimates baseline emissions, reduced emissions, cost-effectiveness for NO_x, $PM_{2.5}$, HC, CO, and CO_2, and PM-related health benefits.

Level of Effort: Low for initial setup. Time varies with scale of inputs.

Input Data Requirements:

- State in which fleet is located.
- On-road: Vehicle type, model years, costs and quantities; fuels and quantities; VMT; pollution control and idling upgrades; costs for controls.
- Nonroad: Vehicle/equipment type, model years, horsepower, costs, and quantities; pollution control upgrades; fuels and quantities; run time; repowering, retrofits and upgrades; costs for controls.
- Marine: Vessel type; engines; fuels and quantities; run time; repowering, retrofits and upgrades; costs for controls.

Functions Performed: The Diesel Emissions Quantifier calculates emission reductions for four criteria pollutants: NO_x, $PM_{2.5}$, HC, CO, and CO_2. Outputs for each pollutant include annual results (in short tons), baseline for retrofitted vehicles, amount and percent reduced, lifetime results (in short tons), baseline for retrofitted vehicles, amount and percent reduced, capital cost-effectiveness ($/short ton), total cost-effectiveness ($/short ton), health benefits.

Strengths: Simple web-based program for users with little or no modeling experience. Useful for evaluation of emissions-control technologies in agency or contractor fleets, as well as broader evaluation of clean vehicle technology policies.

Limitations: Includes CO_2, but not other GHG emissions.

Sample applications: Use when making choices about buying new vehicles or equipment, repowering with new engines, putting control technologies on, or switching fuels.

References/links:

https://19january2017snapshot.epa.gov/cleandiesel/diesel-emissions-quantifier-deq_.html

B.2.21 Market Acceptance of Advanced Automotive Technologies (MA3T)

Developer/Sponsor Agency: Oak Ridge National Laboratory.

Year of Inception/Latest Update: 2019.

Availability: Free/public.

Platform: Spreadsheet tool.

Description: Spreadsheet-based tool with Visual Basic programming to estimate EV market uptake and consumer response to a variety of EV pricing and policy incentives. Oak Ridge National Laboratory (ORNL) also maintains the MA3T MiniTool, a web-based lite version of the MA3T model that is a collection of predetermined scenario results.

Level of Effort: Low to Medium.

Input Data Requirements: MA3T can run on four different categories of potential shifts: Technology, Consumer, Policy, and Infrastructure. For example, under the Technology category, a user can choose their type of technology (fuel cell, battery, ICE, etc.) and then choose between baseline and optimistic projections.

Functions Performed: MA3T considers U.S. household users of these vehicles as the consumer market, which is disaggregated into 1,458 segments based on six dimensions: census divisions, residential areas, attitudes toward novel technologies, driving patterns, home recharging situations, and work recharging situations. MA3T projections currently cover the period from 2005 to 2050 and capture the temporal interaction between market penetrations and product diversity and risk. Model outputs include estimates of LDV sales and fleet size and energy usage.

Strengths: MA3T is a publicly available model that can be used for light-duty EV forecasting and incentive policy evaluation. The model is richly detailed, containing detailed consumer segmentation, market dynamics, and driving distance distributions for households.

Limitations: Set up for national application, a run for a single State requires running all 50 States. Only includes light-duty EVs.

Sample Applications: A 2012 ORNL study used MA3T to model a number of possible strategies that could achieve one million plug-in electric vehicles (PEVs) on the road in the U.S. by 2015 and evaluate the impact of each strategy on PEV market share. MA3T was used to evaluate EV policy incentives in Boston (Green Ribbon Commission and Boston University, 2019).

References/links:

https://teem.ornl.gov/assets/custom/pdf/MA3T%20User%20Guide%20v20130729.pdf

https://teem.ornl.gov/assets/custom/pdf/ma3t_fact_sheet.pdf

Dong, J. and Z. Lin. (2012). *Exploring the Paths to One Million Plug-in Electric Vehicles by 2015 Using MA 3 T Model*. Oak Ridge National Laboratory. https://pdfs.semanticscholar.org/a266/a14cc9ebcfb2baf02b4edf5eb37fc199fa51.pdf

B.2.22 Infrastructure Voluntary Evaluation Sustainability Tool (INVEST)

Developer/Sponsor Agency: FHWA.

Year of Inception/Latest Update: 2018 (update).

Availability: Free/public.

Platform: Web-based tool.

Description: A web-based self-evaluation tool providing voluntary best practices to improve sustainability. Covers full life-cycle of transportation services, including system planning, project planning, design, and construction. Also provides best practices focused on operations and maintenance.

Level of Effort: Medium to High.

Input Data Requirements: INVEST criteria are divided into four modules: System Planning for States, System Planning for Regions (SPR), Project Development, and Operations and Maintenance. These four sets of criteria comprise a comprehensive self-evaluation tool to aid agencies in evaluating the sustainability performance of their projects and programs.

Functions Performed: Based on the criteria, agency staff conduct a self-evaluation that results in a score based on a predetermined point system (the point values vary depending on the project/policy specifications). These point values are sometimes linked to a tiered rating (i.e., “Platinum,” “Gold,” “Silver,” “Bronze”).

Strengths: Can assist DOTs with identifying, implementing, and evaluating overall sustainability efforts (including reducing GHG emissions) across all aspects of their operations.

Limitations: Does not quantify GHG emissions.

Sample Applications: The Sustainable Highways website contains a number of examples of INVEST applications from over 15 States. For example, the Cape Cod Commission decided to use INVEST to

evaluate the sustainability of the completed Hyannis Access Study with the goal of using the evaluation results to improve future corridor planning efforts on the Cape.

References/links:

https://www.sustainablehighways.org/100/about.html

https://www.sustainablehighways.org/779/case-studies.html

Previous | Next

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