California Air Resources Board

Clean Mobility Benefits Quantification Methodology

California Climate Investments

Final
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List of Acronyms and Abbreviations

Acronym	Term
AHSC	Affordable Housing and Sustainable Communities
CARB	California Air Resources Board
CMO	Clean Mobility Options
CMIS	Clean Mobility in Schools
Diesel PM	Diesel particulate matter
GGE	Gasoline gallon equivalent
GHG	Greenhouse gas
kWh	Kilowatt-hour
MJ	Megajoules
$MTCO_2e$	Metric tons of carbon dioxide equivalent
NOx	Nitrous oxide
$PM_{2.5}$	Particulate matter with a diameter less than 2.5 micrometers
PV	Photovoltaic
ROG	Reactive organic gas
STEP	Sustainable Transportation Equity Project
SUV	Sports utility vehicle
UCF	Urban and Community Forestry
UTV	Utility terrain vehicle
VMT	Vehicle miles traveled

List of Definitions

Term	Definition
Bike Infrastructure	Project component that creates new Class I bike paths, Class II bike lanes, or Class IV cycle tracks, or convert Class II bike lanes to Class IV cycle tracks.
Co-benefit	A social, economic, or environmental benefit of a project beyond its GHG emission reduction benefit. Types of co-benefits include air pollutant emission reductions, net passenger auto VMT reductions, net energy use reductions, net energy cost savings, net travel cost savings, jobs supported by the project and community engagement conducted by the project.
Component	Component of a mobility project. Types of components include new or expanded service, vehicle replacement, subsidies, system / efficiency improvement, bike infrastructure, pedestrian infrastructure, solar PV generation, lawn and garden equipment replacement, tree planting, and non-quantifiable component.
Lawn and Garden Equipment Replacement	Project component that replaces existing lawn and garden equipment with new equipment. Examples include replacing fossil-fueled lawn mowers, leaf blowers, and utility carts with zero-emission models. This component supports mobility projects by reducing emissions, noise pollution, and enabling broader usage and benefits to the community including safety improvements and community pride around bus stops, transit hubs, bicycle and pedestrian pathways.
Net Energy Cost Savings	Net reductions in energy costs for the provider of mobility services as a result of the project.
Net Energy Use Reductions	Net reductions in the quantity of energy used in terms of GGE as a result of the project.
Net Passenger Auto VMT Reductions	Net reductions in passenger auto VMT, which is defined and calculated as the passenger auto VMT that is displaced by the project, minus the passenger auto VMT that sedans and SUVs of the project create.

Term	Definition
Net Travel Cost Savings	Net reductions in travel cost for the user of mobility services due to mode shift as a result of the project.
New or Expanded Service	Project component that creates a new service or expand an existing service. Examples include establishing a new car sharing program or expanding an existing program with additional vehicles, procuring school buses to serve new routes, and developing a new public transit service or expanding the routes and frequency of existing transit services.
Non-Quantifiable Component	Project component that may reduce emissions but do not have quantification methodologies developed. Examples include administrative expenses, planning, or needs assessments components of a project.
Pedestrian Infrastructure	Project component that creates new pedestrian facility for active transportation. Examples include installation of new pathways, safety improvements such as buffer zones to and from schools, community centers, and transit hubs.
Project	The overarching mobility project including all components.
Quantification Period	Number of years that the project component will provide emission reductions. It is also referred to as project lifetime, useful life, or implementation timeframe.
Solar PV Generation	Project component that installs new solar PV panels. This component supports mobility projects by providing clean electricity to charge electric vehicles and equipment associated with the project.
Subsidies	Project component that provides free or reduced fare vouchers that increase the use of an existing service. Examples include free rides on an existing transit service or reduced fares for an existing bike sharing program.
System / Efficiency Improvements	Project component that improves an overall transportation and mobility system. Examples include infrastructure for express routes (bus-only lanes or traffic signal coordination), accessibility improvements, or network/fare integration.

Term	Definition
Tree Planting	Project component that plants trees within the project community. Trees support mobility projects by storing or absorbing emissions and providing shading to reduce the energy consumption and associated emissions of the project buildings. Examples include planting trees to provide shading over pathways to provide comfort to pedestrians and reduce the urban heat island effect.
Vehicle Replacement	Project component that replaces existing vehicles with new vehicles without expanding the service. Examples include replacing gasoline or diesel vehicles with zero-emission vehicles that run on the same routes.

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Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating GHG emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as priority populations. Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

CARB is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects funded by California Climate Investments. This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculators. CARB develops these methodologies and tools based on the project types eligible for funding by each administering agency, as reflected in the *program expenditure records*.

Part of the California Climate Investments' portfolio is a group of Low Carbon Transportation programs, which includes CMO, CMIS, and STEP. For the clean mobility projects that are funded by CMO, CMIS, and STEP, CARB staff developed this Clean Mobility Benefits Quantification Methodology for estimating the GHG emission reductions and selected co-benefits of each proposed project type. These three programs share many common project types. This quantification methodology consolidates the previous program specific methods and best practices into one method. The goal of this new consolidated tool is to allow CARB staff from various programs to streamline the calculation of many different projects and component types. This methodology was designed as non-program specific, meaning that it can be used to quantify the benefits of the projects funded by these three programs. The core methods for quantification have not changed but the equations have been updated to reflect the most up-to-date assumptions.

CARB staff have developed the Benefits Calculator for clean mobility projects as an Excel tool to automate the methods and equations described in this document. The Benefits Calculator provides the total project GHG emission reductions and co-benefits estimation. The Benefits Calculator is available for download on the *California Climate Investments Resources webpage*.

Various types of mobility projects are included in the Benefits Calculator. However, it is not comprehensive of all possible projects and there could be project types that are not considered here. The project types that are included here are not guaranteed to receive funding from California Climate Investments. Each funding program determines which project types are eligible for their own program. The project types covered in this Benefits Calculator are:

- New or Expanded Service
- Vehicle replacement
- Subsidies
- System and Efficiency Improvements
- Bike Infrastructure
- Pedestrian Infrastructure
- Solar PV Generation
- Lawn and Garden Equipment Replacement
- Tree Planting
- Non-Quantifiable Components

Using many of the same inputs required to estimate GHG emission reductions, the Clean Mobility Benefits Calculator estimates the following co-benefits from clean mobility projects:

- Diesel PM emission reductions (lbs)
- NO_x emission reductions (lbs)
- $PM_{2.5}$ emission reductions (lbs)
- ROG emission reductions (lbs)
- Net passenger auto VMT reductions (miles)
- Travel cost savings ($)
- Net fossil fuel use reductions (GGE)
- Community engagement level (low, medium, or high)
- Jobs supported

Additional co-benefits for which CARB assessment methodologies were not incorporated into the Clean Mobility Benefits Calculator may also be applicable to the project. Users should consult the funding programs' guidelines, solicitation materials, and agreements to ensure they are meeting all requirements. All CARB co-benefit assessment methodologies are available on the *California Climate Investments Resources webpage*.

A.1. Methodology Development

CARB developed this quantification methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability. CARB developed this Clean Mobility Benefits Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology will:

- Apply at the project-level;
- Provide methods to be applied consistently throughout California, and be accessible by all users;
- Use existing and proven methods;
- Use project-level data, where available and appropriate; and
- Result in GHG emission reductions and co-benefits estimates that are conservative and supported by empirical literature.

During initial development, CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the clean mobility project types. CARB consulted with STEP, CMO, and CMIS program staff to determine project-level inputs available. CARB staff also consulted with ASHC and UCF programs to ensure consistency of methods and assumptions regarding transportation and tree planting projects. The quantification methods for all California Climate Investments programs are available on the *Quantification Benefits and Reporting Materials webpage*.

In addition, CARB staff, in collaboration with the University of California, Berkeley, have developed assessment methodologies for the co-benefits listed above. CARB solicited public comment on their draft versions in Spring 2018 prior to posting the final methodologies. These co-benefit assessment methodologies are available on the *California Climate Investments Resources webpage*.

The Clean Mobility Benefits Calculator relies on emission factors that are obtained from the California Climate Investments Emission Factor Database. CARB staff have developed this database in an effort to increase transparency and continue to use the most up-to-date emission factors when estimating project benefits. This database is available on the *California Climate Investments Resources webpage*.

In addition to project components that provide clean mobility services, the Clean Mobility Benefits Calculator has integrated three types of components that support mobility projects. These include solar PV generation, lawn and garden equipment replacement, and tree planting. Installation of solar panels supports mobility projects by providing clean electricity to charge electric vehicles associated with the project. Replacing existing lawn and garden equipment with new equipment supports mobility projects by reducing emissions from landscaping of lawn and garden around buildings, community centers, transit stations, bus stops, bike and pedestrian infrastructure, and other elements of the mobility project. Planting trees in these areas supports mobility projects by providing shading to improve comfort of the transportation system and mobility services, particularly in summer and during extreme heat events. Shading also supports the mobility projects by reducing the energy consumption of the buildings associated with the project. In addition to the benefits of shading, trees absorb or store emissions, supporting the environmental goals of the mobility project.

A.2. Tools

Users must use the Clean Mobility Benefits Calculator to estimate the GHG emission reductions and co-benefits of the proposed project. The Clean Mobility Benefits Calculator can be downloaded from the *California Climate Investments Resources webpage*.

The Clean Mobility Benefits Calculator has integrated all the reference tools, resources, databases, and updates that CARB staff have developed for transportation and mobility projects, so users do not need to run any other tool for transportation and mobility components of their projects. For the supporting components of solar PV generation and tree planting, this quantification methodology requires inputs that should be obtained from the external tools PVWatts Calculator and i-Tree Planting Calculator, respectively.

The PVWatts Calculator is a web application developed by the National Renewable Energy Laboratory to estimate the electricity production of photovoltaic systems based on a few simple inputs. This calculator is available from the *PVWatts webpage*.

The i-Tree Planting Calculator is a web application developed by the United States Department of Agriculture Forest Service to provide urban and rural forestry analysis and benefits assessment. This calculator is available from the *i-Trees Tools webpage*.

A.3. Updates

CARB staff periodically review each quantification methodology to evaluate their effectiveness and update the methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated the Clean Mobility Benefits Quantification Methodology from the previous versions to enhance the analysis and provide additional clarity. It also incorporates more accurate assumptions for key variables, such as adjustment factors, deadhead miles, and renewable electricity used for electric vehicle charging.

Please send any questions or comments regarding the calculator tool to the *main GGRF Program email*.

Section B. Greenhouse Gas Emission Reductions Quantification

This section provides the details of the methodologies that the Clean Mobility Benefits Calculator uses for quantification of GHG emission reductions from each component type.

The Clean Mobility Benefits Calculator has integrated all the quantification methods that are presented in this section.

For all the following calculations, users should provide the project location (air basin or county) as basic input. For new or expanded service, vehicle replacement, subsidies, and system / efficiency improvement components, users should also provide the final year of the component. For other types of project components, the final year is calculated based on default values for their quantification period as described below. The emission factors are obtained from the California Climate Investments Emission Factor Database based on the project component type, the project location, and the first year and the final year of the project component.

B.1. New or Expanded Service

Emission reductions from new or expanded service are estimated as the difference between the emissions of the passenger autos that are displaced by the project and the emissions that project vehicles create. Vehicle types include transit bus, sedan, SUV, shuttle, van, school bus, standard bicycle, electric bicycle, electric moped, and electric scooter.

The VMT of the project vehicles is calculated in the first year and final year of the project component as follows:

Equation (1): Project VMT in the First Year

$$VMT_{Project,1} = V_1 \times (VMT\ Per\ Vehicle)_{Project,1} = V_1 \times T_1 \times L$$

Equation (2): Project VMT in the Final Year

$$VMT_{Project,F} = V_F \times (VMT\ Per\ Vehicle)_{Project,F} = V_F \times T_F \times L$$

Table 1. Variables of Equations (1) and (2): Project VMT

Variable	Variable Definition	Units
VMT	VMT	miles
Project	Indicator of variables associated with the project vehicles	N/A
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
V	Number of vehicles	N/A
T	Number of vehicle trips	N/A
L	Length of average vehicle trip	miles

The following paragraphs provide more descriptions and technical details for the above variables and calculations.

For Equations (1) and (2), users should input the number of vehicles in the first year and the final year. Users should also input the VMT per vehicle in the first year and the final year, or alternatively, the number of vehicle trips and the length of average vehicle trip in the first year and the final year of the project component.
In Equations (1) and (2), the VMT per vehicle and the vehicle trip length inputs include miles traveled carrying passengers as well as deadhead miles. Deadhead miles refer to miles driven that are associated with or support travel periods without a passenger in the vehicle. Examples include ride-hailing service vehicles en route to pick up passengers or carsharing services that redistribute the vehicles among pickup locations.

The VMT of the passenger autos that are displaced by the project is the VMT that would have occurred without the project. This displaced VMT is calculated in the first year and the final year of the project component as follows:

Equation (3): Displaced Passenger Auto VMT in the First Year

For Transit Buses:

$$VMT_{Displaced,1} = A \times R_1 \times D$$

For Other Vehicles:

$$VMT_{Displaced,1} = A \times O_1 \times (100\% - DM\%) \times VMT_{Project,1}$$

Equation (4): Displaced Passenger Auto VMT in the Final Year

For Transit Buses:

$$VMT_{Displaced,F} = A \times R_F \times D$$

For Other Vehicles:

$$VMT_{Displaced,F} = A \times O_F \times (100\% - DM\%) \times VMT_{Project,F}$$

Table 2. Variables of Equations (3) and (4): Displaced Passenger Auto VMT

Variable	Variable Definition	Units
VMT	VMT	miles
Displaced	Indicator of variables associated with displaced passenger autos	N/A
Project	Indicator of variables associated with the project vehicles	N/A
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
A	Adjustment factor between 0 and 1	N/A
R	Increase in ridership on fixed-route transit	N/A
D	Average passenger trip length on fixed-route transit	miles
O	Average occupancy per vehicle	N/A
DM%	Percentage of deadhead miles out of total vehicle miles	N/A

The following paragraphs provide more descriptions and technical details for the above variables and calculations.

For Equations (3) and (4), users should input the adjustment factor for all vehicle types. They should also input the increase in ridership and average passenger trip length for transit buses, or the average occupancy per vehicle for other vehicle types. The VMT of project vehicles in the first year and final year have been calculated using Equations (1) and (2).

In Equations (3) and (4), the calculation for transit bus is different from other vehicle types, because fixed-route transit systems use ridership data for the overall system instead of occupancy data per vehicle.

In Equations (3) and (4), the adjustment factor accounts for the trips that are actually displaced by the project, so it includes the trips that would have happened in a passenger auto if the project was not available, and it excludes the trips that would have happened on transit or as walking and biking trips in the absence of the project. Suggested values for the adjustment factor are 0.50 for short-distance passenger trips (typically below 10 miles) and 0.83 for long-distance passenger trips (typically above 10 miles). For transit services, CARB staff have developed more accurate estimates of adjustment factors in the Quantification Methodology for the Affordable

Housing and Sustainable Communities (AHSC) Program, available on the Air *Resources Board's webpage.*

In Equations (3) and (4), the percentage of deadhead miles is subtracted, because deadhead miles do not carry any passengers, so they do not displace any passenger auto trips.

In Equations (3) and (4), the average vehicle occupancy should exclude the duration of deadhead miles with zero passengers, because the percentage of deadhead miles already accounts for deadhead miles. The average vehicle occupancy should also exclude hired drivers for ride-hailing and other services, because they are not passengers and do not displace any passenger auto trips. For ride-hailing services, the suggested value for vehicle occupancy is 1.55 and the suggested value for percentage of deadhead miles is 40% based on the *CARB Clean Miles Standard Base Inventory Report*.

The annual average emissions of the project vehicles and the displaced passenger autos are calculated as follows:

Equation (5): Annual Average Emissions of Project Vehicles

$$AAE_{Project} = \left(\frac{VMT_{Project,1} + VMT_{Project,F}}{2}\right) \times EF_{Project} \times (100\% - RE\%) \times 10^{-6}$$

Equation (6): Annual Average Emissions of Displaced Passenger Autos

$$AAE_{Displaced} = \frac{VMT_{Displaced,1} \times EF_{Displaced,1} + VMT_{Displaced,F} \times EF_{Displaced,F}}{2} \times 10^{-6}$$

Table 3. Variables of Equations (5) and (6): Annual Average Emissions

Variable	Variable Definition	Units
AAE	Annual average emissions	MTCO2e per year
VMT	VMT	miles
Displaced	Indicator of variables associated with displaced passenger autos	N/A
Project	Indicator of variables associated with the project vehicles	N/A
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
EF	Vehicle emission factor	grams of CO2e per mile
RE%	Percentage of renewable energy used for electric vehicle charging	N/A
10^{-6}	Conversion of grams of CO2e to MTCO2e	N/A

The following paragraphs provide more descriptions and technical details for the above variables and calculations.

For Equations (5) and (6), the VMT of project vehicles and the VMT of displaced autos have been calculated using Equations (1)-(4). The emission factors for displaced autos are obtained from the California Climate Investments Emission Factor Database based on the project region, the first year and the final year of the project component. The emission factors for project vehicles are obtained from the California Climate Investments Emission Factor Database based on their model year and fuel type, which users provide as inputs, and the mid-year of the project component, which is calculated as the average of the first year and the final year, then rounded down. The percentage of renewable energy used for electric vehicle charging is an optional input that users can provide as described below.

In Equation (5), the renewable energy for electric vehicle charging should include only the renewable electricity that is used in addition to the standard grid renewable electricity. Therefore, it includes the renewable electricity that is generated on-site from installed solar panels and other renewable sources, plus the renewable electricity that is purchased from the local utility or electricity provider in addition to the standard grid renewable electricity. For on-site solar power, the percentage of renewable energy should include solar power that is already available on-site or solar power that is planned to be installed outside the scope of the project. Solar panels that are directly funded by the project are considered a component of the project and their emission reductions are calculated separately. Therefore, to avoid double counting, the percentage of renewable energy in Equation (5) should exclude the portion of on-site solar power that is funded by the project.

Finally, the net emission reductions are calculated as follows:

Equation (7): Net Emission Reductions

$$E = \left(AAE_{Displaced} - AAE_{Project} \right) \times QP$$

Table 4. Variables of Equation (7): Net Emission Reductions

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e
AAE	Annual average emissions	MTCO2e per year
Displaced	Indicator of variables associated with displaced passenger autos	N/A
Project	Indicator of variables associated with the project vehicles	N/A
QP	Quantification period	years

For Equations (7), the annual average emissions of the displaced autos and the project vehicles have been calculated using Equations (5) and (6). The quantification period is the number of years between the first year and the final year of the project component.

B.2. Vehicle Replacement

Emission reductions from vehicle replacement are estimated as the difference between the emissions of the baseline vehicles that are replaced by the project and the emissions that project vehicles create. Vehicle types include transit bus, sedan, SUV, shuttle, van, school bus, UTV, medium heavy-duty vehicle / truck, and heavy heavy-duty vehicle / truck.

Replacement of vehicles does not change their VMT. Therefore, the VMT of the baseline vehicles is equal to the VMT of the project vehicles, and is calculated for the first year and the final year of the project component as follows:

Equation (8): VMT in the First Year

$$VMT_1 = V_1 \times (VMT\ Per\ Vehicle)_1$$

Equation (9): VMT in the Final Year

$$VMT_F = V_F \times (VMT\ Per\ Vehicle)_F$$

Table 5. Variables of Equations (8) and (9): VMT

Variable	Variable Definition	Units
VMT	VMT	miles
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A

For Equations (8) and (9), users should input the number of vehicles in the first year and the final year, and the VMT per vehicle in the first year and the final year.

Equations (8) and (9) are used for all vehicle types except UTVs. UTV operations are considered in terms of hours of activity instead of miles traveled. Therefore, UTVs do not have VMT calculations. Instead, their baseline fuel consumption is calculated for the first year and the final year of the project component follows:

Equation (10): UTV Fuel Consumption in the First Year

$$FC_1 = V_1 \times HP \times LF \times BSFC \times H_1$$

Equation (11): UTV Fuel Consumption in the Final Year

$$FC_F = V_F \times HP \times LF \times BSFC \times H_F$$

Table 6. Variables of Equations (10) and (11): UTV Fuel Consumption

Variable	Variable Definition	Units
FC	Fuel consumption of the baseline UTVs	gallons
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
V	Number of the UTVs	N/A
HP	Maximum rated horsepower of the baseline UTVs	brake horsepower (bhp)
LF	Load factor, indicating the average operational level of the baseline UTVs as a fraction of the UTV manufacturer's maximum rated horsepower	N/A
BSFC	Brake specific fuel consumption	gallons per bhp per hour
H	number of hours of operation	hours

For Equation (10) and (11), users should input the maximum rated horsepower, the number of vehicles in the first year and the final year, and the number of hours of operation in the first year and the final year of the project component. The load factor and the brake specific fuel consumption are obtained from the California Climate Investments Emission Factor Database

For replacement of all vehicle types except UTVs, the annual average emissions of the project vehicles and the baseline vehicles are calculated as follows:

Equation (12): Annual Average Emissions of Project Vehicles

$$AAE_{Project} = \left(\frac{VMT_1 + VMT_F}{2}\right) \times EF_{Project} \times (100\% - RE\%) \times 10^{-6}$$

Equation (13): Annual Average Emissions of Baseline Vehicles

$$AAE_{Baseline} = \left(\frac{VMT_1 + VMT_F}{2}\right) \times EF_{Baseline} \times 10^{-6}$$

Table 7. Variables of Equations (12) and (13): Annual Average Emissions

Variable	Variable Definition	Units
AAE	Annual average emissions	MTCO2e per year
VMT	VMT	miles
Project	Indicator of variables associated with the project vehicles	N/A
Baseline	Indicator of variables associated with the baseline vehicles	N/A
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
EF	Vehicle emission factor	grams of CO2e per mile
RE%	Percentage of renewable energy used for electric vehicle charging	N/A
10^{-6}	Conversion of grams of CO2e to MTCO2e	N/A

The following paragraphs provide more descriptions and technical details for the above variables.

For Equations (12) and (13), the VMT of the project vehicles and the baseline vehicles in the first year and final year have been calculated using Equations (8) and (9). The emission factors for the project vehicles and the baseline vehicles are obtained from the California Climate Investments Emission Factor Database based their model years and fuel types, which users provide as inputs, and the mid-year of the project component, which is calculated as the average of the first year and the final year, then rounded down. The percentage of renewable energy used for electric vehicle charging is an optional input that users can provide as described below.

In Equation (12), the renewable energy for electric vehicle charging should include only the renewable electricity that is used in addition to the standard grid renewable electricity. Therefore, it includes the renewable electricity that is generated on-site from installed solar panels and other renewable sources, plus the renewable electricity that is purchased from the local utility or electricity provider in addition to the standard grid renewable electricity. For on-site solar power, the percentage of renewable energy should include solar power that is already available on-site or solar power that is planned to be installed outside the scope of the project. Solar panels that are directly funded by the project are considered a component of the project and their emission reductions are calculated separately. Therefore, to avoid double counting, the percentage of renewable energy in Equation (10) should exclude the portion of on-site solar power that is funded by the project.

For UTV replacement, the annual average emissions of the project UTVs and the baseline UTVs are calculated as follows:

Equation (14): Annual Average Emissions of Project UTVs

$$AAE_{Project} = \left(\frac{FC_1 + FC_F}{2}\right) \times \left(\frac{EDB}{EDE \times EER}\right) \times CCE \times 10^{-6}$$

Equation (15): Annual Average Emissions of Baseline UTVs

$$AAE_{Baseline} = \left(\frac{FC_1 + FC_F}{2}\right) \times CCB \times 10^{-6}$$

Table 8. Variables of Equations (14) and (15): UTV Annual Average Emissions

Variable	Variable Definition	Units
AAE	Annual average emissions	MTCO2e per year
Project	Indicator of variables associated with the project vehicles	N/A
Baseline	Indicator of variables associated with the baseline vehicles	N/A
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
FC	fuel consumption of the baseline UTVs	gallons
EDB	Energy density of the baseline fuel of the UTVs	MJ per gallon
EDE	Energy density of electricity	MJ per kWh
EER	Energy efficiency ratio of electricity relative to baseline fuel	N/A
CCE	Carbon content of electricity	Grams of CO2e per kWh
CCB	Carbon content of the baseline fuel	Grams of CO2e per gallon
10^{-6}	Conversion of grams of CO2e to MTCO2e	N/A

For Equations (14) and (15), the fuel consumption of the baseline UTVs in the first year and the final year have been calculated using Equations (10) and (11). The energy density and carbon content of the baseline fuel and the energy efficiency ratio are obtained from the California Climate Investments Emission Factor Database based the baseline UTV fuel type, which users provide as input. The energy density and carbon content of electricity are available from the California Climate Investments Emission Factor Database.

Finally, the net emission reductions are calculated as follows:

Equation (16): Net Emission Reductions

$$E = (AAE_{Baseline} - AAE_{Project}) \times QP$$

Table 9. Variables of Equation (16): Net Emission Reductions

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e
AAE	Annual average emissions	MTCO2e per year
Baseline	Indicator of variables associated with the baseline vehicles	N/A
Project	Indicator of variables associated with the project vehicles	N/A
QP	Quantification period	years

For Equations (16), the annual average emissions of the baseline vehicles and the project vehicles have been calculated using Equations (12) and (13) for all vehicle types except UTVs, or Equations (14) and (15) for UTVs. The quantification period is the number of years between the first year and final year of the project component.

B.3. Subsidies

Emission reductions from subsidies are estimated as the difference between the emissions of the passenger autos that are displaced by the project and the emissions that project vehicles create. Vehicle types include train, transit bus, sedan, SUV, shuttle, van, standard bicycle, electric bicycle, electric moped, and electric scooter.

Emission reductions for subsidies use the same equations as new or expanded service. The only difference is for vehicle types of train and transit bus in Equations (1) and (2). Trains do not create VMT, so their VMT is zero in Equations (1) and (2). Transit buses create VMT. However, subsidies for transit buses only increase their ridership without creating additional VMT, so their VMT is zero in Equations (1) and (2).

B.4. System / Efficiency Improvements

Emission reductions from system / efficiency improvements use the same equations as subsidies. Vehicle types are also the same as those considered for subsidies. The Clean Mobility Benefits Calculator considers as separate components only because they have different calculations for the travel cost savings co-benefit as will be shown in Section C.5.

B.5. Bike Infrastructure

As mentioned before, emission reductions from bike infrastructure are estimated as emissions of the passenger autos that are displaced by the project.

The annual average VMT of passenger autos that is displaced by bike infrastructure is calculated as follows:

Equation (17): Annual Average VMT of Displaced Passenger Autos

$$AAVMT = DPY \times ADT \times (ATA + KDC) \times GFA \times ATL$$

Table 10. Variables of Equation (17): Annual Average VMT

Variable	Variable Definition	Units
AAVMT	Annual average VMT of displaced passenger autos	miles per year
DPY	Annual days of use of the new facility	days per year
ADT	Average two-way daily traffic on the road parallel to the new facility	trips per day
ATA	Active transportation adjustment factor	N/A
KDC	Key destination credit	N/A
GFA	growth factor adjustment	N/A
ATL	average trip length on the new facility	miles per trip

The following paragraphs provide more descriptions and technical details for the above variables.

For Equation (17), users should input the annual days of use of the new infrastructure and the average two-way daily traffic on the road parallel to the new infrastructure. Suggested value for the annual days of the use is 200 days per year.

For Equation (17), the Benefits Calculator determines the active transportation adjustment factor from Tables 1 which needs users to input the one-way facility length in miles and determine whether the new infrastructure is in a university town with population less than 250,000 or not. Users should measure and input the facility length in one direction because the active transportation adjustment factor from Table 2 already accounts for two-way trips.

Table 11. Adjustment Factors for Active Transportation

Average Daily Traffic (vehicle trips per day)	One-way Facility Length (miles)	Adjustment Factor for Population > 250,000 or Non-university Town with Population < 250,000	Adjustment Factor for University Town with Population < 250,000
1 to 12,000	≤ 1	0.0019	0.0104
1 to 12,000	1.01 to 2	0.0029	0.0155
1 to 12,000	> 2	0.0038	0.0207
12,001 to 24,000	≤ 1	0.0014	0.0073
12,001 to 24,000	1.01 to 2	0.0020	0.0109
12,001 to 24,000	> 2	0.0027	0.0145
24,001 to 30,000	≤ 1	0.0010	0.0052
24,001 to 30,000	1.01 to 2	0.0014	0.0078
24,001 to 30,000	> 2	0.0019	0.0104

For Equation (17), the Benefits Calculator determines the key destination credit from Table 2 which needs users to input the number of key destinations within 1/4 mile and within 1/2 mile of any part of the new facility. Examples of key destinations include bank or post office, child care center, grocery store, medical center, office park, and pharmacy.

Table 12. Key Destination Credits For Active Transportation

Number of Key Destinations	Credit Within ½ Mile of Facility	Credit Within ¼ Mile of Facility
0 to 2	0	0
3	0.0005	0.001
4 to 6	0.0010	0.002
≥ 7	0.0015	0.003

For Equation (17), the Benefits Calculator determines the growth factor adjustment based on the existing bikeway class and the new bikeway class which users should provide as inputs. The growth adjustment factor is 1 for new Class II bike lanes, 1.54 for new Class I bike paths or Class IV cycle tracks, and 0.54 for converting Class II bike lanes to Class IV cycle tracks.

For Equation (17), the Benefits Calculator considers 1.5 miles as default value for the average trip length on the new facility.

More details about Equation (17) are presented in the *technical documentation that CARB staff have developed for bike facilities*.

The annual average emissions of the displaced passenger autos are calculated as follows:

Equation (18): Annual Average Emissions

$$AAE_{Displaced} = AAVMT \times \left(\frac{EF_{Displaced,1} + EF_{Displaced,F}}{2}\right) \times 10^{-6}$$

Table 13. Variables of Equation (18): Annual Average Emissions

Variable	Variable Definition	Units
AAE	Annual average emissions	MTCO2e per year
AAVMT	Annual average VMT of displaced passenger autos	miles per year
Displaced	Indicator of variables associated with displaced passenger autos	N/A
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
EF	Vehicle emission factor	grams of CO2e per mile
10^{-6}	Conversion of grams of CO2e to MTCO2e	N/A

For Equations (18), the annual average VMT of displaced passenger autos has been calculated using Equation (17). The emission factors for displaced autos are obtained from the California Climate Investments Emission Factor Database based on the project region and the first year of the project component, which users should provide as inputs, and the final year of the project component, which the Benefits Calculator determines based on the following default values for the quantification period of the project component: 20 years for new Class I bike paths, 15 years for new Class II bike lanes or Class IV cycle tracks, and 15 years for converting Class II bike lanes to Class IV cycle tracks.

Finally, the net emission reductions are calculated as follows:

Equation (19): Net Emission Reductions

$$E = AAE_{Displaced} \times QP$$

Table 14. Variables of Equation (19): Net Emission Reductions

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e
AAE	Annual average emissions	MTCO2e per year
Displaced	Indicator of variables associated with displaced passenger autos	N/A
QP	Quantification period	years

For Equations (19), the annual average emissions of the displaced passenger autos have been calculated using Equations (18). The quantification period is a default value that the Benefits Calculator determines as described for Equation (18).

B.6. Pedestrian Infrastructure

Emission reductions from pedestrian infrastructure use the same equations as bike infrastructure. Their only differences are in the following default values: For pedestrian infrastructure, the growth factor adjustment is 1, and the average trip length is 0.3 miles for Equation (17), and the quantification period is 20 years for Equations (18) and (19).

More details about pedestrian infrastructure quantification methodology are presented in the *technical documentation that CARB staff have developed for pedestrian facilities*.

B.7. Solar PV Generation

Emission reductions from solar PV generation are estimated as the displaced emissions of the electricity grid, which are the emissions that would be created if the amount of power that solar panels provide were provided by the electricity grid. This is calculated as follows:

Equation (20): Displaced Emissions of Electricity Grid

$$E = \sum_{n=1}^{30} (1 - DR)^{n-1} \times ASEG \times EGEF$$

Table 15. Variables of Equation (20): Displaced Emissions of Electricity Grid

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e
n	Index of summation (sigma) from the first year to 30 years covering the estimated useful life of solar panels	N/A
DR	System degradation rate of solar panels	N/A
ASEG	Annual solar electricity generated by solar panels	kWh per year
EGEF	Electricity grid emission factor	MTCO2e per kWh

The following paragraphs provide more descriptions and technical details for the above variables.

For Equation (20), users should input the annual electricity generated by solar panels. To obtain this data, users should run the PVWatts Calculator, which is an external tool available from *the PVWatts webpage.*

For Equation (20), the electricity grid emission factor are obtained from the California Climate Investments Emission Factor Database. The Benefits Calculator considers a default value of 0.005 or 0.5% for the system degradation rate

B.8. Lawn and Garden Equipment Replacement

Emission reductions from lawn and garden equipment replacement are estimated as the difference between emissions of the equipment that are replaced by the project and the emissions that project equipment create. Equipment types include commercial the walk behind lawn mowers, standing ride mowers, ride-on mowers, chainsaws, leaf blowers / vacuums, and trimmers / edgers / brush cutters.

The net emission reductions are calculated as follows:

Equation (21): Net Emission Reductions

$$E = N \times LGEF$$

Table 16. Variables of Equation (21): Net Emission Reductions

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e
N	Number of pieces of lawn and garden equipment	N/A
LGEF	Lawn and garden equipment emission factor over lifetime	MTCO2e

For Equation (21), users should input the equipment type and the number of pieces of equipment. The emission factor for each equipment type is obtained from the California Climate Investments Emission Factor Database. The lawn and garden equipment emission factors consider the following default values for the commercial equipment lifetime: 5 years for walk behind lawn mowers, standing ride mowers, and ride-on mowers, and 4 years for leaf blowers / vacuums, chainsaws, and trimmers / edgers / brush cutters.

B.9. Tree Planting

Emission reductions from tree planting are estimated as the emissions that are stored or removed from the atmosphere by the trees, plus the emissions that are reduced by energy savings as a result of strategically planting trees to shade buildings. To obtain the necessary inputs for this calculation, users should run *the external i-Tree Planting Calculator.*

Users should input the lifetime of the tree planting project in the "years of project" input of the i-Tree Planting Calculator. The lifetime is the number of years for tree growth, which is considered to be the number of years between planting the trees and 40 years after the project starts. For example, if a project starts in 2024 and plants a tree in 2026, the lifetime is 38 years, which means 38 years of growth until 2064.

Users should input zero in the "tree mortality over project lifetime" input of the i-Tree Planting Calculator to avoid double counting the mortality rate, because Equation (22) has already applied the tree mortality rate of 3% separately.

Users can keep the default values of the i-Tree Planting Calculator for its "electricity emissions factor" and the "fuel emissions factor" inputs. The emission factors of the i-Tree Planting Calculator do not impact the outputs that are needed as inputs for the following calculations.

After running the i-Tree Planting Calculator, users should copy the following outputs from the i-Tree Planting Calculator and input them into the Clean Mobility Benefits Calculator:

- The "CO2 sequestered (pounds)" output of the i-Tree Planting Calculator should be input into the Clean Mobility Benefits Calculator, which converts it to units of MTCO2e for the trees' lifetime emission reductions;
- The "electricity saved (kWh)" output of the i-Tree Planting Calculator should be input into the Clean Mobility Benefits Calculator for the buildings' lifetime electricity usage saving; and
- The "fuel saved (MMBtu)" output of the i-Tree Planting Calculator should be input into the Clean Mobility Benefits Calculator for the buildings' lifetime natural gas usage saving.

The emission reductions are calculated for each group of trees as follows:

Equation (22): Net Emission Reductions

$$E = (TE + BEUS \times EGEF + BNGS \times NGEF) \times 0.97^{10 - Min(YC, 9)} \times 0.95$$

Table 17. Variables of Equation (22): Net Emission Reductions

Variable	Variable Definition	Units
E	Net emission reductions over the lifetime	MTCO2e
TE	Trees' lifetime emission reductions	MTCO2e
BEUS	Buildings' lifetime electricity usage saving	kWh
EGEF	Electricity grid emission factor	MTCO2e per kWh
BNGS	Buildings' lifetime natural gas usage saving	MMBtu
NGEF	Natural gas combustion emission factor	MTCO2e per MMBtu
10	Indicating the first ten years after planting when trees are at the greatest risk of mortality	years
0.97	Applying an annual tree mortality rate of 3% for the years after the period of establishment and replacement care through year 10, at which time tree mortality is substantially reduced.	N/A
YC	Number of years of establishment and replacement care provided by the project to reduce the risk of mortality of trees	years
Min	Minimum function which returns the smaller value of *YC* and 9 in order to ensure that at least one year of mortality of trees is considered	N/A
0.95	Applying a deduction of 5% in emission reductions to account for the emissions that are created by planting trees, maintenance, and other activities related to project implementation	N/A

For Equation (22), users should input the i-Tree Planting Calculator outputs as described before, and the number of years of establishment and replacement care. The electricity grid emission factor and the natural gas combustion emission factor are obtained from the California Climate Investments Emission Factor Database.

Technical details of tree planting projects are available from the *quantification methodology that CARB staff have developed for the Urban and Community Forestry Program*.

Section C. Co-Benefits Assessment

This section provides the quantification or evaluation methods for the following environmental, social and economic co-benefits of mobility projects:

1. Local air pollutant emission reductions
2. Net passenger auto VMT reductions
3. Net energy use reductions
4. Net energy cost savings
5. Net travel cost savings
6. Jobs supported by the project
7. Community engagement

The Clean Mobility Benefits Calculator has integrated all the quantification and evaluation methods that are presented in this section.

C.1. Local Air Pollutant Emission Reductions

Net reductions of local air pollutant emissions are estimated as the difference between air pollutant emissions of the baseline scenario and the air pollutant emissions created by the project. This co-benefit is considered for all types of project components except non-quantifiable components.

The equations for net emission reductions of $PM_{2.5}$, NOx, ROG, and Diesel PM are calculated similar to the equations for net GHG emission reductions. The main difference is that the air pollutant emission factors are in units of pounds per mile. These emission factors are obtained from the California Climate Investments Emission Factor database.

C.2. Net Passenger Auto VMT Reductions

Net passenger auto VMT reductions are estimated as the difference between the passenger auto VMT that is displaced by the project and the passenger auto VMT that is created by passenger autos of the project. This co-benefit is considered for the following project component types:

- New or expanded service
- Subsidies
- System / efficiency improvements
- Bike infrastructure
- Pedestrian infrastructure

For new or expanded service, subsidies, and system / efficiency improvements project components, sedans and SUVs are the only vehicle types that are passenger autos, so their VMT should be subtracted from the displaced passenger auto VMT to obtain the net reductions of passenger auto VMT. For other vehicle types, the net passenger auto VMT reduction is the displaced passenger auto VMT. For bike infrastructure and pedestrian infrastructure, the net passenger auto VMT reduction is the displaced passenger auto VMT. This is calculated as follows:

Equation (23): Net Passenger Auto VMT Reductions

For Sedans and SUVs:

$$VMT_{Net} = \left(\frac{VMT_{Displaced,1} + VMT_{Displaced,F}}{2} - \frac{VMT_{Project,1} + VMT_{Project,F}}{2} \right) \times QP$$

For Other Vehicles:

$$VMT_{Net} = \frac{VMT_{Displaced,1} + VMT_{Displaced,F}}{2} \times QP$$

For Bike Infrastructure and Pedestrian Infrastructure:

$$VMT_{Net} = AAVMT \times QP$$

Table 18. Variables of Equation (23): Passenger Auto VMT Reduction

Variable	Variable Definition	Units
VMT	VMT	miles
Net	Indicator of net reductions	N/A
Displaced	Indicator of variables associated with displaced passenger autos	N/A
Project	Indicator of variables associated with the project vehicles	N/A
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
AAVMT	Annual average VMT of displaced passenger autos	miles per year
QP	Quantification period that is used for calculation of GHG emission reductions	years

For Equation (23), the VMT of project vehicles and the VMT of displaced autos have been calculated using Equations (1)-(4). The annual average VMT of displaced passenger autos for bike infrastructure and pedestrian infrastructure has been calculated using Equation (17)

C.3. Net Energy Use Reductions

Net energy use reductions are estimated as the difference between the energy consumption of the baseline scenario and the energy consumption of the project. This co-benefit is considered for all types of project components except non-quantifiable components.

The equations for net energy use reductions are calculated similar to the equations for net GHG emission reductions. The main difference is that, instead of emission factors, the net energy use calculations use GGE factors, in units of GGE per mile. The GGE factors are obtained from the California Climate Investments Emission Factor Database.

C.4. Net Energy Cost Savings

Net energy cost savings for the operators or providers of mobility services are estimated as the difference between the cost of energy in the baseline scenario and the cost of energy in the project scenario. This co-benefit is considered for the following project component types:

- Vehicle replacement
- Solar PV generation
- Lawn and garden equipment replacement

The equations for net energy cost savings are calculated similar to the equations for net energy saving. For each fuel type, the GGE factor (GGE per mile) is multiplied by the cost factor ($ per GGE) to obtain the energy cost ($ per mile). The GGE factors are obtained from the California Climate Investments Emission Factor Database. The cost factors, along with more technical details of the energy cost saving methodology are presented in the *California Climate Investments Energy Cost Savings Co-Benefit Assessment Methodology*.

C.5. Net Travel Cost Savings

Net travel cost savings for the users of mobility services are estimated as the difference between the cost of travel in the baseline scenario and the cost of travel in the project scenario. This co-benefit is considered for the following project component types:

- New or expanded service
- Subsidies
- System / efficiency improvement
- Bike infrastructure
- Pedestrian infrastructure

The cost of travel with passenger autos that are displaced by the project is calculated as follows:

Equation (24): Travel Cost of Displaced Passenger Autos

$$TC_{Displaced} = CPM_{Displaced} \times \frac{VMT_{Displaced,1} + VMT_{Displaced,F}}{2} \times QP$$

Table 19. Variables of Equation (24): Travel Cost of Displaced Passenger Autos

Variable	Variable Definition	Units
TC	Travel Cost	$
Displaced	Indicator of variables associated with displaced passenger autos	N/A
CPM	Cost per mile of travel	$ per mile
VMT	VMT	miles
1	Indicator of variables associated with the first year	N/A
F	Indicator of variables associated with the final year	N/A
QP	Quantification period that is used for calculation of emission reductions	years

For Equation (24), the VMT of displaced autos in the first year and the final year have been calculated using Equations (3) and (4). The cost per mile of travel is obtained from the *California Climate Investments Travel Cost Savings Co-Benefit Assessment Methodology*.

The cost of travel in the project scenario is calculated as follows:

Equation (25): Travel Cost of Project Scenario

For New or Expanded Service and System / Efficiency Improvements:

$$TC_{Project} = A \times ANF \times FV \times QP$$

For Subsidies:

$$TC_{Project} = -(1 - A) \times ANS \times SV \times QP$$

For Bike Infrastructure:

$$TC_{Project} = CPM_{Project} \times AAVMT \times QP$$

For Pedestrian Infrastructure:

$$TC_{Project} = 0$$

Table 20. Variables of Equation (25): Travel Cost of Project Scenario

Variable	Variable Definition	Units
TC	Travel Cost	$
Project	Indicator of variables associated with the project scenario	N/A
A	Adjustment factor that is used for quantification of emission reductions	N/A
ANF	Annual number of fares associated with the project	N/A
FV	Average fare value	$ per fare
ANS	Annual number of subsidies associated with the project	N/A
SV	Average subsidy value	$ per subsidy
CPM	Cost per mile of travel	$ per mile
AAVMT	Annual average VMT of displaced passenger autos	miles per year
QP	Quantification period that is used for calculation of emission reductions	years

For Equation (25), users should input the annual number of fares and the average fare value, or the annul number of subsidies and the average subsidy value. The annual average VMT of displaced passenger autos for bike infrastructure has been calculated using Equation (17). The cost per mile of travel is obtained from the *California Climate Investments Travel Cost Savings Co-Benefit Assessment Methodology*.

Finally, the net savings in travel cost are calculated as follows:

Equation (26): Net Travel Cost Saving

$$TC_{Net} = TC_{Displaced} - TC_{Project}$$

Table 21. Variables of Equation (26): Net Travel Cost Saving

Variable	Variable Definition	Units
TC	Travel Cost	$
Net	Indicator of net reductions	N/A
Displaced	Indicator of variables associated with displaced passenger autos	N/A
Project	Indicator of variables associated with the project	N/A

For Equation (26), the travel cost of the passenger autos that are displaced by the project has been calculated using Equation (24). The travel cost in the project scenario has been calculated using Equation (25).

C.6. Jobs Supported

The jobs co-benefit refers to the jobs supported, not created, by the project. A job is defined as one full-time equivalent employee position over one year, equal to approximately 2,000 hours of work. Jobs supported by the project include direct, indirect, and induced employment. The jobs modeling tool within the Clean Mobility Benefits Calculator prospectively estimates the number of direct, indirect, and induced jobs supported by the project. Technical details of this modeling tool are presented in the *California Climate Investments Jobs Co-Benefit Assessment Methodology*.

C.7. Community Engagement

Community engagement refers to the process of cultivating active public participation in planning, design, and implementation of the projects. The community engagement assessment questionnaire within the Clean Mobility Benefits Calculator evaluates the quantity, quality, and equity of community engagement conducted by the project. Technical details of this assessment are presented in the *California Climate Investments Community Engagement Co-Benefit Assessment Methodology*.

Section D. References

The following references were used in the development of this Quantification Methodology and the Clean Mobility Benefits Calculator.

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