California Air Resources Board

Quantification Methodology

California Department of Transportation
Low Carbon Transit Operations Program

California Climate Investments

DRAFT
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List of Acronyms and Abbreviations

Acronym	Term
CARB	California Air Resources Board
Caltrans	California Department of Transportation
CB	commuter bus
CC	cable car
CMAQ	Congestion Mitigation and Air Quality
CR	commuter rail
Diesel PM	diesel particulate matter
DMU	diesel multiple unit
DO	directly operated
DR	demand response
DT	demand response taxi
EMU	electric multiple unit
FB	ferryboat
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
HR	heavy rail
kWh	kilowatt hours
lbs	pounds
LCTOP	Low Carbon Transit Operations Program
LR	light rail
MB	bus
MG	monorail/automated guideway
MJ	megajoule
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	nitrous oxide
PM	particulate matter
$PM_{2.5}$	particulate matter with a diameter less than 2.5 micrometers
PM_{10}	particulate matter with a diameter less than 10 micrometers
PT	purchased transportation
RB	bus rapid transit
ROG	reactive organic gas
SAFE	Safer Affordable Fuel-Efficient Vehicles Rule
SR	streetcar rail
TAC	transit and connectivity
TB	trolley bus
TN	transportation network company
TX	taxi
VMT	vehicle miles traveled
VP	vanpool
YR	hybrid rail

List of Definitions

Term	Definition
Adjustment Factor	Discount factor applied to annual ridership to account for transit-dependent riders.
Baseline Vehicle	The vehicle that is currently owned/in operation that will be replaced by a new zero- or near zero-emission vehicle purchase, or the vehicle that would have been purchased if not for this project (e.g., 2022 diesel bus).
CMAQ Methods	The methods to find the cost-effectiveness of funding air quality projects for evaluating motor vehicle registration fee projects and Congestion Mitigation and Air Quality Improvement Projects.
Co-benefit	A social, economic, or environmental benefit as a result of the proposed project in addition to the GHG reduction benefit.
Directly Operated	Transportation service provided directly by a transit agency, using their employees to supply the necessary labor to operate the revenue vehicles. This includes instances where an agency's employees provide purchased transportation (PT) services to the agency through a contractual agreement.
Energy and Fuel Cost Savings	Changes in energy and fuel costs to the transit operator as a result of the project. Savings may be achieved by changing the quantity of energy or fuel used, conversion to an alternative energy or fuel source/vehicle, or renewable energy or fuel generation to displace existing fuel purchases.
Fuel/Energy Reduction	Quantification method that identifies projects that result in using less fuel or energy from existing transit services or producing renewable energy/fuel. This includes projects that reduce transit vehicle miles traveled (VMT) and idling or generate renewable electricity. For example, optimizing bus routes to reduce diesel fuel usage or installing solar panels to displace grid electricity is a project that would use the "fuel/energy reduction" quantification method.
Increased Ridership	Quantification method that identifies projects that result in increased ridership for existing routes. This may include projects that increase service levels, reliability, safety, or decrease travel times. For example, implementing integrated ticketing and

Term	Definition
	improving scheduling systems is a project that would use the "increased ridership" quantification method.
Key Variable	Project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., passenger VMT reductions, renewable energy generated).
New Service	Quantification method that identifies projects that result in a new transportation service. This may include expansion of an existing service. For example, constructing a new rail line or adding new buses to an existing transit route is a project that would use the "new service" quantification method.
Project Type	For the purposes of the LCTOP Quantification Methodology, eligible projects fall into fifteen project types that meet the objectives of the program and for which there are methods to quantify GHG emission reductions.
Purchased Transportation	Transportation service provided to a public transit agency or governmental unit from a public or private transportation provider based on a written contract. The provider is obligated in advance to operate public transportation services for a public transit agency or governmental unit for a specific monetary consideration, using its own employees to operate revenue vehicles.
Quantification Period	Number of years that the project will provide GHG emission reductions that can reasonably be achieved and assured. Sometimes referred to as "Project Life" or "Useful Life".
Vehicle Replacement	Identifies projects that replace a baseline vehicle(s) with a new vehicle(s) without resulting in new service.
Technology Conversion	Quantification method that identifies projects that result in the use of cleaner vehicles, technologies, or fuels. For example, replacing existing diesel buses with electric buses or using renewable natural gas instead of fossil natural gas is a project that would use the "technology conversion" quantification method.
Travel Cost Savings	Changes in travel costs to the user as a result switching travel modes.
Unlinked Passenger Trips	Number of passengers who board public transportation vehicles.

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (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.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, benefits calculator tools, and associated user guides. 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 available on the Expenditure Record webpage.

For the California Department of Transportation (Caltrans) Low Carbon Transit Operations Program (LCTOP), CARB staff developed this LCTOP Quantification Methodology and accompanying LCTOP Benefits Calculator Tool to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project type. This methodology uses calculations to estimate GHG emission reductions and avoided GHG emissions from transit operation and capital projects.

The LCTOP Benefits Calculator Tool automates methods described in this document, outlines documentation requirements, and provides a link to a step-by-step user guide with project examples. Projects will report the total project GHG emission reductions and co-benefits estimated using the LCTOP Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds. The LCTOP Benefits Calculator Tool is available for download on the California Climate Investments Resources webpage.

Using many of the same inputs required to estimate GHG emission reductions, the LCTOP Benefits Calculator Tool estimates the following co-benefits and key variables from LCTOP projects:

- Local reactive organic gas (ROG) emission reductions (lbs),
- Remote ROG emission reductions (lbs),
- Local nitrous oxide (NO_x) emission reductions (lbs),
- Remote NO_x emission reductions (lbs),

- Local Particulate Matter with a diameter less than 2.5 micrometers ($PM_{2.5}$) emission reductions (lbs),
- Remote $PM_{2.5}$ emission reductions (lbs),
- Local Diesel Particulate Matter (PM) emission reductions (lbs),
- Remote Diesel PM emission reductions (lbs),
- Passenger Vehicle Miles Traveled (VMT) reductions (miles),
- Fossil fuel use reductions (gallons),
- Renewable energy generated in kilowatt hours (kWh),
- Fossil fuel energy use reductions (kWh),
- Passenger travel cost savings ($), and
- Energy and fuel cost savings ($).

Additional co-benefits for which CARB assessment methodologies were not incorporated into the LCTOP Benefits Calculator Tool may also be applicable to the project. Applicants should consult the Caltrans LCTOP Guidelines, solicitation materials, and agreements to ensure they meet LCTOP requirements. All CARB co-benefit assessment methodologies are available on the California Climate Investments Co-benefits webpage.

Methodology Development

CARB and Caltrans developed this LCTOP Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability, 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:

- Applies at the project-level;
- Provides uniform methods to be applied statewide and is accessible by all applicants;
- Uses existing and proven tools and methods;
- Uses project-level data, where available and appropriate; and
- Results in GHG and air pollutant emission reduction estimates that are conservative and supported by empirical literature.

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the LCTOP project types. CARB also consulted with Caltrans to determine project-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level. CARB released the Draft LCTOP Quantification Methodology and Draft LCTOP Benefits Calculator Tool for public comment on January 10, 2024. This Final LCTOP Quantification Methodology and accompanying LCTOP Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the LCTOP Guidelines.

Congestion Mitigation and Air Quality (CMAQ) Methods were used as the basis for developing the GHG emission reduction estimates for certain project components, specifically transit and connectivity (TAC) features. The CMAQ Methods are a set of equations for evaluating the cost-effectiveness of certain types of transportation projects, including bicycle paths, vanpools, and new bus service. CARB and Caltrans developed the CMAQ Methods, which are used statewide by transportation agencies to assess criteria and toxic air pollutant emission reductions from transportation projects competing for State motor vehicle fee and federal CMAQ funding. All of the CMAQ Methods equations and assumptions needed for this quantification method are included in this document, and some assumptions have been modified as necessary. Therefore, the equations used in this Quantification Methodology are referred to as TAC Methods. The CMAQ Methods document can be accessed on the CMAQ webpage.

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, lessening the impacts and effects of climate change, and strengthening community engagement. As they become available, co-benefit assessment methodologies are posted on the California Climate Investments Co-benefits webpage.

Tools

The LCTOP Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available on the California Climate Investments Resources webpage. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the LCTOP Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The LCTOP Benefits Calculator Tool can be downloaded on the California Climate Investments Resources webpage.

Updates

CARB staff periodically review each quantification methodology and benefits calculator tool to evaluate their effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the quantified projects. CARB updated the previous version of the LCTOP Quantification Methodology to enhance the analysis and provide additional clarity. The changes include:

- Updated fuel type Energy Economy Ratios based on most recent Emission Factor Database updates, added Energy Economy Ratios for hydrogen fuels relative to electricity.
- Updated back-end calculations to be more efficient, fixed various known bugs.

Program Assistance

CARB staff will provide feedback on the quantification portions of the LCTOP Allocation Requests to check if the methods described in this document are used to reasonably estimate GHG emission reductions and air pollutant emission co-benefits for the proposed project. Applicants should use the following resources for additional questions and comments:

- Questions on this document should be sent to the GGRF program email.
- For more information on CARB efforts to support implementation of GGRF investments, see the California Climate Investments webpage.
- Questions pertaining to LCTOP should be sent to the LCTOP program email.

Section B. Methods

The following section provides details on the methods supporting emission reductions in the LCTOP Benefits Calculator Tool.

Project Types

Caltrans developed 15 project types that meet the objectives of LCTOP and have methods to quantify GHG emission reductions. Other project features may be eligible for funding under LCTOP; however, each project requesting GGRF funding must include at least one of the following:

- Provision of a new expanded/enhanced transit service;
- Creation of new alternative transportation services (e.g., new or expanded car-sharing program);
- Purchase of replacement vehicle(s) and equipment/infrastructure in support of new expanded/enhanced transit service;
- Purchase, construction, and installation of equipment and facilities needed to provide expanded/enhanced transit service;
- Purchase of expansion zero-emission vehicle(s) and equipment/infrastructure in support of new expanded/enhanced transit service;
- Purchase, construction, and/or installation of infrastructure to support zero-emission or low-emission vehicles in support of new expanded/enhanced transit service;
- Purchase, construction, and installation of renewable energy/fuel for transit facilities in support of new expanded/enhanced transit service;
- Purchase of expansion zero-emission vehicle(s) (may include equipment/infrastructure);
- Purchase of replacement zero-emission vehicle(s) (may include equipment/infrastructure);
- Purchase, construction, and/or installation of infrastructure, equipment, or facilities to support zero-emission vehicle(s);
- Purchase and installation of equipment on transit vehicles to encourage increased transit ridership;
- Purchase, construction, and/or installation of transit-related amenities or infrastructure to encourage increased transit ridership;
- Purchase and construction of active transportation facilities that connect to stops/stations and encourage ridership;
- Implementation of free or reduced fares; and
- Network/fare integration.

General Approach

Methods used in the LCTOP Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by quantification method are provided in this section. These methods account for emission reductions from displaced vehicle miles traveled, vehicle and equipment replacement, and the generation and use of renewable fuels/energy. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

In general, the GHG emission reductions, air pollutant emission co-benefits, and key variables are estimated in the LCTOP Benefits Calculator Tool using the quantification approaches by project type outlined in Table 1 below.

Table 1. General Approach to Quantification by Method

New Service
Emission Reductions = Emission Reductions from Displaced Autos – Emissions from New Service

Increased Ridership
Emission Reductions = Emission Reductions from Displaced Autos

Technology Conversion
Emission Reductions = Emissions from Displaced (Baseline) Vehicle – Emissions from New Vehicle

Fuel/Energy Reductions
Emission Reductions = Emission Reductions from Reduced Fuel/Energy Usage or Displaced Fuel/Energy Usage from Renewable Energy/Fuel Production

Based upon the project type selected, one or a combination of the four quantification methods shown in Table 1 will apply. The 15 project types fall into five possible quantification method combinations, including additional optional quantification methods available dependent upon the project type, as shown in Table 2.

Table 2. Project Types by Quantification Method

Project Type	Method
Provision of a new expanded/enhanced transit service	New Service (Optional Technology Conversion and Fuel/Energy Reductions)
Creation of new alternative transportation services (e.g., new or expanded car-sharing program)	New Service (Optional Technology Conversion and Fuel/Energy Reductions)
Purchase, construction, and/or installation of infrastructure to support zero-emission or low-emission vehicles in support of new expanded/enhanced transit service	New Service (Optional Technology Conversion and Fuel/Energy Reductions)
Purchase, construction, and installation of equipment and facilities needed to provide expanded/enhanced transit service	New Service (Optional Technology Conversion and Fuel/Energy Reductions)
Implementation of free or reduced fares	Increased Ridership (Optional Fuel/Energy Reductions)
Network/fare integration	Increased Ridership (Optional Fuel/Energy Reductions)
Purchase, construction, and/or installation of transit-related amenities or infrastructure to encourage increased transit ridership	Increased Ridership (Optional Fuel/Energy Reductions)
Purchase and construction of active transportation facilities that connect to stops/stations and encourage ridership	Increased Ridership (Optional Fuel/Energy Reductions)
Purchase and installation of equipment on transit vehicles to encourage increased transit ridership	Increased Ridership (Optional Fuel/Energy Reductions)
Purchase expansion zero-emission vehicle(s) (may include equipment/infrastructure)	Technology Conversion (Optional Fuel/Energy Reductions)
Purchase replacement zero-emission vehicle(s) (may include equipment/infrastructure)	Technology Conversion (Optional Fuel/Energy Reductions)
Purchase, construction, and/or installation of infrastructure, equipment, or facilities to support zero-emission vehicle(s)	Technology Conversion (Optional Fuel/Energy Reductions)
Purchase of expansion zero-emission vehicle(s) and equipment/infrastructure in support of new expanded/enhanced transit service	New Service and Technology Conversion (Optional Fuel/Energy Reductions)
Purchase of replacement vehicle(s) and equipment/infrastructure in support of new expanded/enhanced transit service	New Service and Technology Conversion (Optional Fuel/Energy Reductions)
Purchase, construction, and installation of renewable energy/fuel for transit facilities in support of new expanded/enhanced transit service	New Service and Fuel/Energy Reductions

A. Emission Reductions from New Service

Equation 1 estimates both the GHG and air pollutant emission reductions from New Service, calculated as the difference between the emission reductions from displaced autos and emissions associated with operation of the new service.

Equation 1: Emission Reductions from New Service

$$E = E_{Reduced} - E_{New}$$

Table 3. Variables of Equation 1: Emission Reductions from New Service

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e or lbs
$E_{Reduced}$	Total emission reductions from displaced auto VMT	MTCO2e or lbs
E_{New}	Total emissions from new service	MTCO2e or lbs

Equation 2 calculates the total emission reductions associated with auto VMT displaced by the new service.

Equation 2: Emission Reductions from Displaced Auto VMT

$$E_{Reduced} = \frac{E_{Reduced\_Yr1} + E_{Reduced\_YrF}}{2} \times QP$$

Table 4. Variables of Equation 2: Emission Reductions from Displaced Auto VMT

Variable	Variable Definition	Units
$E_{Reduced}$	Total emission reductions from displaced auto VMT	MTCO2e or lbs
$E_{Reduced\_Yr1}$	Emission reductions from displaced autos in first year	MTCO2e or lbs
$E_{Reduced\_YrF}$	Emission reductions from displaced autos in final year	MTCO2e or lbs
QP	Quantification period	years

Equation 3 calculates the annual emission reductions associated with auto VMT displaced from the project.

Equation 3: Annual Emission Reductions from Displaced Auto VMT

$$E_{Reduced\_Yr} = \frac{AutoVMT_{Displaced\_Yr} \times EF_{Yr}}{CF}$$

Table 5. Variables of Equation 3: Annual Emissions Reductions from Displaced Auto VMT

Variable	Variable Definition	Units
$E_{Reduced\_Yr}$	Annual emission reductions from displaced auto VMT	MTCO2e/year or lbs/year
$AutoVMT_{Displaced\_Yr}$	Estimated annual VMT displaced attributed to the operation of the new service	Miles/year
EF_{Yr}	Emission Factor in the first or final year (based on weighted fleet average)	Grams/mile
CF	Conversion factor	Grams/MTCO2e or grams/lb

Equation 4 calculates the annual auto VMT displaced by the new service.

Equation 4: Annual Auto VMT Displaced

$$AutoVMT_{Yr} = R_{Yr} \times A \times L$$

Table 6. Variables of Equation 4: Annual Auto VMT Displaced

Variable	Variable Definition	Units
$AutoVMT_{Yr}$	Annual Auto VMT displaced in the first or final year	Miles
R_{Yr}	Annual increase in unlinked passenger trips directly associated with the first or final year of the project	Riders
A	Adjustment factor to account for transit dependency. Use documented, project-specific data or system average development from recent, statistically-valid survey or default. Applicants may use default values in Appendix A for similar service.	N/A
L	Estimated length of average unlinked passenger trip directly associated with the project, calculated as passenger-miles divided by unlinked trips. Applicants may use data reported to National Transit Database (Appendix A) for similar service.	Miles/rider

Equation 5 calculates the total emissions associated with the operation of the new service.

Equation 5: Emissions from New Service

$$E_{New} = AE_{New} \times QP$$

Table 7. Variables of Equation 5: Emissions from New Service

Variable	Variable Definition	Units
E_{New}	Total emissions from new service	MTCO2e or lbs
AE_{New}	Average annual emissions from new service	MTCO2e/year or lbs/year
QP	Quantification period	years

Equation 6 calculates the annual emission estimates associated with the operation of the new service. For train and ferry services, annual emissions may alternatively be calculated based upon inputs for annual fuel consumption. Train services include heavy rail, light rail, and diesel multiple units/electric multiple units (DMUs/EMUs).

Equation 6: Annual Emissions from New Service

$$AE_{New} = \frac{NSVMT \times NSEF \times HDR}{CF} \quad \textbf{Or (for train/ferry service only)} \quad AE_{New} = \frac{NSFuel \times FuelEF \times HDR}{CF}$$

Table 8. Variables of Equation 6: Annual Emissions from New Service

Variable	Variable Definition	Units
AE_{New}	Average annual emissions from new service	MTCO2e/year or lbs/year
NSVMT	Estimated annual VMT attributed to the operation of the new service	Miles
NSEF	Emission factor based on service type, in the mid-year of the project	Grams/miles
NSFuel	Estimated annual fuel attributed to the operation of the new service- only available for train and ferry services	Unit of fuel
FuelEF	Emission factor based on fuel type, and engine tier for train, in the mid-year of the project	Grams/unit of fuel
HDR	Hybrid discount rate (0.8), if applicable	N/A
CF	Conversion factor	Grams/MTCO2e or grams/lb

B. Emission Reductions from Increased Ridership

Equation 7 estimates the GHG and air pollutant emission reductions from Increased Ridership as the emission reductions from displaced auto VMT.

Equation 7: Emission Reductions from Increased Ridership

$$E = E_{Reduced}$$

Table 9. Variables of Equation 7: Emission Reductions from New Service

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e or lbs
$E_{Reduced}$	Total emission reductions from displaced auto VMT	MTCO2e or lbs

Equation 8 calculates the total emission reductions associated with auto VMT displaced.

Equation 8: Emission Reductions from Displaced Auto VMT

$$E_{Reduced} = \frac{E_{Reduced\_Yr1} + E_{Reduced\_YrF}}{2} \times QP$$

Table 10. Variables of Equation 8: Emission Reductions from Displaced Auto VMT

Variable	Variable Definition	Units
$E_{Reduced}$	Total emission reductions from displaced auto VMT	MTCO2e or lbs
$E_{Reduced\_Yr1}$	Emission reductions from displaced autos in first year	MTCO2e or lbs
$E_{Reduced\_YrF}$	Emission reductions from displaced autos in final year	MTCO2e or lbs
QP	Quantification period	years

Equation 9 calculates the annual emission reductions associated with auto VMT displaced.

Equation 9: Annual Emission Reductions from Displaced Auto VMT

$$E_{Reduced\_Yr} = \frac{AutoVMT_{Displaced\_Yr} \times EF_{Yr}}{CF}$$

Table 11. Variables of Equation 9: Annual Emissions Reductions from Displaced Auto VMT

Variable	Variable Definition	Units
$E_{Reduced\_Yr}$	Annual emission reductions from displaced auto VMT	MTCO2e/year or lbs/year
$AutoVMT_{Displaced\_Yr}$	Estimated annual VMT displaced attributed to the operation of the new service	Miles/year
EF_{Yr}	Emission Factor in the first or final year (based on weighted fleet average)	Grams/mile
CF	Conversion factor	Grams/MTCO2e or grams/lb

Equation 10 calculates the annual auto VMT displaced from the project.

Equation 10: Annual Auto VMT Displaced in Miles per Year

$$AutoVMT_{Yr} = R_{Yr} \times A \times L$$

Table 12. Variables of Equation 10: Annual Auto VMT Displaced

Variable	Variable Definition	Units
$AutoVMT_{Yr}$	Annual Auto VMT displaced in the first or final year	Miles
R_{Yr}	Annual increase in unlinked passenger trips directly associated with the first or final year of the project	Riders
A	Adjustment factor to account for transit dependency. Use documented, project-specific data or system average development from recent, statistically valid survey or default. Applicants may use default values in Appendix A for similar service.	N/A
L	Estimated length of average unlinked passenger trip directly associated with the project, calculated as passenger-miles divided by unlinked trips. Applicants may use data reported to National Transit Database (Appendix A) for similar service.	Miles/rider

C. Emission Reductions from Technology Conversion

Equation 11 estimates both the GHG and air pollutant emission reductions from Technology Conversion as the difference between the emissions associated with the baseline vehicle and emissions associated with the new vehicle.

Equation 11: Emission Reductions from Cleaner Vehicles / Technology / Fuels

$$E = E_{Vehicle\_Baseline} - E_{Vehicle\_New}$$

Table 13. Variables of Equation 11: Emission Reductions from Cleaner Vehicles/Technology/Fuels

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e or lbs
$E_{Vehicle\_Baseline}$	Total emission from baseline vehicles	MTCO2e or lbs
$E_{Vehicle\_New}$	Total emissions from new vehicle	MTCO2e or lbs

Equation 12 calculates the emissions associated with the baseline and new vehicles.

Equation 12: Emissions from Baseline or New Vehicle

$$E_{Vehicle} = AE_{Vehicle} \times QP$$

Table 14. Variables of Equation 12: Emissions from Baseline or New Vehicle

Variable	Variable Definition	Units
$E_{Vehicle}$	Total emissions from baseline or new vehicle(s)	MTCO2e or lbs
$AE_{Vehicle}$	Average annual emissions from the baseline or new vehicle	MTCO2e/year or lbs/year
QP	Quantification period	years

Equation 13 calculates the annual emissions associated with the baseline and new vehicles. For train and ferry services, annual emissions may be calculated based upon inputs for annual fuel consumption. Train services include heavy rail, light rail, and DMUs/EMUs.

Equation 13: Annual Emissions from Baseline or New Vehicle

$$AE_{Vehicle} = \frac{VMT \times VehicleEF \times HDR}{CF} \quad \text{Or (for train/ferry only)} \quad AE_{Vehicle} = \frac{Fuel \times FuelEF \times HDR}{CF}$$

Table 15. Variables of Equation 13: Annual Emissions from Baseline or New Vehicle

Variable	Variable Definition	Units
$AE_{Vehicle}$	Average annual emissions from baseline or new vehicle	MTCO2e/year or lbs/year
VMT	Estimated annual VMT of the vehicle to be acquired	Miles/year
VehicleEF	Emission factor, based on project-specific inputs, from the mid-year of the project	Grams/miles
Fuel	Estimated annual fuel of the vehicle to be acquired, only available for train and ferry services	Unit of fuel
FuelEF	Emission factor based on fuel type, and engine tier for train, for the displaced or new vehicle, in the mid-year of the project	Grams/unit of fuel
HDR	Hybrid discount rate (0.8), if applicable	N/A
CF	Conversion factor	Grams/MTCO2e or grams/lbs

For the acquisition of a new zero-emission vehicle where there is no current vehicle to be replaced, applicants will enter current vehicle information of the newest available fossil fuel-equivalent vehicle. For example, if the project was to purchase a zero-emission vehicle that would be operational in 2021, the applicant should input a 2021 model year fossil fuel vehicle in place of the current vehicle information.

For the acquisition of a new vehicle where there is a current vehicle to be replaced, the LCTOP Calculator Tool requires project-specific inputs regarding the current vehicle to calculate the emission estimates.

D. Emission Reductions from Fuel/Energy Reduction

Equation 14 estimates the GHG and air pollutant emission reductions from Fuel/Energy Reduction as the emission reductions from reduced fuel or energy usage.

Equation 14: Emission Reduction Estimates from Fuel/Energy Reduction

$$E = AE_{Fuel\,/Energy} \times QP$$

Table 16. Variables of Equation 14: Emission Reductions Estimates from Fuel/Energy Reduction

Variable	Variable Definition	Units
E	Net emission reductions	MTCO2e or lbs
$AE_{Fue;/Energy}$	Annual emission reductions from fuel/energy reduction	MTCO2e/year or lbs/year
QP	Quantification period	Years

Equation 15 calculates the annual GHG emission reductions associated with fuel/energy reduction.

Equation 15: Annual GHG Emission Reductions from Fuel/Energy Reduction

$$AE_{Fuel/Energy\_GHG} = \frac{Fuel \times FuelEF \times ED}{CF}$$

Table 17. Variables of Equation 15: Annual GHG Emission Reductions from Fuel/Energy Reduction

Variable	Variable Definition	Units
$AE_{Fuel/Energy\_GHG}$	Annual GHG emission reductions from fuel/energy reduction	MTCO2e/year or lbs/year
Fuel	Estimated annual fuel/energy reductions	Unit of fuel/year
FuelEF	Emission factor based on fuel type, in the mid-year of the project	Grams/MJ
ED	Energy density, based on fuel type	MJ/ unit of fuel
CF	Conversion factor	Grams/MTCO2e

Equation 16 calculates the annual air pollutant emission reductions associated with fuel/energy reduction.

Equation 16: Annual Air Pollutant Emission Reductions from Fuel/Energy Reduction

$$AE_{Fuel/Energy\_AP} = \frac{Fuel \times FuelCR \times FuelEF}{CF}$$

Table 18. Variables of Equation 16: Annual Air Pollutant Emission Reductions from Fuel/Energy Reduction

Variable	Variable Definition	Units
$AE_{Fuel/Energy\_AP}$	Annual air pollutant emission reductions from fuel/energy reductions	lbs/year
Fuel	Estimated annual fuel/energy reductions	Unit of fuel/year
FuelCR	Fuel consumption rate of the vehicle from the mid-year of the project	Miles/unit of fuel
FuelEF	Air pollutant emission factor based on fuel type, from the mid-year of the project	Grams/mile
CF	Conversion factor	Grams/MTCO2e

Section C. References

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

California Air Resources Board. (2019). California Climate Investments Quantification Methodology Emission Factor Database. http://www.arb.ca.gov/cci-resources

California Air Resources Board, California Department of Transportation. (2005). Methods to Find the Cost-Effectiveness of Funding Air Quality Projects for Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement Projects. https://www.arb.ca.gov/planning/tsaq/eval/eval.htm

Federal Transit Administration. National Transit Database. https://www.transit.dot.gov/ntd

Institute of Transportation Studies, University of California, Davis. Updated Default Values for Transit Dependency and Average Length of Unlinked Transit Passenger Trips, for Calculations Using TAC Methods for California Climate Investments Programs. https://ww3.arb.ca.gov/cc/capandtrade/auctionproceeds/transit_factors_technical_081319.pdf

National Renewable Energy Laboratory. (2012). Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics. https://www.nrel.gov/docs/fy13osti/56487.pdf

National Renewable Energy Laboratory. (2017). PV Watts Calculator. https://pvwatts.nrel.gov/

Appendix A. Default Lookup Tables

CARB staff developed these recommended values for applicants to use for the length of the average unlinked passenger trip and baseline average fare cost, by agency or statewide, by mode, and by type of service using 2021 Annual data from the National Transit Database, supplemented by the previously used 2017 data for transit services that are absent from the 2021 data due to COVID-19 service interruptions or other reasons (identified in red italics). These values were calculated by dividing passenger miles traveled by unlinked passenger trips. Adjustment factors were developed by the Institute of Transportation Studies based on a review of research on transit dependency and data from the 2013 California Household Travel Survey.

List of Acronyms and Abbreviations

Acronym	Term
CB	commuter bus
CC	cable car
CR	commuter rail
DO	directly operated
DR	demand response
DT	demand response taxi
FB	ferryboat
HR	heavy rail
LR	light rail
MB	bus
MG	monorail/automated guideway
PT	purchased transportation
RB	bus rapid transit
SR	streetcar rail
TB	trolley bus
TN	transportation network company
TX	taxi
VP	vanpool
YR	hybrid rail

Table A-1. Length of Average Trip and Adjustment Factor by Mode

Mode Type	Mode	Type of Service	Length of Average Trip (Miles/Trip)	Adjustment Factor
Commuter Bus (Express/Intercity)	CB	DO	23.15	0.705
Commuter Bus (Express/Intercity)	CB	PT	22.61	0.705
Cable Car	CC	DO	1.26	0.479
Commuter Rail	CR	DO	25.63	
Commuter Rail	CR	PT	33.55	0.867
Demand Response	DR	DO	5.81	0.540
Demand Response	DR	PT	8.88	0.540
Demand Response Transportation Network Company	DR	TN	4.64	0.540
Demand Response Taxi	DR	TX	9.10	0.540
Ferryboat	FB	DO	12.01	1
Ferryboat	FB	PT	23.70	1
Heavy Rail	HR	DO	9.24	0.794
Light Rail	LR	DO	6.03	0.685
Bus (Local)	MB	DO	3.29	0.561 (Transit Bus) 0.585 (Shuttle)
Bus (Local)	MB	PT	4.20	0.561 (Transit Bus) 0.585 (Shuttle)
Monorail/Automated Guideway	MG	PT	3.18	0.479
Bus Rapid Transit	RB	DO	4.61	0.542
Streetcar Rail	SR	DO	1.43	0.479
Trolley Bus	TB	DO	1.53	0.479
Vanpool	VP	DO	31.72	0.879
Vanpool	VP	PT	48.56	0.879
Hybrid Rail	YR	DO	6.86	0.738
Hybrid Rail	YR	PT	7.29	0.738

Table A-2. Length of Average Trip and Average Fare Cost by Transit Agency

A dash represents no data being available. If an agency does not have their own calculated value, and there's no default average value for that particular agency, mode, and service type, then the agency should choose a number from a comparable agency, mode, and service type.

Transit Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Access Services	DR	TX	12.04	$2.56
Access Services	DR	PT	10.76	$2.41
Access Services	DT	PT	14.69	$2.39
Alameda-Contra Costa Transit District	CB	DO	13.68	$4.46
Alameda-Contra Costa Transit District	DR	PT	7.71	$2.60
Alameda-Contra Costa Transit District	MB	DO	3.89	$1.20
Alameda-Contra Costa Transit District	MB	PT	12.60	$1.21
Alameda-Contra Costa Transit District	RB	DO	3.07	$0.44
Altamont Corridor Express	CR	PT	55.57	$9.18
Anaheim Transportation Network	DR	PT	1.35	-
Anaheim Transportation Network	MB	PT	2.32	$0.80
Antelope Valley Transit Authority	CB	PT	56.54	$6.56
Antelope Valley Transit Authority	DR	PT	8.86	$1.23
Antelope Valley Transit Authority	MB	PT	5.41	$1.08
Butte County Association of Governments	DR	PT	2.89	$2.66
Butte County Association of Governments	MB	PT	4.92	$1.81
California Vanpool Authority	VP	DO	31.72	$3.49
Central Contra Costa Transit Authority	DR	PT	7.32	$1.96
Central Contra Costa Transit Authority	MB	DO	4.32	$0.97
Central Contra Costa Transit Authority	MB	PT	14.60	-
City and County of San Francisco	DR	PT	6.76	$2.39
City and County of San Francisco	LR	DO	0.74	$0.25
City and County of San Francisco	MB	DO	2.01	$0.32
City and County of San Francisco	TB	DO	1.53	$0.23
City of Commerce	DR	DO	4.99	-
City of Commerce	MB	DO	3.83	-
City of Culver City	DR	DO	1.69	$0.83
City of Culver City	MB	DO	4.43	$0.46
City of Elk Grove	CB	PT	14.06	$2.81
City of Elk Grove	DR	PT	4.68	$6.63
City of Elk Grove	MB	PT	3.44	$1.06
City of Fairfield, California	CB	PT	23.56	$3.90

Transit Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
City of Fairfield, California	DR	PT	10.18	$1.92
City of Fairfield, California	MB	PT	2.86	$0.40
City of Fresno	DR	PT	5.74	$1.22
City of Fresno	MB	DO	2.88	$0.31
City of Gardena	DR	DO	2.59	*$0.50*
City of Gardena	MB	DO	3.34	*$0.77*
City of Glendale	DR	PT	3.04	*$1.09*
City of Glendale	MB	PT	2.18	$0.01
City of La Mirada	DR	PT	2.34	$0.64
City of Los Angeles	CB	PT	10.91	$0.83
City of Los Angeles	DR	PT	3.81	$0.26
City of Los Angeles	DR	TX	2.38	$1.38
City of Los Angeles	MB	PT	1.19	*$0.37*
City of Modesto	DR	PT	4.50	$2.96
City of Modesto	DR	TX	5.33	$1.58
City of Modesto	MB	PT	4.19	$0.89
City of Montebello	DR	TX	1.80	$0.69
City of Montebello	MB	DO	3.30	$0.68
City of Montebello	MB	PT	2.47	$1.29
City of Norwalk	DR	PT	2.47	$0.69
City of Norwalk	MB	DO	4.20	*$0.88*
City of Pasadena	DR	PT	2.94	$0.13
City of Pasadena	MB	PT	1.99	$0.10
City of Petaluma	DR	PT	4.09	$1.02
City of Petaluma	MB	PT	2.73	$0.41
City of Redondo Beach	DR	PT	5.40	*$0.85*
City of Redondo Beach	MB	PT	3.60	*$0.84*
City of Riverside	DR	DO	5.63	$2.47
City of San Luis Obispo	MB	PT	3.10	$1.80
City of Santa Clarita	CB	PT	24.78	$0.86
City of Santa Clarita	DR	PT	6.54	$0.98
City of Santa Clarita	MB	PT	4.23	$0.15
City of Santa Maria	DR	PT	8.30	*$0.44*
City of Santa Maria	MB	PT	3.49	*$1.02*
City of Santa Monica	DR	PT	1.84	$0.57
City of Santa Monica	DR	TN	1.57	$0.57
City of Santa Monica	MB	DO	3.36	$0.40
City of Santa Rosa	DR	PT	3.99	$1.35
City of Santa Rosa	MB	DO	2.75	$0.29

Transit Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
City of Santa Rosa	MB	PT	3.61	$20.05
City of Torrance	DR	TX	3.47	$1.97
City of Torrance	MB	DO	4.95	$0.01
City of Tulare	DR	PT	4.21	$1.14
City of Tulare	MB	PT	6.06	$0.60
City of Turlock	DR	PT	7.09	$2.01
City of Turlock	MB	PT	3.34	$1.36
City of Visalia	CB	PT	51.99	$2.89
City of Visalia	DR	PT	6.38	$3.61
City of Visalia	MB	PT	6.68	$0.93
County of Placer	CB	PT	24.74	$6.61
County of Placer	DR	DO	10.80	$3.50
County of Placer	DR	PT	4.22	$0.82
County of Placer	MB	DO	7.76	$1.24
County of Placer	MB	PT	3.32	$0.64
County of Placer	VP	PT	33.91	$4.68
County of Sonoma	DR	PT	12.17	$0.71
County of Sonoma	MB	PT	8.33	$0.57
El Dorado County Transit Authority	CB	DO	31.03	$5.37
El Dorado County Transit Authority	DR	DO	11.22	$10.25
El Dorado County Transit Authority	MB	DO	8.97	$1.47
Foothill Transit	MB	PT	6.07	$0.66
Gold Coast Transit District	DR	PT	6.29	$0.73
Gold Coast Transit District	MB	DO	3.58	$0.15
Golden Empire Transit District	DR	DO	5.17	$6.13
Golden Empire Transit District	MB	DO	3.46	$0.87
Golden Gate Bridge, Highway and Transportation District	DR	PT	11.99	$5.67
Golden Gate Bridge, Highway and Transportation District	FB	DO	12.01	$9.44
Golden Gate Bridge, Highway and Transportation District	MB	DO	18.84	$6.22
Imperial County Transportation Commission	DR	PT	26.67	$2.48
Imperial County Transportation Commission	MB	PT	9.91	$0.05
Kings County Area Public Transit Agency	DR	PT	2.90	$2.42
Kings County Area Public Transit Agency	MB	PT	5.21	$1.02
Kings County Area Public Transit Agency	VP	PT	38.69	$3.70

Transit Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Laguna Beach Municipal Transit	MB	DO	2.22	$0.04
Livermore / Amador Valley Transit Authority	DR	PT	4.75	$3.82
Livermore / Amador Valley Transit Authority	MB	PT	4.27	$1.98
Long Beach Transit	DR	PT	4.14	$1.67
Long Beach Transit	MB	DO	3.12	$0.01
Los Angeles County Metropolitan Transportation Authority	DR	DO	2.49	-
Los Angeles County Metropolitan Transportation Authority	HR	DO	5.24	$0.14
Los Angeles County Metropolitan Transportation Authority	LR	DO	6.61	$0.13
Los Angeles County Metropolitan Transportation Authority	MB	DO	2.86	$0.11
Los Angeles County Metropolitan Transportation Authority	MB	PT	3.79	$0.01
Los Angeles County Metropolitan Transportation Authority	RB	DO	5.85	$0.13
Los Angeles County Metropolitan Transportation Authority	VP	PT	46.98	$7.49
Marin County Transit District	DR	PT	6.77	$4.46
Marin County Transit District	MB	PT	5.63	$1.06
Metropolitan Transportation Commission	VP	PT	56.57	$7.43
Monterey-Salinas Transit	CB	DO	40.49	$16.91
Monterey-Salinas Transit	DR	PT	8.57	$1.23
Monterey-Salinas Transit	MB	DO	6.90	$1.42
Monterey-Salinas Transit	MB	PT	3.70	$1.27
Napa Valley Transportation Authority	CB	PT	16.63	$1.11
Napa Valley Transportation Authority	DR	PT	2.61	$3.21
Napa Valley Transportation Authority	MB	PT	9.54	$0.75
North County Transit District	CR	PT	26.44	$5.58
North County Transit District	DR	PT	13.48	$14.64
North County Transit District	MB	PT	4.34	$0.85
North County Transit District	YR	PT	7.29	$1.18
Omnitrans	DR	PT	9.85	$4.87
Omnitrans	MB	DO	5.63	$1.69
Omnitrans	MB	PT	3.77	$1.55
Orange County Transportation Authority	CB	DO	21.11	$1.68

Transit Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Orange County Transportation Authority	CB	PT	19.28	$1.44
Orange County Transportation Authority	DR	PT	10.46	$4.26
Orange County Transportation Authority	DR	TX	4.76	$3.09
Orange County Transportation Authority	DT	PT	3.02	$3.44
Orange County Transportation Authority	MB	DO	4.41	$0.70
Orange County Transportation Authority	MB	PT	5.12	$0.53
Orange County Transportation Authority	VP	PT	36.82	$6.47
Paratransit, Inc.	DR	DO	9.82	*$4.20*
Paratransit, Inc.	DR	PT	10.46	$7.07
Paratransit, Inc.	DT	PT	8.37	$4.47
Peninsula Corridor Joint Powers Board dba: Caltrain	CR	PT	22.28	$25.68
Peninsula Corridor Joint Powers Board dba: Caltrain	MB	PT	3.47	-
Pomona Valley Transportation Authority	DR	PT	6.02	$0.33
Pomona Valley Transportation Authority	DR	TX	4.34	$1.45
Pomona Valley Transportation Authority	DT	PT	4.81	$1.94
Redding Area Bus Authority	DR	PT	6.36	$3.53
Redding Area Bus Authority	MB	PT	5.30	$1.14
Riverside County Transportation Commission	VP	PT	39.33	$6.72
Riverside Transit Agency	CB	DO	26.21	$1.56
Riverside Transit Agency	CB	PT	23.22	$2.08
Riverside Transit Agency	DR	PT	11.38	$5.13
Riverside Transit Agency	DT	PT	17.51	$4.05
Riverside Transit Agency	MB	DO	6.84	$0.73
Riverside Transit Agency	MB	PT	11.80	$1.52
Sacramento Regional Transit District	DR	DO	5.82	$3.58
Sacramento Regional Transit District	LR	DO	5.78	$1.43
Sacramento Regional Transit District	MB	DO	3.73	$1.38
San Bernardino County Transportation Authority	VP	PT	40.47	$7.66
San Diego Association of Governments	VP	PT	55.11	$6.61
San Diego Metropolitan Transit System	CB	PT	26.10	$6.78
San Diego Metropolitan Transit System	DR	PT	10.04	$4.26
San Diego Metropolitan Transit System	DR	TX	12.05	$4.58
San Diego Metropolitan Transit System	LR	DO	6.32	$0.99
San Diego Metropolitan Transit System	MB	DO	5.32	$1.68
San Diego Metropolitan Transit System	MB	PT	3.86	$1.23

Transit Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
San Francisco Bay Area Rapid Transit District	HR	DO	13.65	$3.50
San Francisco Bay Area Rapid Transit District	MG	PT	3.18	$5.78
San Francisco Bay Area Rapid Transit District	YR	DO	6.86	$2.88
San Francisco Bay Area Water Emergency Transportation Authority	FB	PT	23.70	$7.32
San Francisco Municipal Railway	CC	DO	1.26	$4.34
San Francisco Municipal Railway	DR	PT	6.17	$2.29
San Francisco Municipal Railway	LR	DO	2.73	$0.77
San Francisco Municipal Railway	MB	DO	2.15	$0.77
San Francisco Municipal Railway	SR	DO	1.43	$0.77
San Francisco Municipal Railway	TB	DO	1.48	$0.77
San Joaquin Council	VP	PT	47.37	$7.05
San Joaquin Regional Transit District	CB	PT	44.32	$5.30
San Joaquin Regional Transit District	DR	PT	7.29	$3.97
San Joaquin Regional Transit District	DR	TX	5.13	$4.77
San Joaquin Regional Transit District	DT	PT	5.83	$3.73
San Joaquin Regional Transit District	MB	DO	3.51	$0.66
San Joaquin Regional Transit District	MB	PT	4.55	$0.59
San Luis Obispo Regional Transit Authority	DR	DO	7.11	$3.12
San Luis Obispo Regional Transit Authority	MB	DO	12.09	$0.62
San Mateo County Transit District	DR	PT	8.14	$2.08
San Mateo County Transit District	DR	TX	15.51	$1.73
San Mateo County Transit District	DT	PT	11.89	$2.38
San Mateo County Transit District	MB	DO	3.57	$1.15
San Mateo County Transit District	MB	PT	5.20	$1.30
Santa Barbara Metropolitan Transit District	MB	DO	4.09	$0.17
Santa Clara Valley Transportation Authority	DR	PT	8.08	$2.71
Santa Clara Valley Transportation Authority	DT	PT	10.68	$2.86
Santa Clara Valley Transportation Authority	LR	DO	6.44	$1.10

Transit Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Santa Clara Valley Transportation Authority	MB	DO	5.00	$1.10
Santa Clara Valley Transportation Authority	MB	PT	4.50	$2.65
Santa Cruz Metropolitan Transit District	CB	DO	30.59	$4.43
Santa Cruz Metropolitan Transit District	DR	DO	6.36	$2.95
Santa Cruz Metropolitan Transit District	DT	PT	7.23	$2.09
Santa Cruz Metropolitan Transit District	MB	DO	4.41	$4.70
Solano County Transit	CB	PT	13.78	$4.17
Solano County Transit	DR	PT	3.59	$3.72
Solano County Transit	MB	PT	2.82	$1.22
Sonoma-Marin Area Rail Transit District	CR	DO	25.63	$5.75
Southern California Regional Rail Authority	CR	PT	39.20	$7.73
SunLine Transit Agency	DR	DO	8.00	$1.37
SunLine Transit Agency	MB	DO	6.05	$0.12
SunLine Transit Agency	VP	PT	57.99	$7.50
The Eastern Contra Costa Transit Authority	DR	PT	4.74	$4.18
The Eastern Contra Costa Transit Authority	DR	TN	6.17	$4.00
The Eastern Contra Costa Transit Authority	MB	PT	4.52	$0.37
Transit Joint Powers Authority for Merced County	DR	PT	5.87	$0.92
Transit Joint Powers Authority for Merced County	MB	PT	6.36	$1.63
University of California, Davis (Unitrans)	MB	DO	2.16	$12.78
Ventura County Transportation Commission	CB	PT	26.77	*$1.60*
Ventura County Transportation Commission	DR	PT	2.80	*$1.75*
Ventura County Transportation Commission	MB	PT	4.37	*$0.85*
Victor Valley Transit Authority	CB	PT	52.89	$13.08
Victor Valley Transit Authority	DR	PT	13.92	$3.29
Victor Valley Transit Authority	MB	PT	6.85	$1.52
Victor Valley Transit Authority	VP	PT	45.48	$6.23
Western Contra Costa Transit Authority	CB	PT	28.39	$1.79

Transit Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Western Contra Costa Transit Authority	DR	PT	6.08	$0.59
Western Contra Costa Transit Authority	MB	PT	6.27	$0.42
Yolo County Transportation District	DR	PT	11.29	$4.83
Yolo County Transportation District	MB	PT	11.50	$2.54
Yuba-Sutter Transit Authority	CB	PT	39.30	$6.69
Yuba-Sutter Transit Authority	DR	PT	5.86	$5.67
Yuba-Sutter Transit Authority	MB	PT	3.04	$1.04