California Air Resources Board

Quantification Methodology

California State Transportation Agency
Transit and Intercity Rail Capital Program

California Climate Investments

FINAL
October 18, 2019

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List of Acronyms and Abbreviations

Acronym	Term
CARB	California Air Resources Board
CalSTA	California State Transportation Agency
CB	commuter bus
CC	cable car
CCI	California Climate Investments
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
hp	horsepower
HR	heavy rail
kWh	kilowatt hours
lbs	pounds
LHD1	light-heavy-duty trucks (8,501 – 10,000 lbs gross vehicle weight rating)
LR	light rail
MB	Bus
MDV	medium-duty trucks (6,000 – 8,000 lbs gross vehicle weight rating)
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
SR	streetcar rail
TAC	transit and connectivity
TB	trolley bus
TIRCP	Transit and Intercity Rail Program
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).
Cleaner Vehicles / Technology / Fuels	Project type that identifies project subcomponents 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 would be considered the "cleaner vehicles/technology/fuels" project type.
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	Project type that identifies project subcomponents that result in using less fuel or energy from existing transit services, or producing renewable energy/fuel. This includes projects that reduce transit 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 would be considered the "fuel/energy reduction" project type.
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).

Term	Definition
New Service	Project type that identifies project subcomponents that result in a new transportation service. This may include expansion of an existing service. For example, constructing a new rail line, providing a new transit route, or adding new buses to an existing transit route that expands service would be considered the "new service" project type.
Project Component	An overarching activity which may encompass more than one project subcomponent.
Project Type	For the purposes of the TIRCP Quantification Methodology, eligible projects fall into four project types that meet the objectives program and for which there are methods to quantify GHG emission reductions.
Project Subcomponent	A project activity that corresponds to a specific project type for which GHG emission reductions and air pollutant emission co-benefits may be estimated, evaluated and reported separately from other subcomponents within a TIRCP project component.
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 subcomponent will provide GHG emission reductions that can reasonably be achieved and assured. Sometimes referred to as "Project Life" or "Useful Life."
Replacement	Identifies project subcomponents that replace a baseline vehicle(s) with a new vehicle(s) without resulting in new service.
System and Efficiency Improvements	Project type that identifies project subcomponents 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 or improving scheduling systems would be considered the "system and efficiency improvements" project type.
Travel Cost Savings	Changes in travel costs to the user as a result of the project from switching travel modes.

Term	Definition
Unlinked Passenger Trips	The number of times passengers board public transportation vehicles. Passengers are counted each time they board vehicles no matter how many vehicles they use to travel from their origin to their destination and regardless of whether they pay a fare, use a pass or transfer, ride for free, or pay in some other way. A person riding only one vehicle from origin to destination takes one unlinked passenger trip; a person who transfers to a second vehicle takes a total of two unlinked passenger trips; a person who transfers to a third vehicle takes a total of three unlinked passenger trips. Also called boardings.

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 receiving monies from the GGRF This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the elements eligible for funding by each administering agency, as reflected in the program expenditure records available at: www.arb.ca.gov/cci-expenditurerecords.

For the CalSTA TIRCP, CARB staff developed this TIRCP Quantification Methodology and accompanying TIRCP 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 capital projects.

The TIRCP 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 TIRCP Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds. The TIRCP Benefits Calculator Tool is available for download at: www.arb.ca.gov/cci-resources.

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

- ROG emission reductions (lbs),
- NO_x emission reductions (lbs),
- $PM_{2.5}$ emission reductions (lbs),
- Diesel PM emission reductions (lbs),
- Passenger VMT reductions (miles),
- Fossil fuel use reductions (gallons),
- 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 TIRCP Benefits Calculator Tool may also be applicable to the project. Applicants should consult the TIRCP guidelines, solicitation materials, and agreements to ensure they are meeting TIRCP requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB developed this Quantification Methodology in consultation with CalSTA consistent with the guiding implementation principles of California Climate Investments, including ensuring transparency and accountability.[1] The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods to be applied statewide and to be accessible by all applicants;
- Use existing and proven methods;
- Use project-level data, where available and appropriate; and
- Result in GHG and air pollutant emission reduction estimates that are conservative and supported by empirical literature.

CARB and CalSTA developed this Quantification Methodology to be used to estimate the outcomes of proposed projects, to inform project selection, and to track results of funded projects. CARB also consulted with CalSTA to identify available project-level inputs.

CARB assessed peer-reviewed literature and tools, and consulted with experts as needed, to determine methods appropriate for the TIRCP project types. 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 TIRCP Quantification Methodology and Draft TIRCP Benefits Calculator Tool for public comment on September 13, 2019. This Final TIRCP Quantification Methodology and accompanying TIRCP Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the TIRCP Guidelines.

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 (CMAQ Methods) were used as the basis for developing the GHG emission reduction estimates for certain project features, specifically transit and connectivity (TAC) features.[2] The CMAQ Methods are a set of equations for

[1] California Air Resources Board. www.arb.ca.gov/cci-fundingguidelines
[2] California Air Resources Board. 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. May 2005. www.arb.ca.gov/planning/tsaq/eval/eval.htm.

evaluating the cost-effectiveness of certain types of transportation projects, including bicycle paths, vanpools, and new bus service. CARB and the California Department of Transportation developed the CMAQ Methods, which are used statewide by transportation agencies to assess criteria and toxic 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 at: www.arb.ca.gov/planning/tsaq/eval/eval.htm.

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. Co-benefit assessment methodologies are posted at: www.arb.ca.gov/cci-cobenefits.

Tools

The TIRCP Benefits Calculator Tool relies on project-specific outputs from the following tools:

The National Renewable Energy Laboratory PVWatts® Calculator is a web-based tool that uses simple inputs to estimate the electricity production of a grid-connected roof- or ground-mounted solar PV system. PVWatts® calculates estimated values for the proposed system's monthly and annual electricity production. The tool is publicly available to anyone with internet access and is free of charge. It is subject to regular updates to incorporate new information. The tool can be accessed at: http://pvwatts.nrel.gov/.

In addition to the tool above, the TIRCP Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in quantification methodologies, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database).[3] The Database documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the TIRCP Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The TIRCP Calculator Tool can be downloaded from www.arb.ca.gov/cci-quantification.

[3] California Air Resources Board (2019). California Climate Investments Quantification Methodology Emission Factor Database. www.arb.ca.gov/cci-quantification.

Updates

CARB staff periodically review each quantification methodology to evaluate its effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated the TIRCP Quantification Methodology from the previous version[4] to enhance the analysis and provide additional clarity. Changes include the following:

- Updated the data source of air pollutant emission factors and fuel consumption factors from EMFAC2014 to EMFAC2017[5];
- Added air pollutant emissions from idling for on-road heavy-duty vehicles;
- Added air pollutant emissions from brake wear and tire wear for all on-road vehicles;
- For "Van" emission factors and fuel consumption factors, used a population-weighted average of light-heavy-duty trucks (LHD1) and medium-duty trucks (MHD) vehicle categories[6];
- Added GHG and co-benefit calculations for diesel multiple units (DMUs);
- Refined rail and ferry air pollutant emission factors to vary by engine tier; and
- When quantifying reductions for "New Service" and "Displaced Vehicle" project types, used mid-year (middle calendar year based upon the useful life) emission factors instead of averaging first and final year emission factors.

Program Assistance

CARB staff will review the quantification portions of the TIRCP project applications to ensure that the methods described in this document are properly applied to 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: GGRFProgram@arb.ca.gov.
    - **Note:** Frequently asked questions (FAQs) may be issued, as necessary. Applicants are encouraged to check the FAQ page regularly during the application process, available at: www.arb.ca.gov/cci-quantification.
- For more information on CARB efforts to support implementation of GGRF investments, see: www.arb.ca.gov/caclimateinvestments.
- Questions pertaining to TIRCP should be sent to: TIRCPcomments@dot.ca.gov.

[4] Quantification Methodology for the California State Transportation Agency Transit and Intercity Rail Capital Program for FY 2018-19. October 13, 2017. https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/calsta_tircp_finalqm_18-19.pdf.

[5]

[6] CARB (2017). EMFAC2017 User's Guide. https://ww3.arb.ca.gov/msei/downloads/emfac2017_users_guide_final.pdf

Section B. Quantification Methodology

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

Project Types

TIRCP funds capital improvements that will modernize California's intercity, commuter, and urban rail (train), bus, ferry, shuttle bus, and vanpool transit systems. These capital improvements reduce GHG emissions, improve/expand transit service, increase ridership, integrate existing bus and rail operations with each other and with high-speed rail, and improve safety.

For the purposes of this Quantification Methodology, eligible TIRCP projects fall into four project types that meet the objectives of TIRCP and for which there are methods to quantify GHG emission reductions.[7] Each project requesting GGRF funding must include at least one of the following project types:

1. New Service
2. System and Efficiency Improvements
3. Cleaner Vehicles/Technology/Fuels
4. Fuel/Energy Reduction

Some projects may include more than one project type, such as those that provide operational improvements that reduce travel time (generating ridership increases) and also deploy new, lower-emitting vehicles that replace current, higher-emitting vehicles; or those that involve different types of baseline or replacement vehicles. If more than one project type applies to the project, information can be entered in different sub-component columns or component tabs.

General Approach

Methods used in the TIRCP Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by project type 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 TIRCP Benefits Calculator Tool using the quantification approaches by project type outlined in Table 1 below.

[7] California State Transportation Agency. Transit and Intercity Rail Capital Program Guidelines. https://dot.ca.gov/programs/rail-and-mass-transportation/transit-and-intercity-rail-capital-program.

Table 1. General Approach to Emission Estimates by Project Type

New Service
Emission Reductions = Emission Reductions from Displaced Autos – Emissions from New Service
System and Efficiency Improvements
Emission Reductions = Emission Reductions from Displaced Autos
Cleaner Vehicles/Technology/Fuels
Emission Reductions = Emission Reductions from Displaced (Baseline) Vehicle – Emissions from New Vehicle
Fuel/Energy Reduction
Emission Reductions = Emission Reductions from Reduced Fuel/Energy Usage or Displaced Fuel/Energy Usage from Renewable Energy/Fuel Production

Unless otherwise specified, if values are expected to vary between the first and final year of operation, use an average value.

A. Emission Reductions from New Service

The New Service project type identifies project subcomponents 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 would be considered the "new service" project type.

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

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

Where,			Units
E	=	Net emission reductions	$MTCO_2e$ or lbs
$E_{Reduced}$	=	Total emission reductions from displaced auto VMT	$MTCO_2e$ or lbs
E_{New}	=	Total emissions from new service	$MTCO_2e$ 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

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

Where,			Units
$E_{Reduced}$	=	Total emission reductions from displaced auto VMT	$MTCO_2e$ or lbs
$E_{Reduced\_Yr1}$	=	Emission reductions from displaced autos in first year	$MTCO_2e$ or lbs
$E_{Reduced\_YrF}$	=	Emission reductions from displaced autos in final year	$MTCO_2e$ or lbs
QP	=	Quantification period	years

Equation 3 calculates the annual emission reductions associated with auto VMT displaced from the project subcomponent. Note that auto VMT reductions are only calculated if directly tied to the transit operation. Thus, potential auto VMT reductions from other secondary impacts or mode shifts such as bicycle or other active transportation improvements are not included.

Equation 3: Annual Emission Reductions from Displaced Auto VMT

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

Where,			Units
$E_{Reduced\_Yr}$	=	Annual emission reductions from displaced auto VMT	$MTCO_2e$/yr or lbs/yr
$AutoVMT_{Displaced\_Yr}$	=	Estimated annual VMT reduced attributed to the operation of the new service	miles/yr
EF_{Yr}	=	Emission factor in the first or final year (based on weighted fleet average)	grams/mile
CF	=	Conversion factor	grams/MT or grams/lb

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

Equation 4: Annual Auto VMT Reduced

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

Where,			Units
$AutoVMT_{Yr}$	=	Annual auto VMT reduced 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 subcomponent	riders
A	=	Adjustment factor to account for transit dependency. Use documented, project-specific data or system average developed from recent, statistically-valid survey or default. Applicants may use default values in Appendix A for similar service.	unitless
L	=	Estimated length of average unlinked passenger trip directly associated with the project subcomponent, calculated as passenger-miles divided by unlinked trips. Applicants may use data reported to National Transit Database (Appendix A) for similar service.	mile(s) per rider

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

Equation 5: Emissions from New Service

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

Where,			Units
E_{New}	=	Total emissions from new service	$MTCO_2e$ or lbs
AE_{New}	=	Average annual emissions from new service	$MTCO_2e$/yr or lbs/yr
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 DMUs.

Equation 6: Annual Emissions from New Service

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

Where,			Units
AE_{New}	=	Average annual emissions from new service	$MTCO_2e$/yr or lbs/yr
NSVMT	=	Estimated annual VMT attributed to the operation of the new service (average over Yr1 and YrF)	miles
NSEF	=	Emission factor based on service type, in the mid-year of the project subcomponent	grams/mile
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 subcomponent (average over Yr1 and YrF)	grams/unit of fuel
HDR	=	Hybrid discount rate (0.8), if applicable	unitless
CF	=	Conversion factor	grams/MT or grams/lb

B. Emission Reductions from System and Efficiency Improvements

The System and Efficiency Improvements project type identifies project subcomponents 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 or improving scheduling systems would be considered the "system and efficiency improvements" project type.

Equation 7 estimates the GHG and air pollutant emission reductions from System and Efficiency Improvements as the emission reductions from displaced autos.

Equation 7: Emission Reductions from System and Efficiency Improvements

$$E = E_{Reduced}$$

Where,			Units
E	=	Net emission reductions	$MTCO_2e$ or lbs
$E_{Reduced}$	=	Total emission reductions from displaced auto VMT	$MTCO_2e$ or lbs

Equation 8 calculates the total emission reductions associated with auto VMT displaced by the system and efficiency improvements.

Equation 8: Emission Reductions from Displaced Auto VMT

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

Where,			Units
$E_{Reduced}$	=	Total emission reductions from displaced auto VMT	$MTCO_2e$ or lbs
$E_{Reduced\_Yr1}$	=	Emission reductions from displaced autos in first year	$MTCO_2e$ or lbs
$E_{Reduced\_YrF}$	=	Emission reductions from displaced autos in final year	$MTCO_2e$ or lbs
QP	=	Quantification period	years

Equation 9 calculates the annual emission reductions associated with auto VMT displaced by the system and efficiency improvements. Note that auto VMT reductions are only calculated if directly tied to the transit operation. Thus, potential auto VMT reductions from other secondary impacts or mode shifts such as bicycle or other active transportation improvements are not included.

Equation 9: Annual Emission Reductions from Displaced Auto VMT

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

Where,			Units
$E_{Reduced\_Yr}$	=	Annual emission reductions from displaced auto VMT	$MTCO_2e$/yr or lbs/yr
$AutoVMT_{Displaced\_Yr}$	=	Estimated annual VMT reduced attributed to the operation of the new service	miles/yr
EF_{Yr}	=	Emission factor in the first or final year (based on weighted fleet average)	grams/mile
CF	=	Conversion factor	grams/MT or grams/lb
$E_{Reduced\_Yr}$	=	Emission reductions from displaced autos per year	$MTCO_2e$/yr or lbs/yr

Equation 10 calculates the annual auto VMT reductions from the project subcomponent.

Equation 10: Annual Auto VMT Reduced in Miles per Year

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

Where,			Units
$AutoVMT_{Yr}$	=	Annual auto VMT reduced in the first or final year	miles
R_{Yr}	=	Annual increase in unlinked passenger trips directly associated with the first or final year	riders
A	=	Adjustment factor to account for transit dependency. Use documented, project-specific data or system average developed from recent, statistically-valid survey or default. Applicants may use default values in Appendix A for similar service.	unitless
L	=	Estimated length of average unlinked passenger trip directly associated with the project subcomponent, calculated as passenger-miles divided by unlinked trips. Applicants may use data reported to National Transit Database (Appendix A) for similar service.	mile(s) per rider

C. Emission Reductions from Cleaner Vehicles / Technology / Fuels

The Cleaner Vehicles / Technology / Fuels project type identifies project subcomponents 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 would be considered the "cleaner vehicles/technology/fuels" project type.

Equation 11 estimates both the GHG and air pollutant emission reductions from Cleaner Vehicles / Technology / Fuels 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

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

Where,			Units
E	=	Net emission reductions	$MTCO_2e$ or lbs
$E_{Vehicle\_Baseline}$	=	Total emissions from baseline vehicle	$MTCO_2e$ or lbs
$E_{Vehicle\_New}$	=	Total emissions from new vehicle	$MTCO_2e$ or lbs

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

Equation 12: Emissions from Baseline or New Vehicle

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

Where,			Units
$E_{Vehicle}$	=	Total emissions from baseline or new vehicle(s)	$MTCO_2e$ or lbs
$AE_{Vehicle}$	=	Average annual emissions from the displaced or new vehicle	$MTCO_2e$/yr or lbs/yr
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 alternatively be calculated based upon inputs for annual fuel consumption. Train services include heavy rail, light rail, and DMUs.

Equation 13: Annual Emissions from Baseline and New Vehicle

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

Where,			Units
$AE_{Vehicle}$	=	Average annual emissions from the displaced or new vehicle	$MTCO_2e$/yr or lbs/yr
VMT	=	Estimated annual VMT of the vehicle to be acquired (average over Yr1 and YrF)	mile/yr
VehicleEF	=	Emission factor, based on project-specific inputs for the current or new vehicle, from the mid-year of the project subcomponent	grams/mile
Fuel	=	Estimated annual fuel of the vehicle to be acquired, only available for train and ferry services (average over Yr1 and YrF)	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 subcomponent	grams/unit of fuel
HDR	=	Hybrid discount rate (0.8), if applicable	unitless
CF	=	Conversion factor	grams/MT or grams/lb

D. Emission Reductions from Fuel/Energy Reduction

The Fuel/Energy Reduction project type identifies project subcomponents that result in using less fuel or energy from existing transit services, or producing renewable energy/fuel. This includes projects that reduce transit VMT and reduce idling, or generate renewable electricity. For example, optimizing bus routes to reduce diesel fuel usage or installing solar panels to displace grid electricity would be considered the "fuel/energy reduction" project type. However, facility energy efficiency improvements are not eligible for quantification.

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

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

Where,			Units
E	=	Net emission reductions	$MTCO_2e$ or lbs
$AE_{Fuel/Energy}$	=	Annual emission reductions from fuel/energy reduction	$MTCO_2e$/yr or lbs/yr
QP	=	Quantification period	years

Equation 15 calculates the annual GHG emission reductions associated with fuel/energy reduction. For projects that generate renewable electricity using solar photovoltaic panels, the estimated annual energy reduction (i.e., grid electricity displaced) should be calculated using the PVWatts® Calculator to estimate the energy production from a solar installation.[8]

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

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

Where,			Units
$AE_{Fuel/Energy\_GHG}$	=	Annual GHG emission reductions from fuel/energy reduction	$MTCO_2e$/yr
$Fuel$	=	Estimated annual fuel/energy reductions	unit of fuel/yr
$FuelEF$	=	GHG emission factor, based on fuel type and mid-year of the project subcomponent	grams/MJ
ED	=	Energy density, based on fuel type	MJ/unit of fuel
CF	=	Conversion factor	grams/MT

[8] From PVWatts® tool, which can be accessed at: http://pvwatts.nrel.gov/. The calculator includes a solar degradation rate of 0.5% per year for calculating total lifetime energy generation

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

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

Where,			Units
$AE_{Fuel/Energy\_AP}$	=	Annual air pollutant emission reductions from fuel/energy reductions	lbs/yr
Fuel	=	Estimated annual fuel/energy reductions	unit of fuel/yr
FuelCR	=	Fuel consumption rate of the vehicle from the mid-year of the project subcomponent	miles/unit of fuel
FuelEF	=	Air pollutant emission factor based on fuel type, from the mid-year of the project subcomponent	grams/mile
CF	=	Conversion factor	grams/MT

Section C. References

The following references were used in the development of this Quantification Methodology and the TIRCP 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

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 2017 Annual data from the National Transit Database[9]. 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[10].

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	17.57	70.5
		PT	21.83	
Cable Car	CC	DO	1.26	47.9
Commuter Rail	CR	PT	25.69	86.7
Demand Response	DR	DO	9.08	54.0
		PT	9.94	
Demand Response Taxi	DT	PT	12.35	54.0
Ferryboat	FB	DO	10.85	100
		PT	15.01	
Heavy Rail	HR	DO	11.48	79.4
Light Rail	LR	DO	5.44	68.5
Bus (Local)	MB	DO	3.77	56.1 (Transit Bus)
		PT	4.27	58.5 (Shuttle)
Monorail/Automated Guideway	MG	PT	3.18	47.9
Bus Rapid Transit	RB	DO	6.56	54.2
Streetcar Rail	SR	DO	1.43	47.9
Trolley Bus	TB	DO	1.48	47.9
Vanpool	VP	DO	42.28	87.9
		PT	44.27	
Hybrid Rail	YR	PT	8.58	73.8

[9] Federal Transit Administration. National Transit Database. Available at https://www.transit.dot.gov/ntd.
[10] Handy, Susan, Elisa Barbour, Alissa Kendall, Jamey Volker (2019) Updated Default Values for Transit Dependency and Average Length of Unlinked Transit Passenger Trips, for Calculations Using TAC Methods for California Climate Investments Programs. Institute of Transportation Studies, University of California, Davis.
https://ww3.arb.ca.gov/cc/capandtrade/auctionproceeds/transit_factors_technical_081319.pdf

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

Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Access Services	DR	PT	11.47	$2.22
Access Services	DT	PT	14.69	$2.39
Alameda-Contra Costa Transit District	CB	DO	14.19	$2.49
Alameda-Contra Costa Transit District	DR	PT	10.47	$3.81
Alameda-Contra Costa Transit District	MB	DO	3.28	$1.36
Alameda-Contra Costa Transit District	MB	PT	13.03	$2.48
Altamont Corridor Express	CR	PT	42.86	$6.85
Anaheim Transportation Network	MB	PT	1.98	$0.55
Antelope Valley Transit Authority	CB	PT	42.05	$8.53
Antelope Valley Transit Authority	DR	PT	9.18	$2.21
Antelope Valley Transit Authority	MB	PT	7.15	$1.13
Butte County Association of Governments	DR	PT	4.33	$2.09
Butte County Association of Governments	MB	PT	4.92	$1.11
California Vanpool Authority	VP	DO	42.28	$3.27
Central Contra Costa Transit Authority	DR	PT	9.89	$3.55
Central Contra Costa Transit Authority	MB	DO	4.54	$1.12
City of Commerce Municipal Buslines	DR	DO	9.36	$0.00
City of Commerce Municipal Buslines	MB	DO	4.03	$0.00
City of Elk Grove	CB	PT	13.46	$1.80
City of Elk Grove	DR	PT	6.27	$5.17
City of Elk Grove	MB	PT	4.00	$1.34
City of Fairfield - Fairfield and Suisun Transit	CB	PT	20.40	$3.88
City of Fairfield - Fairfield and Suisun Transit	DR	PT	9.63	$4.94
City of Fairfield - Fairfield and Suisun Transit	MB	PT	3.17	$1.03
City of Gardena Transportation Department	DR	DO	3.17	$0.50
City of Gardena Transportation Department	MB	DO	3.20	$0.77
City of Glendale	DR	PT	5.26	$1.09
City of Glendale	MB	PT	2.20	$0.62
City of La Mirada Transit	DR	PT	2.86	$0.77
City of Los Angeles Department of Transportation	CB	PT	17.00	$3.03
City of Los Angeles Department of Transportation	DR	PT	4.69	$0.92

Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
City of Los Angeles Department of Transportation	DT	PT	2.18	$2.77
City of Los Angeles Department of Transportation	MB	PT	1.55	$0.37
City of Petaluma	DR	PT	3.90	$2.23
City of Petaluma	MB	PT	2.76	$0.64
City of Redondo Beach - Beach Cities Transit	DR	PT	4.43	$0.85
City of Redondo Beach - Beach Cities Transit	MB	PT	4.10	$0.84
City of Riverside Special Transportation	DR	DO	7.79	$2.11
City of San Luis Obispo	MB	PT	3.10	$0.62
City of Santa Rosa	DR	PT	5.46	$3.13
City of Santa Rosa	MB	DO	3.94	$0.77
City of Santa Rosa	MB	PT	3.00	$10.28
City of Tulare	DR	PT	5.38	$2.27
City of Tulare	MB	PT	4.36	$0.84
City of Turlock	DR	PT	7.42	$3.01
City of Turlock	MB	PT	3.33	$0.56
City of Visalia - Visalia City Coach	CB	PT	45.01	$7.69
City of Visalia - Visalia City Coach	DR	PT	7.69	$3.93
City of Visalia - Visalia City Coach	MB	PT	6.26	$0.90
Culver City Municipal Bus Lines	DR	DO	2.03	$0.45
Culver City Municipal Bus Lines	MB	DO	3.33	$0.63
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	7.62	$1.19
Fresno Area Express	DR	PT	7.30	$1.30
Fresno Area Express	MB	DO	2.60	$0.79
Gold Coast Transit	DR	PT	7.45	$2.62
Gold Coast Transit	MB	DO	4.25	$0.81
Golden Empire Transit District	DR	DO	6.48	$2.69
Golden Empire Transit District	MB	DO	3.59	$0.84
Golden Gate Bridge, Highway and Transportation District	DR	PT	11.82	$4.09
Golden Gate Bridge, Highway and Transportation District	FB	DO	10.85	$8.05
Golden Gate Bridge, Highway and Transportation District	MB	DO	18.65	$4.79

Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Imperial County Transportation Commission	DR	PT	18.47	$2.09
Imperial County Transportation Commission	MB	PT	9.91	$0.83
Kings County Area Public Transit Agency	DR	PT	3.75	$1.92
Kings County Area Public Transit Agency	MB	PT	6.46	$0.73
Laguna Beach Municipal Transit	MB	DO	2.22	$0.04
Livermore / Amador Valley Transit Authority	DR	PT	6.02	$4.14
Livermore / Amador Valley Transit Authority	MB	PT	4.62	$1.22
Long Beach Transit	DR	PT	4.76	$1.66
Long Beach Transit	MB	DO	3.23	$0.61
Los Angeles County Metropolitan Transportation Authority dba: Metro	HR	DO	5.00	$0.78
Los Angeles County Metropolitan Transportation Authority dba: Metro	LR	DO	7.31	$0.78
Los Angeles County Metropolitan Transportation Authority dba: Metro	MB	DO	4.03	$0.82
Los Angeles County Metropolitan Transportation Authority dba: Metro	MB	PT	4.72	$0.43
Los Angeles County Metropolitan Transportation Authority dba: Metro	RB	DO	6.56	$0.78
Los Angeles County Metropolitan Transportation Authority dba: Metro	VP	PT	44.79	$3.93
Marin County Transit District	DR	PT	8.10	$3.33
Marin County Transit District	MB	PT	4.09	$1.08
Modesto Area Express	DR	PT	6.84	$2.87
Modesto Area Express	DT	PT	4.90	$1.69
Modesto Area Express	MB	PT	4.26	$0.89
Montebello Bus Lines	DT	PT	2.16	$0.29
Montebello Bus Lines	MB	DO	3.25	$0.76
Montebello Bus Lines	MB	PT	2.90	$1.20
Monterey-Salinas Transit	CB	DO	40.49	$16.91
Monterey-Salinas Transit	DR	PT	8.58	$2.59
Monterey-Salinas Transit	MB	DO	6.21	$2.14
Monterey-Salinas Transit	MB	PT	3.71	$1.92
Napa Valley Transportation Authority	CB	PT	30.84	$2.33
Napa Valley Transportation Authority	DR	PT	7.19	$2.43
Napa Valley Transportation Authority	MB	PT	7.42	$0.69

Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
North County Transit District	CR	PT	26.44	$4.04
North County Transit District	DR	PT	12.97	$3.83
North County Transit District	MB	PT	4.32	$0.95
North County Transit District	YR	PT	8.58	$1.06
Norwalk Transit System	DR	PT	3.41	$1.14
Norwalk Transit System	MB	DO	4.19	$0.88
Omnitrans	DR	PT	14.01	$3.78
Omnitrans	MB	DO	5.14	$1.01
Omnitrans	MB	PT	3.12	$1.08
Orange County Transportation Authority	CB	DO	21.11	$1.68
Orange County Transportation Authority	CB	PT	19.28	$1.44
Orange County Transportation Authority	DR	PT	11.29	$4.42
Orange County Transportation Authority	DT	PT	3.02	$3.44
Orange County Transportation Authority	MB	DO	3.35	$0.99
Orange County Transportation Authority	MB	PT	3.88	$0.97
Orange County Transportation Authority	VP	PT	34.51	$3.95
Paratransit, Inc.	DR	DO	9.74	$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	21.77	$4.96
Peninsula Corridor Joint Powers Board dba: Caltrain	MB	PT	3.47	$0.00
Placer County Department of Public Works and Facilities	CB	PT	20.11	$5.37
Placer County Department of Public Works and Facilities	DR	DO	11.84	$3.53
Placer County Department of Public Works and Facilities	DR	PT	3.41	$0.73
Placer County Department of Public Works and Facilities	DT	PT	15.71	$3.54
Placer County Department of Public Works and Facilities	MB	DO	7.64	$1.05
Placer County Department of Public Works and Facilities	MB	PT	3.09	$0.67
Placer County Department of Public Works and Facilities	VP	PT	33.94	$2.79
Pomona Valley Transportation Authority	DR	PT	5.50	$0.81
Pomona Valley Transportation Authority	DT	PT	4.81	$1.94
Redding Area Bus Authority	DR	PT	8.86	$3.26

Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Redding Area Bus Authority	MB	PT	6.99	$1.02
Riverside Transit Agency	CB	DO	19.49	$3.83
Riverside Transit Agency	CB	PT	23.22	$2.08
Riverside Transit Agency	DR	PT	11.28	$3.68
Riverside Transit Agency	DT	PT	17.51	$4.05
Riverside Transit Agency	MB	DO	6.27	$0.90
Riverside Transit Agency	MB	PT	6.64	$1.33
Sacramento Regional Transit District	DR	DO	2.59	$1.38
Sacramento Regional Transit District	LR	DO	6.01	$1.29
Sacramento Regional Transit District	MB	DO	3.46	$1.53
San Diego Association of Governments	VP	PT	48.70	$3.11
San Diego Metropolitan Transit System	CB	PT	24.51	$4.17
San Diego Metropolitan Transit System	DR	PT	10.38	$4.52
San Diego Metropolitan Transit System	LR	DO	5.61	$1.04
San Diego Metropolitan Transit System	MB	DO	4.51	$1.02
San Diego Metropolitan Transit System	MB	PT	3.25	$1.00
San Francisco Bay Area Rapid Transit District	HR	DO	13.72	$3.64
San Francisco Bay Area Rapid Transit District	MG	PT	3.18	$5.58
San Francisco Bay Area Water Emergency Transportation Authority	FB	PT	15.01	$7.07
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 Regional Transit District	CB	PT	44.30	$4.45
San Joaquin Regional Transit District	DT	PT	5.83	$3.73
San Joaquin Regional Transit District	MB	DO	3.53	$0.82
San Joaquin Regional Transit District	MB	PT	4.56	$0.82
San Luis Obispo Regional Transit Authority	DR	DO	7.85	$3.05
San Luis Obispo Regional Transit Authority	MB	DO	11.05	$1.31
San Mateo County Transit District	DR	PT	8.10	$2.51
San Mateo County Transit District	DT	PT	11.89	$2.38
San Mateo County Transit District	MB	DO	3.61	$1.32
San Mateo County Transit District	MB	PT	6.19	$1.34
Santa Barbara Metropolitan Transit District	MB	DO	4.09	$1.12

Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Santa Clara Valley Transportation Authority	DR	PT	10.24	$3.45
Santa Clara Valley Transportation Authority	DT	PT	10.68	$2.86
Santa Clara Valley Transportation Authority	LR	DO	5.25	$0.88
Santa Clara Valley Transportation Authority	MB	DO	5.18	$0.88
Santa Clara Valley Transportation Authority	MB	PT	3.68	$0.00
Santa Clarita Transit	CB	PT	24.78	$3.03
Santa Clarita Transit	DR	PT	6.11	$1.14
Santa Clarita Transit	MB	PT	4.23	$0.84
Santa Cruz Metropolitan Transit District	CB	DO	31.21	$5.42
Santa Cruz Metropolitan Transit District	DR	DO	7.24	$4.08
Santa Cruz Metropolitan Transit District	DT	PT	7.23	$2.09
Santa Cruz Metropolitan Transit District	MB	DO	4.27	$1.52
Santa Maria Area Transit	DR	PT	7.40	$0.44
Santa Maria Area Transit	MB	PT	3.73	$1.02
Santa Monica's Big Blue Bus	DR	PT	2.27	$0.41
Santa Monica's Big Blue Bus	MB	DO	3.81	$0.89
Solano County Transit	CB	PT	13.78	$2.50
Solano County Transit	DR	PT	5.36	$2.21
Solano County Transit	MB	PT	2.64	$2.43
Sonoma County Transit	DR	PT	12.17	$3.77
Sonoma County Transit	MB	PT	8.33	$1.49
Southern California Regional Rail Authority dba: Metrolink	CR	PT	29.15	$5.79
SunLine Transit Agency	DR	DO	12.02	$2.05
SunLine Transit Agency	MB	DO	6.86	$0.65
The Eastern Contra Costa Transit Authority	DR	PT	6.00	$3.08
The Eastern Contra Costa Transit Authority	MB	PT	7.23	$1.11
Torrance Transit System	DT	PT	5.20	$1.74
Torrance Transit System	MB	DO	4.95	$0.66
Transit Joint Powers Authority for Merced County	DR	PT	6.36	$3.69
Transit Joint Powers Authority for Merced County	MB	PT	6.22	$1.57

Agency	Mode	Type of Service	Length of Average Trip	Average Fare Cost per Trip
Unitrans - City of Davis/ASUCD	MB	DO	2.15	$0.79
Ventura Intercity Service Transit Authority	CB	PT	20.34	$1.60
Ventura Intercity Service Transit Authority	DR	PT	3.18	$1.75
Ventura Intercity Service Transit Authority	MB	PT	4.37	$0.85
Victor Valley Transit Authority	CB	PT	52.89	$10.12
Victor Valley Transit Authority	DR	PT	13.17	$2.96
Victor Valley Transit Authority	MB	PT	6.74	$1.08
Victor Valley Transit Authority	VP	PT	48.72	$4.17
Western Contra Costa Transit Authority	CB	PT	23.95	$4.12
Western Contra Costa Transit Authority	DR	PT	8.15	$1.35
Western Contra Costa Transit Authority	MB	PT	7.29	$1.10
Yolo County Transportation District	DR	PT	12.25	$4.88
Yolo County Transportation District	MB	PT	10.63	$1.67
Yuba-Sutter Transit Authority	CB	PT	39.33	$4.48
Yuba-Sutter Transit Authority	DR	PT	5.87	$1.83
Yuba-Sutter Transit Authority	MB	PT	3.05	$0.65