California Air Resources Board

Quantification Methodology

California Natural Resources Agency
Urban Greening Grant Program

California Climate Investments

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Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating 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 net GHG benefit and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. 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 at: www.arb.ca.gov/cci-expenditurerecords.

For the California Natural Resources Agency (CNRA) Urban Greening Grant Program (Urban Greening), CARB staff developed this Urban Greening Quantification Methodology to provide guidance for estimating the net GHG benefit and selected co-benefits of each proposed project activity. This methodology uses calculations to estimate carbon sequestration in planted trees, GHG emission reductions from the effects of tree shade on building energy use, avoided GHG emissions due to the reduction in vehicle miles traveled (VMT) from bicycle and walking paths, and GHG emissions associated with the implementation of Urban Greening projects.

The Urban Greening Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with a project example, and outlines documentation requirements. Projects will report the total project GHG benefit and co-benefits estimated using the Urban Greening Benefits Calculator Tool, as well as the total project GHG benefit per dollar of GGRF funds requested. The Urban Greening Benefits Calculator Tool is available for download at: http://www.arb.ca.gov/cci-resources.

Using many of the same inputs required to estimate net GHG benefit, the Urban Greening Benefits Calculator Tool estimates the following co-benefits and key variables from Urban Greening projects: passenger VMT reductions (miles), transportation fuel use reductions (gallons), travel cost savings (dollars), trees planted (quantity of trees), energy use reductions (kWh and therms) energy and fuel cost savings (dollars), water savings (gallons and acre feet per year), and select criteria and toxic air pollutant emissions (pounds) – including reactive organic gases (ROG), nitrogen oxide (NOx), fine particulate matter less than 2.5 micrometers ($PM_{2.5}$), and diesel particulate matter (diesel PM). Key variables are project characteristics that contribute to a project's net GHG benefit and signal an additional benefit (e.g., energy use reductions, number of trees planted, and passenger VMT reductions). Additional co-benefits for which CARB assessment methodologies were not incorporated into the Urban Greening Benefits Calculator Tool may also be applicable to the project. Applicants should consult the Urban Greening Program guidelines, solicitation materials, and agreements to ensure they are meeting Urban Greening Program requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB and CNRA developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[1] CARB and CNRA developed this Urban Greening Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven tools and methods;
- Use project-level data, where available and appropriate; and
- Result in net GHG benefit 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 Urban Greening project types. CARB also consulted with CNRA 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 Urban Greening Quantification Methodology and Draft Urban Greening Benefits Calculator Tool for public comment in December 2018. This Final Urban Greening Quantification Methodology and accompanying Urban Greening Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the Urban Greening Guidelines.

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.

[1] California Air Resources Board (2018). *CCI Funding Guidelines for Administrating Agencies*. www.arb.ca.gov/cci-fundingguidelines.

Tools for Tree Planting

The Urban Greening Benefits Calculator Tool relies on project-specific outputs from one of the two U.S. Department of Agriculture Forest Service (USFS) urban tree carbon accounting tools:

The USFS i-Tree Planting web based tool provides quantitative data for an individual or population of trees to be planted as part of the project including the amount of carbon stored, the estimated effects of tree shade on building energy use, and rainfall interception based on project characteristics such as the climate zone, tree species, tree age, tree diameter at breast height (DBH), and tree location relative to a building. i-Tree Planting can be accessed at: https://planting.itreetools.org/. A description about the tool can be accessed at: https://planting.itreetools.org/help/.

The USFS i-Tree Streets software tool provides quantitative data for an entire population of urban trees to be planted as part of a project, including the amount of carbon stored, the estimated effects of tree shade on building energy use, and rainfall interception based on project characteristics such as the climate zone, tree species, and tree DBH. i-Tree Streets can be downloaded from: https://www.itreetools.org/. A user manual for i-Tree Streets is available from: https://www.itreetools.org/resources/manuals/Streets_Manual_v5.pdf.

The i-Tree Planting and i-Tree Streets tools are used statewide, subject to regular updates to incorporate new information, free of charge, and publicly available to anyone with internet access.

Tools for Bicycle and Pedestrian Facilities

The methodology for bicycle and pedestrian facilities is based on 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"[2] (CMAQ Methods) to estimate the reduction in vehicle miles traveled (VMT) and associated GHG emission reductions based on transportation characteristics of the proposed project. 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. The CMAQ Methods were developed by CARB and Caltrans, and are used statewide by transportation agencies to evaluate criteria pollutant emission reductions from transportation projects competing for State motor vehicle fee and federal CMAQ funding. The CMAQ Methods were used as the basis for developing the GHG emission reduction estimates for the bicycle and pedestrian facilities project activities. The CMAQ Methods document can be downloaded from https://www.arb.ca.gov/planning/tsaq/eval/eval.htm. However, all of the equations and inputs needed for this quantification method are included in this document and the

[2] California Air Resources Board, California Department of Transportation, and the California Air Pollution Control Officers Association. (2005). *Methods to Find the Cost-Effectiveness of Funding Air Quality Projects*. https://www.arb.ca.gov/planning/tsaq/eval/eval.htm.

associated Urban Greening Calculator Tool. Some assumptions have been modified, as necessary.

GGRF eligible bike facilities include Class I, Class II, and Class IV bikeways, as defined below (from Assembly Bill 1193).[3]

- Class I bike paths or shared-use paths provide a completely separated right-of-way designated for the exclusive use of bicycles and pedestrians with crossflows by motorists minimized.
- Class II bike lanes provide a restricted right-of-way designated for the exclusive or semi-exclusive use of bicycles with through travel by motor vehicles or pedestrians prohibited, but with vehicle parking and crossflows by pedestrians and motorists permitted.
- Class IV separated bikeways provide a right-of-way designated exclusively for bicycle travel adjacent to a roadway and are protected from vehicular traffic by features such as grade separation, physical barriers, or on-street parking.

Multi-use projects (e.g., Class I Bike Path) that will result in reduced VMT from bicycle and pedestrian uses may account for both uses. Contiguous projects are considered to be a single project for quantification of emission reductions.

Note that Class III bike routes, which provide a right-of-way designated by signs or permanent markings and shared with pedestrians and motorists, are not currently quantified in this methodology.

In addition to the tools above, the Urban Greening 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 at: http://www.arb.ca.gov/cci-resources. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the Urban Greening Benefits Calculator Tool to estimate the net GHG benefit and co-benefits of the proposed project. The Urban Greening Benefits Calculator Tool can be downloaded from: http://www.arb.ca.gov/cci-resources.

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 projects being quantified. CARB updated

[3] Assembly Bill 1193, available at: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB1193.

the Urban Greening Quantification Methodology from the previous version[4] to enhance the analysis and provide additional clarity. The changes include:

- Addition of a link to a step-by-step user guide with a project example;
- Updates to GHG emission factors used to estimate energy saved or displaced; and
- Addition of new co-benefits using many of the same inputs used to estimate a net GHG benefit.

[4] Quantification Methodology for the CNRA Urban Greening Program, Greenhouse Gas Reduction Fund FY 2017-18. https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/cnra_ug_finalqm_17-18.pdf.

Section B. Methods

The following section provides details on the methods supporting emission reduction estimates in the Urban Greening Benefits Calculator Tool.

Urban Greening Project Types

CNRA developed three project activities that meet the objectives of the Urban Greening Program and for which there are methods to quantify a net GHG benefit.[5] Other project features may be eligible for funding under the Urban Greening Program; however, each project requesting GGRF funding must include at least one of the following:

- Sequester and store carbon by planting trees;
- Reduce building energy use from strategically planting trees to shade buildings; or
- Reduce commute vehicle miles traveled by constructing bicycle paths, bicycle lanes, or pedestrian facilities that provide safe routes for travel between residences, workplaces, commercial centers, and schools.

General Approach

Methods used in the Urban Greening Benefits Calculator Tool for estimating the net GHG benefit and air pollutant emission co-benefits by activity type are provided in this section. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

These methods account for carbon storage in planted trees, energy savings from the benefits of tree shade, avoided emissions from reduction of VMT due to bicycle or pedestrian paths, and the GHG emissions associated with the implementation of Urban Greening projects. In general, the net GHG benefit is estimated in the Urban Greening Benefits Calculator Tool using the approaches in Table 1. The Urban Greening Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate the net GHG benefit.

[5] California Natural Resources Agency (2019). Urban Greening Grant Program Final Guidelines. http://resources.ca.gov/grants/wp-content/uploads/2019/01/Urban-Greening-Program-Guidelines-Round-Three.pdf.

Table 1. General Approach to Quantification by Project Activity

Tree Planting and Energy Savings from Tree Shade
Net GHG benefit = carbon storage in planted trees – carbon in planted trees not assumed to survive[6] *+ GHG reductions from energy savings from shade*[7] *– GHG emissions from tree planting and maintenance*
Bicycle and Pedestrian Facilities
GHG emission reduction = avoided GHG emissions from reduction of vehicle miles traveled due to bicycle and walking trips

User Tip:
Due to the difference in the outputs from the two urban tree accounting tools available for use, some equations are tool-specific, as indicated below.

A. GHG Benefit from Carbon Stored in Trees Planted by the Urban Greening Project

The GHG benefit from carbon stored in trees planted by the project is calculated as the sum of carbon stored in individual trees 40 years after project start, accounting for a 3% annual tree mortality rate[8] for the years after the period of establishment care (including replacement) provided by the project through year 10.[9] Equation 1 is used to determine the GHG benefit from carbon stored in live project trees at the end of the project if the applicant used i-Tree Planting. Equation 2 is used if the applicant used i-Tree Streets.

[6] This methodology applies a 3% annual tree mortality rate to the years after the period of establishment care (including replacement) provided by the project through year 10, at which time tree mortality is substantially reduced. This assumption is based on USFS publications and personal communication with John Melvin, State Urban Forester, CAL FIRE (April 19, 2016).

[7] Some tree planting sites may not provide shade to buildings and will therefore not result in building energy savings. If there are no trees that provide tree shade to conditioned buildings in the proposed project, this variable may be set to 0. If only a subset of trees will provide shade, see the step-by-step User Guide for additional details about how to apply the third party tools, i-Tree Planting and i-Tree Streets.

[8] Roman, Lara. (Spring 2014). How many trees are enough? Tree death and the urban canopy. *Scenario Journal*. http://www.fs.fed.us/nrs/pubs/jrnl/2014/nrs_2014_roman_001.pdf. United States Department of Agriculture Forest Service. *i-Tree ECO Guide to Using the Forecast Model*. http://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6Guide_UsingForecast.pdf. United States Department of Energy Information Administration. (April 1998). *Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings*. http://www3.epa.gov/climatechange/Downloads/method-calculating-carbon-sequestration-trees-urban-and-suburban-settings.pdf

[9] Establishment and replacement care reduces the risk of mortality of trees planted by the project. Because this methodology applies an increased mortality rate in the first ten years after planting when trees are most at risk, the maximum value for years of establishment care in Equations 1-4 is 9 years to limit the tree mortality rate to 3%.

Equation 1: GHG Benefit of Carbon Stored in Live Project Trees *(i-Tree Planting)*

$$GHG_{CSC} = \frac{\sum_i C_{ITP,i} \times (1-0.03)^{10-YC}}{2{,}204.62}$$

Where,			Units
GHG_{CSC}	=	GHG benefit of carbon stored in live project trees estimated using i-Tree Planting	MT CO_2e
$C_{ITP,i}$	=	Carbon stored in each group of project trees i over the 40 year quantification period (from i-Tree Planting)	lb CO_2e
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (The maximum value for the purposes of this equation is 9 years. CNRA requires a minimum of 10 years for establishment and replacement care at the project location, so the calculator is set to a default of 9 years to represent the maximum value.)	years
i	=	Each group of project trees planted	
2,204.62	=	Conversion factor from lb to MT	lb/MT

Equation 2: GHG Benefit of Carbon Stored in Live Project Trees *(i-Tree Streets)*

$$GHG_{CSI} = \frac{\sum_i C_{ITS} \times (1-0.03)^{10-YC}}{2{,}204.62}$$

Where,			Units
GHG_{CSI}	=	GHG benefit of carbon stored in live project trees estimated using i-Tree Streets	MT CO_2e
C_{ITS}	=	Total carbon stored in population of project trees 40 years after project start (from i-Tree Streets)	lb CO_2e
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (The maximum value for the purposes of this equation is 9 years. CNRA requires a minimum of 10 years for establishment and replacement care at the project location, so the calculator is set to a default of 9 years to represent the maximum value.)	years
2,204.62	=	Conversion factor from lb to MT	lb/MT

B. GHG Benefit from Energy Savings as a Result of Strategically Planting Trees to Shade Buildings

The GHG benefit from energy savings is calculated as the total annual energy savings from individual trees planted strategically to shade buildings (i.e., planted within 60 feet) during the 40 year quantification period, taking tree mortality into account. Equation 3 is used to determine the GHG emission reductions from energy savings throughout the quantification period of the project if the applicant used i-Tree Planting.

Equation 4 is used to determine the GHG emission reductions from energy savings throughout the quantification period of the project if the applicant used i-Tree Streets. Because young trees do not provide significant shade during the first 20 years of life and the energy savings value from i-Tree Streets is an estimate of the annual savings when the tree provides the greatest shade, the annual value is multiplied by the remaining 20 years to estimate the GHG emission benefit over 40 years.[10]

Equation 3: GHG Benefit from Energy Savings *(i-Tree Planting)*

$$GHG_{ESC} = (\sum_{i} ER_{ITP,i} \times EF_{ELEC} + \sum_{i} NG_{ITP,i} \times 10 \times EF_{NG}) \times (1 - 0.03)^{10-YC}$$

Where,			Units
GHG_{ESC}	=	GHG benefit from energy savings estimated using i-Tree Planting	MT CO_2e
$ER_{ITP,i}$	=	Total electricity reductions from each group of project trees over the 40 year quantification period (from i-Tree Planting)	kWh
EF_{ELEC}	=	GHG emission factor for electricity	MT CO_2e/ kWh
$NG_{ITP,i}$	=	Total fuel reductions from each group of project trees over the 40 year quantification period (from i-Tree Planting)	MMBtu
10	=	Conversion factor from MMBtu to therms	therms/ MMBtu
EF_{NG}	=	GHG emission factor for natural gas	MT CO_2e/ therm
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (The maximum value for the purposes of this equation is 9 years. CNRA requires a minimum of 10 years for establishment and replacement care at the project location, so the calculator is set to a default of 9 years to represent the maximum value.)	years
i	=	Group of project trees planted	

[10] Greg McPherson, Research Forester, US Forest Service (April 25, 2016) personal communication.

Equation 4: GHG Benefit from Energy Savings *(i-Tree Streets)*

$$GHG_{ESI} = (ER_{ITS} \times Shade\ \% \times EF_{ELEC} + NG_{ITS} \times EF_{NG}) \times (1 - 0.03)^{10-YC} \times PTS \times 20$$

Where,			Units
GHG_{ESI}	=	GHG benefit from energy savings estimated using i-Tree Streets	MT CO_2e
ER_{ITS}	=	Total annual electricity reductions from population of project trees 40 years after project start (from i-Tree Streets)	MWh
Shade %	=	The percent of the trees that will be planted to shade buildings (i.e. within 60 ft)	%
EF_{ELEC}	=	GHG emission factor for electricity	MT CO_2e/ MWh
NG_{ITS}	=	Total annual fuel reductions from population of project trees 40 years after project start (from i-Tree Streets)	therms
EF_{NG}	=	GHG emission factor for natural gas	MT CO_2e/ therm
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (The maximum value for the purposes of this equation is 9 years. CNRA requires a minimum of 10 years for establishment and replacement care at the project location, so the calculator is set to a default of 9 years to represent the maximum value.)	years
PTS	=	Percent of trees to be planted to shade buildings (i.e., within 60 feet)	%
20	=	Years adjusted for annual energy savings output at year 40	years

C. GHG Emissions from Project Implementation

Tree planting projects must account for GHG emissions from tree planting, maintenance, and other tree-related activities. The GHG emissions from implementation of tree planting projects are calculated by deducting 5%[11] of the annual reductions obtained through carbon storage and avoided emissions from energy savings. Equation 5 is used to determine the GHG emissions from implementation of tree planting projects.

Equation 5: GHG Emissions from Tree Planting Project Implementation

$$GHG_{PI} = (GHG_{CSC} + GHG_{CSI} + GHG_{ESC} + GHG_{ESI}) \times EF_{IMP}$$

Where,			Units
GHG_{PI}	=	GHG emissions from tree planting	MT CO_2e
GHG_{CSC}	=	GHG benefit from carbon stored in live project trees estimated using i-Tree Planting (from Equation 1)	MT CO_2e
GHG_{CSI}	=	GHG benefit from carbon stored in live project trees estimated using i-Tree Streets (from Equation 2)	MT CO_2e
GHG_{ESC}	=	GHG benefit from energy savings estimated using i-Tree Planting (from Equation 3)	MT CO_2e
GHG_{ESI}	=	GHG benefit from energy savings estimated using i-Tree Streets (from Equation 4)	MT CO_2e
EF_{IMP}	=	Emission factor for project emissions	

[11] U.S. Department of Agriculture Forest Service, Tree Guides (multiple publications). http://www.fs.fed.us/psw/programs/uesd/uep/tree_guides.shtml.

D. Air Pollutant Co-Benefit from Trees Planted by the Project

The air pollutant emission co-benefit from trees planted by the project is calculated as the sum of air pollutant emissions removed from the atmosphere by individual trees during the 40 year quantification period, accounting for a 3% annual tree mortality rate for the years after the period of establishment care (including replacement) provided by the project through year 10. Equations 6 and 7 are used to determine the air pollutant emission co-benefits from live project trees at the end of the project if the applicant used i-Tree Planting or i-Tree Streets.

Equation 6: $PM_{2.5}$ Emissions Co-benefit from Tree Absorption

$$PM_{2.5,TA} = (ER_{PM,ITP} + (ER_{PM,ITS} \times 20 \times 0.28)) \times (1 - 0.03)^{10-YC}$$

Where,

			Units
$PM_{2.5,TA}$	=	$PM_{2.5}$ benefit of tree planting in live project trees estimated using i-Tree Planting and i-Tree Streets	lb
$ER_{PM,ITP}$	=	Total $PM_{2.5}$ savings over the 40 year quantification period calculated from i-Tree Planting	lb
$ER_{PM,ITS}$	=	Annual PM_{10} savings 40 years after project start calculated from i-Tree Streets	lb
20	=	Years adjusted for annual savings output at year 40	years
0.28	=	Conversion from PM_{10} to $PM_{2.5}$	$PM_{2.5}/PM_{10}$
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

Equation 7: NO_x Emissions Co-benefit from Tree Absorption

$$NO_{x,TA} = (ER_{NOx,ITP} + (ER_{NOx,ITS} \times 20)) \times (1 - 0.03)^{10-YC}$$

Where,

			Units
$NO_{x,TA}$	=	NO_x benefit of tree planting in live project trees estimated using i-Tree Planting and i-Tree Streets	lb
$ER_{NOx,ITP}$	=	Total NO_x savings over the 40 year quantification period calculated from i-Tree Planting	lb
$ER_{NOx,ITS}$	=	Annual NO_x savings 40 years after project start calculated from i-Tree Streets	lb
20	=	Years adjusted for annual savings output at year 40	years
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

E. Air Pollutant Co-benefit from Energy Savings as a Result of Strategically Planting Trees to Shade Buildings

Equations 8 through 10 are used to determine the air pollutant emission co-benefits from energy savings throughout the quantification period of the project if the applicant used i-Tree Planting or i-Tree Streets.

Equation 8: $PM_{2.5}$ Emissions Co-benefit from Energy Savings

$$PM_{2.5.ES} = \Big(\big(ER_{ITP} + (ER_{ITS} \times Shade\,\% \times 20 \times 1{,}000)\big) \times PM_{ELEC} + (NG_{ITP} + (NG_{ITS} \times 0.1 \times 20)) \times PM_{NG}\Big) \times (1 - 0.03)^{10-YC}$$

Where,

			Units
$PM_{2.5,ES}$	=	$PM_{2.5}$ benefit from energy savings estimated using i-Tree Planting and i-Tree Streets	lb
ER_{ITP}	=	Total energy savings over the 40 year quantification period calculated from i-Tree Planting	kWh
ER_{ITS}	=	Annual energy savings 40 years after project start calculated from i-Tree Streets	MWh
Shade %		The percent of the trees that will be planted to shade buildings (i.e. within 60 ft); for users of i-Tree Streets	%
20	=	Years adjusted for annual energy savings output at year 40	years
1,000	=	Conversion factor from MWh to kWh	kWh/MWh
PM_{ELEC}	=	$PM_{2.5}$ emission factor for electricity	lb/kWh
NG_{ITP}	=	Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting	MMBtu
NG_{ITS}	=	Annual natural gas savings 40 years after project start calculated from i-Tree Streets	therms
0.1	=	Conversion from therms to MMBtu	MMBtu/therms
PM_{NG}	=	$PM_{2.5}$ emission factor for natural gas	lb/MMBtu
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

Equation 9: NO_x Emissions Co-benefit from Energy Savings

$$NOx,_{ES} = \quad NO_{x,ES} = \Big(\big(ER_{ITP} + (ER_{ITS} \times Shade\,\% \times 20 \times 1{,}000)\big) \times NOX_{ELEC} + (NG_{ITP} + (NG_{ITS} \times 0.1 \times 20)) \times NOX_{NG}\Big) \times (1 - 0.03)^{10-YC}$$

Where,			Units
$NO_{x,ES}$	=	NO_x benefit from energy savings estimated using i-Tree Planting and i-Tree Streets	lb
ER_{ITP}	=	Total energy savings over the 40 year quantification period calculated from i-Tree Planting	kWh
ER_{ITS}	=	Annual energy savings 40 years after project start calculated from i-Tree Streets	MWh
Shade %		The percent of the trees that will be planted to shade buildings (i.e. within 60 ft); for users of i-Tree Streets	%
20	=	Years adjusted for annual energy savings output at year 40	years
1,000	=	Conversion factor from MWh to kWh	kWh/MWh
NOX_{ELEC}	=	NO_x emission factor for electricity	lb/kWh
NG_{ITP}	=	Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting	MMBtu
NG_{ITS}	=	Annual natural gas savings 40 years after project start calculated from i-Tree Streets	therms
0.1	=	Conversion from therms to MMBtu	MMBtu/therm
NOX_{NG}	=	NO_x emission factor for natural gas	lb/MMBtu
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

Equation 10: ROG Emissions Co-benefit from Energy Savings

$$ROG_{ES} = \left(\left(ER_{ITP} + (ER_{ITS} \times Shade\,\% \times 20 \times 1{,}000)\right) \times ROG_{ELEC} + (NG_{ITP} + (NG_{ITS} \times 0.1 \times 20)) \times ROG_{NG}\right) \times (1 - 0.03)^{10-YC}$$

Where,			Units
ROG_{ES}	=	ROG benefit from energy savings estimated using i-Tree Planting and i-Tree Streets	lb
ER_{ITP}	=	Total energy savings over the 40 year quantification period calculated from i-Tree Planting	kWh
ER_{ITS}	=	Annual energy savings calculated from i-Tree Streets	MWh
Shade %		The percent of the trees that will be planted to shade buildings (i.e. within 60 ft); for users of i-Tree Streets	%
20	=	Years adjusted for annual energy savings output at year 40	years
1,000	=	Conversion factor from MWh to kWh	kWh/MWh
ROG_{ELEC}	=	ROG emission factor for electricity	lb/kWh
NG_{ITP}	=	Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting	MMBtu
NG_{ITS}	=	Annual natural gas savings 40 years after project start calculated calculated from i-Tree Streets	therms
0.1	=	Conversion from therms to MMBtu	MMBtu/therm
ROG_{NG}	=	ROG emission factor for natural gas	lb/MMBtu
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	

F. GHG Benefit from Bicycle Paths and Pedestrian Facilities

GGRF programs estimate transportation-related emissions using a “Well-to-Wheels” approach, which consists of emissions resulting from the production and distribution of different fuel types, including hydrogen and electricity, and any associated exhaust emissions. Urban Greening Program applicants receiving GGRF funds use project-specific data to calculate new or avoided VMT, and VMT is converted to GHG using Well-to-Wheels emission factors embedded in the Urban Greening Calculator Tool. The lookup tables used in the Urban Greening Calculator tool are included in the Database. Equations 11 through 13 are used to determine the GHG and air pollutant emission co-benefits from reduced vehicle miles traveled.

Equation 11: Annual Auto Vehicle Miles Traveled

$$Auto\ VMT\ Reduced = (D) * (ADT) * (A + C) * (L)$$

Where,			Units
Auto VMT Reduced	=	Annual VMT reductions of displaced autos from bicycle paths/lanes and pedestrian facilities	miles
D	=	Days of use per year (default is 200 days)	days
ADT	=	Annual average daily traffic (two-way traffic volume in trips/day on parallel road). Use applicable value from project data (maximum is 30,000);	vehicles/day
A	=	Adjustment factor to account for bike/pedestrian use (use applicable value from Table 2;	N/A
C	=	Activity center credit (use applicable value from Table 3)	N/A
L	=	Bike trip length (1.8 miles per trip in one direction) or walking trip length (1.0 miles per trip in one direction)	miles

Table 2. Adjustment Factor (A) Lookup Table for Equation 11

Average Daily Traffic (ADT)	Length of Bike/Ped Project (one direction)	A (for cities with population >250,000 and non-university towns <250,000)	A (for university towns with population <250,000)
ADT ≤ 12,000 vehicles per day	≤ 1 mile	.0019	.0104
	> 1 & ≤ 2 miles	.0029	.0155
	> 2 miles	.0038	.0207
12,000 < ADT ≤ 24,000 vehicles per day	≤ 1 mile	.0014	.0073
	> 1 & ≤ 2 miles	.0020	.0109
	> 2 miles	.0027	.0145
24,000 < ADT ≤ 30,000 vehicles per day Maximum is 30,000	≤ 1 mile	.0010	.0052
	> 1 & ≤ 2 miles	.0014	.0078
	> 2 miles	.0019	.0104

Table 3. Activity Center Credit (C) Lookup Table for Equation 11[12]

Count your Activity Centers. If there are…	Within 1/2 Mile of Project Area	Within 1/4 Mile of Project Area
3	.0005	.001
More than 3 but fewer than 7	.0010	.002
7 or more	.0015	.003

Activity Center examples: Bank, church, hospital or HMO, light rail station (park & ride), office park, post office, public library, shopping area or grocery store, university, junior college, primary school, or secondary school. These metrics should be evaluated for the project location site and surrounding area which can extend a distance not to exceed one-half (½) mile. If a shopping center has multiple activity centers, each of those activity centers would count individually. For example, if a bank, grocery store, and post office are all located in a shopping center, they would be input as three activity centers for the purposes of this quantification methodology.

[12] Note: The largest value from either column that matches the project activities is used in the Urban Greening calculator as the Activity Center Credit. For example, if there are 3 activity centers within ¼ mile and 3 activity centers within ½ mile, the correct value to use is 0.001.

Equation 12: Auto GHG Reductions for Year 1 and Year F of the Bike or Pedestrian Facility

$$Auto\ Reductions_{Yr1} = \frac{Auto\ VMT\ Reduced * AVEF_{Yr\ 1}}{1{,}000{,}000}$$

$$Auto\ Reductions_{YrF} = \frac{Auto\ VMT\ Reduced * AVEF_{Yr\ F}}{1{,}000{,}000}$$

Where,			Units
Auto Reductions$_{Yr1}$	=	VMT reductions of displaced autos from bicycle paths/lanes and pedestrian facilities in Year 1	MT CO_2e
Auto Reductions$_{YrF}$	=	VMT reductions of displaced autos from bicycle paths/lanes and pedestrian facilities in final year of the project	MT CO_2e
Auto VMT Reduced	=	Annual VMT reductions of displaced autos from bicycle paths/lanes and pedestrian facilities	miles
AVEF	=	Auto vehicle emission factor, see Database	gCO_2e/mile
1,000,000	=	Conversion factor from g to MT	g/MT

Equation 13: GHG Reductions from Reduced VMT

$$GHG_{BP} = \frac{Auto\ Reductions_{Yr1} + Auto\ Reductions_{YrF}}{2} * UL$$

Where,			Units
GHG$_{BP}$	=	GHG emission reductions from bicycle and pedestrian facilities over quantification period	MT CO_2e
Auto Reductions$_{Yr1}$	=	GHG reductions of displaced autos from bicycle paths/lanes and pedestrian facilities in Year 1	MT CO_2e
Auto Reductions$_{YrF}$	=	GHG reductions of displaced autos from bicycle paths/lanes and pedestrian facilities in final year of the project	MT CO_2e
UL	=	Useful life (20 years for Class I and Class IV bicycle paths/lanes, 15 years for Class II bicycle paths/lanes; 20 years for pedestrian facilities)	years

G. Air Pollutant Co-Benefit from Bicycle Paths and Pedestrian Facilities

GGRF programs estimate transportation-related emissions using a "Well-to-Wheels" approach, which consists of emissions resulting from the production and distribution of different fuel types, including hydrogen and electricity, and any associated exhaust emissions. The avoided VMT is converted to air pollutant emissions using Well-to-Wheels emission factors embedded in the Urban Greening Calculator Tool. The lookup tables used in the Urban Greening Calculator tool are included in the Database. Equation 14 is used to determine the air pollutant emission co-benefits from reduced vehicle miles traveled.

Equation 14: Air Pollutant Reductions from Reduced VMT

$$ROG, NOx, PM2.5, or\ Diesel\ PM_{BP} = \frac{Auto\ Reductions_{Yr1} + Auto\ Reductions_{YrF}}{2} * UL$$

Where,			Units
ROG, NOx, $PM_{2.5}$ or Diesel PM_{BP}	=	Air pollutant emission reductions from bicycle and pedestrian facilities over quantification period	lb
Auto $Reductions_{Yr1}$	=	Air pollutant reductions of displaced autos from bicycle paths/lanes and pedestrian facilities in Year 1	lb
Auto $Reductions_{YrF}$	=	Air pollutant reductions of displaced autos from bicycle paths/lanes and pedestrian facilities in final year of the project	lb
UL	=	Useful life (20 years for Class I and Class IV bicycle paths/lanes, 15 years for Class II bicycle paths/lanes; 20 years for pedestrian facilities)	years

H. Net GHG Benefit

The net GHG benefit from any project is the sum of the carbon stored in planted trees, emission reductions from energy savings and emission reductions from reduced VMT, less the GHG emissions associated with the implementation of the project. Equation 15 is used to determine the net GHG benefit from urban greening projects.

Equation 15: Net GHG Benefit

$$GHG = (GHG_{CSC} + GHG_{CSI} + GHG_{ESC} + GHG_{ESI} + GHG_{BP}) - GHG_{PI}$$

Where,			Units
GHG	=	Net GHG benefit from the project	MT CO_2e
GHG_{CSC}	=	GHG benefit of carbon stored in live project trees estimated using i-Tree Planting (from Equation 1)	MT CO_2e
GHG_{CSI}	=	GHG benefit of carbon stored in live project trees estimated using i-Tree Streets (from Equation 2)	MT CO_2e
GHG_{ESC}	=	GHG benefit from energy savings estimated using i-Tree Planting (from Equation 3)	MT CO_2e
GHG_{ESI}	=	GHG benefit from energy savings estimated using i-Tree Streets (from Equation 4)	MT CO_2e
GHG_{BP}	=	GHG reduction due to reduced VMT from bicycle and pedestrian facilities (from Equation 13)	MT CO_2e
GHG_{PI}	=	GHG emissions from project implementation (from Equation 5)	MT CO_2e

I. Net Air Pollutant Co-Benefit

The net air pollutant emission co-benefits from any project is the sum of the individual air pollutant emissions adsorbed by planted trees, emission reductions from energy savings, and emission reductions from reduced VMT. Equations 16 through 19 are used to determine the net air pollutant emission co-benefits from urban greening projects.

Equation 16: $PM_{2.5}$ Net Emissions Benefit

$$PM_{2.5} = PM_{2.5,TA} + PM_{2.5,ES} + PM_{2.5,BP}$$

Where,

			Units
$PM_{2.5}$	=	Net $PM_{2.5}$ benefit from the project	lb
$PM_{2.5,TA}$	=	$PM_{2.5}$ benefit of tree absorption in live project trees estimated using i-Tree Planting or i-Tree Streets (from Equation 6)	lb
$PM_{2.5,ES}$	=	$PM_{2.5}$ benefit from energy savings estimated using i-Tree Planting or i-Tree Streets (from Equation 8)	lb
$PM_{2.5,BP}$	=	$PM_{2.5}$ reduction due to reduced VMT from bicycle and pedestrian facilities (from Equation 14)	lb

Equation 17: NO_x Net Emissions Benefit

$$NO_X = NO_{X,TA} + NO_{x,ES} + NO_{x,BP}$$

Where,

			Units
NO_x	=	Net NO_x benefit from the project	lb
$NO_{x,TA}$	=	NO_x benefit of tree absorption in live project trees estimated using i-Tree Planting or i-Tree Streets (from Equation 7)	lb
$NO_{x,ES}$	=	NO_x benefit from energy savings estimated using i-Tree Planting or i-Tree Streets (from Equation 9)	lb
$NO_{x,BP}$	=	NO_x reduction due to reduced VMT from bicycle and pedestrian facilities (from Equation 14)	lb

Equation 18: ROG Net Emissions Benefit

$$ROG = ROG_{ES} + ROG_{BP}$$

Where,

			Units
ROG	=	Net ROG benefit from the project	lb
ROG_{ES}	=	ROG benefit from energy savings estimated using i-Tree Planting or i-Tree Streets (from Equation 10)	lb
ROG_{BP}	=	ROG reduction due to reduced VMT from bicycle and pedestrian facilities (from Equation 14)	lb

Equation 19: Diesel PM Net Emissions Benefit

$$Diesel\ PM = Diesel\ PM_{BP}$$

			Units
Where,			
Diesel PM	=	Net Diesel PM benefit from the project	lb
Diesel PM_{BP}	=	Diesel PM reduction due to reduced VMT from bicycle and pedestrian facilities (from Equation 14)	lb

Section C. References

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

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