California Air Resources Board

Quantification Methodology

**California Energy Commission
Renewable Energy for Agriculture Program**

California Climate Investments

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Table of Abbreviations and Acronyms

BTU	British Thermal Unit
CARB	California Air Resources Board
CEC	California Energy Commission
diesel PM	diesel particulate matter
EC	Energy Capacity
EER	Energy Economy Ratio
EF	Emission Factor
GGRF	Greenhouse Gas Reduction Fund
GHG	Greenhouse Gas
HP	Horsepower
kWh	kilowatt-hour
mo	month
MT CO2e	Metric Tons of Carbon Dioxide equivalence
NOx	Nitrogen Oxides
PM2.5	Particulate Matter less than 2.5 microns
PV	Photovoltaic
QM	Quantitative Methodology
RE	Renewable Energy
REAP	Renewable Energy for Agriculture Program
ROG	Reactive Organic Gases
TDH	Total Dynamic Head
therm	a unit of heat equivalent to 100,000 BTU
VFD	Variable Force Drive
η	efficiency

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, and benefits calculator tools. CARB develops these methodologies and tools based on the project components 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 Energy Commission (CEC) Renewable Energy for Agriculture Program (REAP), CARB staff developed this REAP Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project component. This methodology uses calculations to estimate GHG emission reductions from the replacement of equipment of equipment powered by fossil fuels with equipment powered by electricity and avoided GHG emissions from the installation of onsite commercially available renewable energy technology.

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

Using many of the same inputs required to estimate GHG emission reductions, the REAP Benefits Calculator Tool estimates the following co-benefits and key variables from REAP projects: reactive organic gases (ROG) (in pounds), nitrogen oxides (NO_x) (in pounds), particulate matter ($PM_{2.5}$) and diesel particulate matter (diesel PM) (in pounds), fossil fuel use reductions (in gallons), fossil fuel based energy use reduction (in kilowatt-hours or therms), energy and fuel cost savings ($), renewable energy

generation (in kilowatt-hours) and land conserved (in acres). Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit. Additional co-benefits for which CARB assessment methodologies were not incorporated into the REAP Benefits Calculator Tool may also be applicable to the project. Applicants should consult the REAP guidelines, solicitation materials, and agreements to ensure they are meeting REAP requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB and CEC developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[1] CARB and CEC developed this REAP 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 GHG 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 REAP project types. CARB also consulted with CEC 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.

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 at: www.arb.ca.gov/cci-cobenefits.

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[1] California Air Resources Board. www.arb.ca.gov/cci-fundingguidelines

Tools

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

The PVWatts® Calculator is an interactive web application that allows homeowners, installers and manufacturers to easily develop estimates of the performance of potential PV installations at specific locations. The calculator estimates the electricity production and energy value of a grid-connected roof- or ground-mounted photovoltaic system based on default inputs or user-defined inputs about the system's location, and basic design parameters. It is used in the REAP Quantitative Methodology to determine the renewable energy generated from the solar photovoltaic system components of REAP projects. The tool can be accessed at: https://pvwatts.nrel.gov/.

The PVWatts® Calculator is used statewide, subject to regular updates to incorporate new information, free of charge, and publicly available to anyone with internet access.

In addition to the tool above, the REAP 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 REAP Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The REAP Benefits Calculator Tool can be downloaded from: http://www.arb.ca.gov/cci-resources.

Section B. Methods

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

Project Components

CEC developed three project components that meet the objectives of REAP and for which there are methods to quantify GHG emission reductions:[2]

- Solar photovoltaic (PV) systems;
- Diesel powered irrigation pump replacement with electric pumps; and
- Battery energy storage.

Other project components, such as wind turbines, may be eligible for funding under the REAP guidelines, but the GHG emission reductions and benefits associated with these other project components are beyond the scope of the REAP QM and Benefits Calculator Tool, and will not be evaluated until the project is implemented.

General Approach

Methods used in the REAP Benefits Calculator Tool for estimating the GHG emission reductions 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 renewable energy generation and reductions in grid electricity and fossil fuel use. In general, the GHG emission reductions are estimated in the REAP Benefits Calculator Tool using the approaches in Table 1. The REAP Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate GHG emission reductions.

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[2] https://efiling.energy.ca.gov/getdocument.aspx?tn=225840

Table 1. General Approach to Quantification by Project Component

Solar photovoltaic (PV) systems
GHG Emission Reductions = GHG emissions avoided due to PV Solar renewable electricity generation
Diesel powered irrigation pump replacement with electric pumps
GHG Emission Reductions = GHG emissions avoided due to elimination of fossil fuel use – GHG emissions from utility energy use
Battery Energy Storage
GHG Emission Reductions = Reduction in renewable electricity availability due to storage efficiency and self-discharge.

A. GHG Emission Reductions from PV Solar Installation

The GHG emission reductions from installing photovoltaic solar panels is estimated as the GHG emissions displaced from the electricity produced from the PV solar panels using Equation 1. Electrical losses due to battery storage are estimated using Equation 2.

Equation 1: GHG Emission Reductions from PV Solar Installation

$$GHG_{PV} = EF_{grid} \times \Sigma_{mo}(RE_{PV,mo} - RE_{loss,mo}) \times 30$$

Where,   <u>Units</u>

GHG_{PV}	=	GHG benefit from PV solar installation	MT CO_2e
EF_{grid}	=	California Grid Average GHG Emission Factor	$\dfrac{\text{MT CO}_2\text{e}}{\text{kWh}}$
$RE_{PV,mo}$	=	Monthly Renewable Electricity production for PV Solar Panels (PVWatts)	$\dfrac{\text{kWh}}{\text{month}}$
$RE_{loss,mo}$	=	Battery storage monthly loss of electricity (Eq. 2)	$\dfrac{\text{kWh}}{\text{month}}$
30	=	PV Solar Panel Project Life	years

Equation 2: Electricity losses from battery storage

$$RE_{loss,mo} = (1 - \eta_{battery}) \times \min\left(RE_{PV,mo}, (Depth_{battery} \times EC_{battery})\right)$$

Where,   Units

$RE_{loss,mo}$	=	Battery storage monthly loss of electricity	$\dfrac{kWh}{month}$
$\eta_{battery}$	=	Storage efficiency by battery type	%
$RE_{PV,mo}$	=	Monthly Renewable Electricity production for PV Solar Panels (PVWatts)	$\dfrac{kWh}{month}$
$Depth_{battery}$	=	Depth of discharge by battery type	%
$EC_{battery}$	=	Energy capacity of battery	kWh

B.   GHG Emission Reductions from Diesel Pump Replacement

The GHG emission reductions from diesel irrigation pump replacement with electric pumps are estimated as the difference between the diesel pump and electric pump scenarios using Equation 3. Equation 4 estimates the GHG emissions from the pre-project diesel pump. Equation 5 estimates the GHG emissions from the post-project diesel pump. Equation 6 estimates total dynamic head, if needed. Equation 7 estimates GHG emission reduction from installation of a variable force drive, if needed.

Equation 3: GHG Emission Reduction from Diesel Irrigation Pump Replacement with Electric Pump

$$GHG_{PR} = GHG_{DP} - (GHG_{EP} - GHG_{VFD})$$

Where,   Units

GHG_{PR}	=	GHG emission reduction from pump replacement	MT CO_2e
GHG_{DP}	=	GHG emissions from existing diesel pump (Eq. 4)	MT CO_2e
GHG_{EP}	=	GHG emissions from proposed electric pump (Eq. 5)	MT CO_2e
GHG_{VFD}	=	GHG emission reduction from variable force drive (if included) (Eq. 7)	MT CO_2e

Equation 4: GHG Emission from Existing Diesel Pump

$$GHG_{DP} = EF_D \times Fuel\ Use \times 10$$

Where,			Units
GHG_{DP}	=	GHG emissions from existing diesel pump	MT CO_2e
EF_D	=	Emission Factor for diesel fuel	$\dfrac{\text{MT } CO_2\text{e}}{\text{gallon}}$
$Fuel\ Use$	=	Annual Diesel Fuel Use of Diesel Pump	$\dfrac{\text{gallons}}{\text{year}}$
10	=	Project life of diesel pump replacement project type	years

Equation 5: GHG Emission from Replacement Electric Pump

$$GHG_{EP} = GHG_{DP} \times \frac{TDH_{post}}{TDH_{pre}} \times \frac{\eta_{pre}}{\eta_{post}} \times \frac{EER\ Adjusted\ Carbon\ Intensity_E}{EER\ Adjusted\ Carbon\ Intensity_D}$$

Where,			Units
GHG_{EP}	=	GHG emissions from proposed electric pump	MT CO_2e
GHG_{DP}	=	GHG emissions from existing diesel pump	MT CO_2e
TDH	=	Total Dynamic Head or system pressure requirement, pre and post project (Equation 6)	Feet of Head
η	=	Overall pumping efficiency, pre and post project. This value incorporates pump efficiency and motor efficiency.	%
EER $Adjusted$ $Carbon$ $Intensity$	=	Energy Economy Ratio lifecycle emission factor for diesel (D) and electricity (E) with an adjustment to reflect for the relative efficiency of a specific fuel used in a motor[3]	$\dfrac{\text{grams of C}}{\text{MJ}}$

Equation 6: Total Dynamic Head Calculation (if needed)

$$TDH = H_e + H_d + H_f$$

Where,			Units
TDH	=	Total Dynamic Head or system pressure requirement	Feet of Head
H_e	=	Elevation head, the vertical distance which the water must be pumped	Feet of Head
H_d	=	Discharge head, the pressure at which water leaves the pump	Feet of Head
H_f	=	Friction head, the loss in pressure caused by friction	Feet of Head

Equation 7: GHG Emission Reduction from Variable Force Drive Installation (if included)

$$GHG_{VFD} = \min\left(50\% \times GHG_{EP}, Energy\ Savings_{VFD} \times HP_{post} \times EF_E \times 10\right)$$

Where,			Units
GHG_{VFD}	=	GHG emission reduction from variable force drive	MT CO_2e
GHG_{EP}	=	GHG emissions from proposed electric pump	MT CO_2e
$Energy\ Savings_{VFD}$	=	Energy savings for VFD installations (from DEER). The energy savings incorporate an assumed VFD efficiency of 97%	$\dfrac{kWh}{bhp}$
HP_{post}	=	Post project rated motor horsepower	bhp
EF_E	=	Emission Factor for electricity	$\dfrac{MT\ CO_2e}{kWh}$
10	=	Project life of diesel pump replacement project type	years

C. Criteria Pollutant Emission Reductions from Avoided California Grid Electricity Use

The criteria pollutant emission reductions from installing photovoltaic solar panels or biomass generation is estimated as the GHG emissions displaced from the electricity produced using Equation 8. Renewable energy produced from PV solar is estimated using Equation 9. Renewable energy produced from biomass generation is estimated using Equation 10.

Equation 8: Criteria Pollutant Emission Reductions from avoided CA Grid Electricity Use

$$ER_{grid,CP} = EF_{CP} \times Elec_{RE}$$

Where,			Units
$ER_{grid,CP}$	=	Criteria Pollutant Emission Reductions from avoided CA Grid Electricity Use (NO_x, ROG, and $PM_{2.5}$)	lbs
EF_{CP}	=	California Grid Average Criteria Pollutant Emission Factor for Criteria Pollutants NO_x, ROG, and $PM_{2.5}$	$\dfrac{lb}{kWh}$
$Elec_{RE}$	=	Electricity produced from renewable energy (PV Solar)	kWh

Equation 9: Renewable Electricity produced by PV Solar

$$Elec_{PV} = (RE_{PV} - RE_{loss}) \times 30$$

Where,   Units

$Elec_{PV}$	=	Electricity produced from photovoltaic solar	kWh
RE_{PV}	=	Renewable Electricity production factor for PV Solar Panels per year (PVWatts)	kWh/yr
RE_{loss}	=	Renewable Electricity loss from battery storage	kWh/yr
30	=	PV Solar Panel Project Life	years

D. Criteria Pollutant Emission Reductions from Diesel Pump Replacement

The criteria pollutant emission reductions from diesel irrigation pump replacement with electric pumps are estimated as the avoided diesel emissions based on diesel pump horsepower rating and annual usage using Equation 10.

Equation 10: Criteria Pollutant Emission Reductions from avoided Diesel fuel use

$$ER_{D,CP} = EF_{CP,HP} \times P_D \times T_D \times 0.65 \times 10$$

Where,   Units

$ER_{D,CP}$	=	Criteria Pollutant Emission Reductions from avoided diesel fuel use (NO_x, ROG, and $PM_{2.5}$)	lbs
$EF_{CP,HP}$	=	Criteria Pollutant Emission Factor for Off-Road Compression Engines by criteria pollutant and engine horsepower	$\frac{lbs}{bhp - hr}$
P_D	=	Diesel pump engine rated horsepower	bhp
T_D	=	Diesel pump engine annual operation time	$\frac{hrs}{year}$
0.65	=	Estimated load factor for diesel pump	Fraction
10	=	Diesel Pump Replacement Project Life	years

Section C. References

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

California Air Resources Board. (2018). *California Greenhouse Gas Inventory for 2000-2016 – by Sector and Activity.* Retrieved from https://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_sector_sum_2000-16.pdf.

California Air Resources Board. (2016). *2016 SIP Emission Projection Data: 2012 Estimated Annual Average Emissions.* Retrieved from https://www.arb.ca.gov/app/emsinv/2017/emssumcat_query.php?F_YR=2012&F_DIV=-4&F_SEASON=A&SP=SIP105ADJ&F_AREA=CA#0.

California Air Resources Board. (2016). *Low Carbon Fuel Standard (LCFS) Program.* Retrieved from https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.

Cal. Code Regs. tit. 13 § 2423.

California Energy Commission. (2018). *California Electrical Energy Generation.* Retrieved from https://www.energy.ca.gov/almanac/electricity_data/electricity_generation.html.

California Energy Commission. (2018). *Greenhouse Gas Reduction Fund: Expenditure Record.* Retrieved from https://ww2.arb.ca.gov/resources/documents/cci-attestation-memorandums-and-expenditure-records.

California Energy Commission. (2012). *Report on Solar Energy Storage Methods and Life Cycle Assessment.* Davis, CA: California Solar Energy Collaborative. https://www.energy.ca.gov/2013publications/CEC-500-2013-073/CEC-500-2013-073.pdf

University of California Cooperative Extension, Agriculture and Natural Resources. (2016). *Irrigation Systems and Energy Efficiency.* Kearny Agricultural Center: Daniele Zaccaria. https://ucanr.edu/sites/Irrigation_and_Soils_/files/242450.pdf.

U.S. Department of Agriculture, Natural Resources Conservation Service (2010). *Engineering Technical Note No. MT-14, "Variable Speed Drive (VSD) for Irrigation Pumping."* Retrieved from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_054026.pdf.

U.S. Department of Energy, National Renewable Energy Laboratory. (2017). *PVWatts®
Calculator*. Golden, CO: Alliance for Sustainable Energy.
https://pvwatts.nrel.gov/index.php.