California Air Resources Board

Quantification Methodology

State Water Resources Control Board
Safe and Affordable Drinking Water Fund

California Climate Investments

Note:
The California Air Resources Board (CARB) is accepting public comments on the Draft Safe and Affordable Drinking Water (SADW) Fund Benefits Calculator Tool and the Draft SADW Fund Quantification Methodology until October 4, 2023. *Email your comments on the draft documents* to GGRFProgram@arb.ca.gov. The Draft Benefits Calculator Tool and Draft Quantification Methodology are subject to change pending stakeholder comments. The Final SADW Fund Benefits Calculator Tool and Final SADW Fund Quantification Methodology will be available on the *California Climate Investments resources webpage*.

DRAFT
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Contents

List of Acronyms and Abbreviations

Acronym	Term
CARB	California Air Resources Board
Diesel PM_{10}	diesel particulate matter with a diameter less than 10 micrometers
DC	direct current
g	grams
gal	gallons
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
kg	kilograms
kW	kilowatts
kWh	kilowatt hours
lb	pounds
local	local air pollutant emission reductions occur at the project location (NOx, ROG, $PM_{2.5}$)
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	nitrous oxide
$PM_{2.5}$	particulate matter with a diameter less than 2.5 micrometers
PV	photovoltaic
remote	remote air pollution emission reductions occur at grid electricity production facilities (NOx, ROG, $PM_{2.5}$)
ROG	reactive organic gas
scf	standard cubic feet
VFD	variable frequency drive
W	watts
yr	year

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*.

For the State Water Resources Control Board (State Water Board) Safe and Affordable Drinking Water (SADW) Fund, part of the Safe and Affordable Funding for Equity and Resilience (SAFER) Drinking Water Program, CARB staff developed this SADW 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 avoided GHG emissions from pump motor replacements, solar PV electricity generation, energy efficiency retrofits, and GHG emissions associated with the implementation of SADW projects.

The SADW 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 SADW Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds requested. The SADW Benefits Calculator Tool is available for download at the *CCI Resources website*

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

- Renewable energy generation (kWh);
- Local and remote ROG emission reductions (lb);
- Local and remote NO_x emission reductions (lb);
- Local and remote $PM_{2.5}$ emission reductions (lb);
- Local diesel PM_{10} emission reductions (lb);

- Fossil fuel use reductions (gallons); and
- Energy and fuel cost savings ($).

Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., renewable energy generated). Additional co-benefits for which CARB assessment methodologies were not incorporated into the SADW Benefits Calculator Tool may also be applicable to the project. Applicants should consult the SADW solicitation materials and agreements to ensure they are meeting SADW requirements. All CARB co-benefit assessment methodologies are available at the *CCI Co-benefits website*.

Methodology Development

CARB and SWRCB developed this SADW Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[1] This Quantification Methodology serves 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 SADW project types. CARB also consulted with the State Water Board 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. *Co-benefit assessment methodologies* are available online.

[1] California Air Resources Board (2018). *Funding Guidelines for Administering Agencies*.

Tools

The SADW Benefits Calculator Tool relies on project-specific outputs from the following tool:

For projects that include solar PV systems, the SADW Benefits Calculator Tool relies on project-specific outputs from the National Renewable Energy Laboratory PVWatts® Calculator, a web-based tool that estimates the electricity production of grid-connected roof- or ground-mounted solar PV systems. PVWatts calculates estimated values for a proposed system's monthly and annual electricity production. *PVWatts* is publicly available to anyone with internet access, free of charge, and is updated at a regular basis.

In addition to the tool above, the SADW 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 the *CCI Resources website*. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the SADW Benefits Calculator Tool to estimate the GHG emission reductions and co-benefits of the proposed project. The SADW Benefits Calculator Tool can be downloaded from the *CCI Resources website*.

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 the SADW Fund Quantification Methodology from the previous version[2] to enhance the analysis and provide additional clarity. The changes include:

- Modifications to bottled water deliveries to account for avoided miles traveled by bottled water delivery recipients, and
- Added additional fuel options for heavy-duty trucks.

[2] "Quantification Methodology for the SADW Fund Program," California Air Resources Board, May 28, 2021. *E-mail the GGRF Program* at GGRFProgram@arb.ca.gov to request a copy.

Section B. Methods

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

Project Components

The State Water Board identified five project types that meet the objectives of the SADW Fund, including two project types for which there are methods to quantify GHG emission reductions: "Construction" and "Interim Water Provision." Project features that are eligible for funding under the SADW Fund listed in the Safe and Affordable Drinking Water Fund Fiscal Year 2021-2022 Expenditure Plan[3] include:

- Construction;
- Interim Water Provision;
- Planning;
- Technical Assistance; and
- Other Project Component Contributing to Climate Adaptation and Resiliency.[4]

Construction

This quantification methodology estimates the GHG and air pollutant emission reductions from the following construction project components:

- GHG and air pollutant emission reductions from pump replacements;
- GHG and air pollutant emission reductions from VFD installations;
- Avoided GHG and air pollutant emissions from solar photovoltaic (PV) electricity generation; and
- GHG and air pollutant emission reductions from energy efficiency retrofits

CARB and the State Water Boards will develop additional methods as they become available. For example, it may be possible to quantify energy use reductions associated with on-site water energy demand reductions for water providers that implement projects that result in water conservation from leak repairs or other system improvements.

[3] *State Water Resources Control Board (2023). FY 2023-24 Fund Expenditure Plan, Safe and Affordable Drinking Water Fund.*

[4] California Air Resources Board (2020). *Safe and Affordable Drinking Water Fund Climate Adaptation and Resiliency Guidance*.

Interim Water Provision

This quantification methodology estimates the GHG and air pollutant emissions from the following interim water provision components:

- GHG and air pollutant emissions from hauled water; and
- GHG and air pollutant emissions from delivery of bottled water.

General Approach

This section describes the methods used in the SADW Benefits Calculator Tool to estimate GHG emission reductions and air pollutant emission co-benefits by project component. These methods account for emission reductions from energy efficiency improvements and avoided emissions from the generation of solar PV electricity, as well as emissions from interim water delivery.

In general, the GHG and air pollutant emission reductions are estimated in the SADW Benefits Calculator Tool using the quantification approaches described for each project component in Table 1 below.

Table 1. General Approach to Quantification by Project Component

Pump Motor Replacement
GHG Emission Reductions *= GHG Emissions of Old Pump – GHG Emissions of New Pump*
VFD Installation
GHG Emission Reductions *= Total Energy Savings x Emission Factor*
Solar PV Electricity Generation
GHG Emission Reductions *= Avoided GHG Emissions from Grid Electricity*
Energy Efficiency Retrofits
GHG Emission Reductions *= Total Energy Savings x Emission Factor*
Interim Water Provision
GHG Emissions Reductions *= Avoided GHG Emissions from Recipient Vehicle – GHG Emissions from Delivery Vehicle*

A. Emission Reductions from Pump Motor Replacements

1. GHG Equations

Equation 1 is used to estimate the GHG emission reductions from pump motor replacement projects over the useful life of the replacement equipment, up to a maximum of ten years (quantification period)[5], using annual emission reductions calculated from Equation 2. The annual GHG emission reductions from pump motor replacements are estimated by Equation 2 as the difference in annual GHG emissions between the baseline and project scenarios.

Annual GHG emissions are calculated for non-electric pump motors with Equation 3 from the estimated fuel use, using fuel-specific emission factors[6]. The fuel use of the baseline equipment and replacement equipment is calculated from Equation 4 for non-electric pump motors using the brake-specific fuel consumption and load factor[7], horsepower[8], and annual activity[9] of the pump motor.

Annual GHG emissions from grid electricity energy use are calculated for electric pump motors using Equation 5, and the energy use of electric pump motor

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[5] The useful life of the replacement equipment (quantification period) is assumed to be ten years at maximum, which aligns with the quantification period assumed for stationary agricultural irrigation pumps funded by the California Air Resources Board's Carl Moyer Program, the Funding Agricultural Replacement Measures for Emissions Reductions (FARMER) program, Community Air Protection program, and State Water Efficiency and Enhancement Program (SWEEP).

Carl Moyer Program Guidelines

"Quantification Methodology for SWEEP." California Air Resources Board, January 11, 2017. *E-mail the GGRF Program* at GGRFProgram@arb.ca.gov to request a copy.

[6] *California Climate Investments Quantification Methodology Emission Factor Database*

[7] The BSFC values and default load factor of 0.65 are from Appendix D of the Carl Moyer Program Guidelines, which aligns with assumptions for stationary agricultural irrigation pump replacement projects funded by the California Air Resources Board's Carl Moyer Program, the Funding Agricultural Replacement Measures for Emissions Reductions (FARMER) program, and Community Air Protection program.

[8] The horsepower of the pump motor engine can be obtained from the manufacturer information available listed on the motor nameplate.

[9] Annual activity estimates used for the purposes of this quantification methodology must be supported by supplemental data to support the observed metered activity of the equipment over a one-year period.

equipment is calculated from energy meter readings, if available.[10] If unavailable, energy use can be calculated from Equation 6 (for prospective estimates), or from Equation 7 (for retrospective estimates).

Equation 1. GHG Emission Reductions from Pump Motor Replacement (Quantification Period)

$$ER_{MR} = GHG_{MR} \times Useful\ Life$$

Variable	Variable Definition	Units
ER_{MR}	Emission reductions from pump motor replacement	$MTCO_2e$
GHG_{MR}	Annual GHG emission reductions from replacing baseline equipment with replacement equipment, from Equation 4	$MTCO_2e/yr$
Useful Life	Useful life of the replacement equipment (quantification period) = 10 years maximum[5]	yr

Equation 2. Annual GHG Emission Reductions from Pump Motor Replacement

$$GHG_{MR} = GHG_{baseline} - GHG_{replacement}$$

Variable	Variable Definition	Units
GHG_{MR}	Annual GHG emission reductions from replacing baseline equipment with replacement equipment, from Equation 1	$MTCO_2e/yr$
$GHG_{baseline}$	Annual GHG emissions from baseline equipment, from Equation 3 for non-electric pump motors, or from Equation 5 for electric pump motors	$MTCO_2e/yr$
$GHG_{replacement}$	Annual GHG emissions from baseline equipment, from Equation 3 for non-electric pump motors, or from Equation 5 for electric pump motors	$MTCO_2e/yr$

[10] Annual energy use estimates used for the purposes of this quantification methodology must be supported by supplemental data such as energy meter reading logs.

Equation 3. GHG Emissions from Non-electric Pump Motor (Baseline or Replacement)

$$GHG_i = Fuel_i \times FSEF \times \frac{1\ MTCO2e}{1{,}000{,}000\ gCO2e}$$

Variable	Variable Definition	Units
GHG_i	Annual emissions from baseline or replacement non-electric pump motor	$MTCO_2e$/yr
$Fuel_i$	Annual fuel usage for baseline or replacement equipment from Equation 4	unit of fuel/yr
FSEF	Fuel-specific emission factor[6]	gCO2e/unit of fuel
1/1,000,000	Conversion unit from grams of carbon dioxide equivalent to metric tons of carbon dioxide equivalent	MTCO2e/ gCO2e
i	Baseline or replacement	

Equation 4 is used to determine the equipment fuel use in the baseline or project scenario for projects that involve spark ignition or compression ignition engines.

Equation 4. Non-Electric Pump Motor Annual Fuel Use (Baseline or Replacement)

$$Fuel_i = \frac{BSFC_i \times LF_i \times hp_i \times Hours_i}{Fuel\ Density}$$

Variable	Variable Definition	Units
Fuel	Annual fuel usage for baseline or project pump motor	unit of fuel/yr
BSFC	Brake-specific fuel consumption factor	lb/bhp-hr
LF	Load factor[7]	unitless
hp	Horsepower	hp
Hours	Annual hours of usage	hours/yr
Fuel Density	Fuel density of equipment fuel	lb/unit of fuel
i	Baseline or replacement	

Equation 5 calculates the GHG emissions from electric pump motors using the energy use measured from energy meters, when available.[10] If unavailable, prospective estimates of energy use from Equation 6, or retrospective estimates of energy use from Equation 6 may also be used.

Equation 5. GHG Emissions from Electric Pump Motors

$$GHG_i = Energy_i \times FSEF \times \frac{1\ MTCO2e}{1{,}000{,}000\ gCO2e}$$

Variable	Variable Definition	Units
GHG_i	Annual emissions from baseline or replacement electric pump motor	$MTCO_2e$/yr
$Energy_i$	Annual energy usage for baseline or replacement equipment from energy meter readings, if available. If unavailable, use Equation 6 (for prospective estimates), or Equation 7 (for retrospective estimates)	kWh/yr
FSEF	Fuel-specific emission factor[6]	gCO2e/kWh
Useful Life	Useful life of the replacement equipment (quantification period)	yr
1/1,000,000	Conversion unit from metric tons of carbon dioxide equivalent to grams of carbon dioxide equivalent	MTCO2e/ gCO2e
i	Baseline or replacement	

Equation 6 is used to estimate annual energy use for electric motors that are replacing non-electric motors by estimating the energy needs of the existing motor using the fuel consumption calculated from Equation 4 and the energy density of the baseline fuel. Equation 6 assumes that the replacement electric motor will need to achieve the same energy needs as the existing motor. Equation 6 adjusts for the energy density of grid electricity and an appropriate energy efficiency factor to account for the improved efficiency of electrified engines. This approach should be used to prospectively estimate the replacement energy use for the replacement of a non-electric pump with an electric pump. When energy meter readings are unavailable, a retrospective estimate of the energy use of electric pumps from Equation 7 may also be used.

Equation 6. Annual Energy Use of Replacement Equipment Electric Motor

$$Energy_{Project} = Fuel_{Baseline} \times ED_{Baseline} \times \frac{1}{ED_{Electricity}} \times \frac{1}{EER}$$

Variable	Variable Definition	Units
$Energy_{Replacement}$	Annual energy usage for replacement pump	kWh
$Fuel_{Baseline}$	Annual fuel usage for baseline pump from Equation 4	gal or scf
$ED_{Baseline}$	Energy density of baseline fuel	MJ/gal or MJ/scf
$ED_{Electricity}$	Energy density of grid electricity	MJ/kWh
EER	Energy efficiency ratio, relative to baseline equipment fuel type[11]	unitless

Equation 7 can be used to estimate the energy use of an electric pump motor using the flow rate in gallons per minutes, the pump head in feet of water column[12], the efficiencies of the pump, motor, and variable frequency drive (if applicable)[13], and the operating hours of the equipment.

[11] The EER is derived from the relative ratio of the energy efficiency of the gasoline powered motor engine to perform the same amount of work compared to an electrified motor engine.

California Climate Investments Quantification Methodology Emission Factor Database.

[12] At sea level (14.7 psi atmospheric pressure) and 75° F, one pound per square inch gauge pressure (1 psig) = 2.31 ft. water column (or 15.7 psia = 2.31 ft. water column)

[13] If no VFD efficiency is provided, an energy efficiency of 97% is assumed.

Romberger, Jeff. 2017. *Chapter 18: Variable Frequency Drive Evaluation Protocol The Uniform Methods Project: Methods for Determining Energy-Efficiency Savings for Specific Measures*. Golden, CO; National Renewable Energy Laboratory. NREL/ SR-7A40-68574.

Equation 7. Energy Use of Baseline or Project Electric Pump Motor

$$Energy_i = \frac{Flow_i \times Head_i}{3{,}956 \times n_{Pump,i} \times n_{Motor,i} \times n_{Drive,i}} \times 0.746 \times Hours$$

Variable	Variable Definition	Units
$Energy_i$	Annual energy usage for baseline or replacement electric pump motor	kWh/yr
$Flow_i$	Flow rate in gallons per minute	gpm
$Head_i$	Pump head in feet water column (ft. w.c)[14] for baseline or replacement electric pump motor	Ft. w.c.
3,956	Conversion unit from the Flow and Head to horsepower	gpm x ft. w.c./Hp
$n_{Pump,i}$	Pump efficiency for baseline or replacement electric pump motor	%
$n_{Motor,i}$	Motor efficiency for baseline or replacement electric pump motor	%
$n_{Drive,i}$	VFD efficiency[15] for baseline or replacement electric pump motor	%
0.746	Conversion unit from horsepower to kWh	kWh/Hp
$Hours_i$	Annual operating hours	hr/yr
i	Baseline or replacement	

2. Criteria and Toxic Air Pollutant Equations

The criteria and toxic air pollutant emission reductions from pump motor replacements are estimated as the total emission reductions over the useful life of the replacement equipment, using Equation 8.

The annual emission reductions are estimated as the difference between the baseline and replacement scenarios using Equation 9. The following calculations are performed for each air pollutant: NOx, ROG, and $PM_{2.5}$.

[14] At sea level (14.7 psi atmospheric pressure) and 75˚ F, one pound per square inch gauge pressure (1 psig) = 2.31 ft. water column (or 15.7 psia = 2.31 ft. water column)

[15] If no VFD efficiency is provided, an energy efficiency of 97% is assumed. Romberger, Jeff. 2017. *Chapter 18: Variable Frequency Drive Evaluation Protocol The Uniform Methods Project: Methods for Determining Energy-Efficiency Savings for Specific Measures*. Golden, CO; National Renewable Energy Laboratory. NREL/ SR-7A40-68574.

Equation 8. Criteria and Toxic Air Pollutant Emission Reductions from Pump Motor Replacement

$$ER_{MR} = AER_{MR} \times Useful\ Life$$

Variable	Variable Definition	Units
ER_{MR}	Emission reductions from pump equipment replacement	lb
AER_{MR}	Annual emission reductions from pump equipment replacement, from	lb/yr
Useful Life	Useful life of the replacement equipment (quantification period)[4]	yr

Equation 9. Annual Emission Reductions from Pump Motor Replacement Projects

$$AER_{MR} = \left(AEP_{baseline} - AEP_{replacement}\right) \times \frac{1}{454}$$

Variable	Variable Definition	Units
AER_{MR}	Annual emission reductions from replacing baseline equipment with replacement equipment	lb/yr
$AEP_{baseline}$	**Annual emissions from baseline equipment, from Equation 10 for non-electric pump motors, or from** Equation 15 for electric pump motors	g/yr
$AEP_{replacement}$	Annual emissions from baseline equipment, from Equation 10 for non-electric pump motors, or from Equation 15 for electric pump motors	g/yr
1/454	Conversion unit from grams to pounds	lb/g

Equation 10 is used to determine the estimated annual air pollutant emissions in the baseline and replacement scenarios, using respective values for emission factors and deterioration product, which is calculated using Equation 11.

Equation 10: Annual Emissions for Baseline and Replacement Equipment for Non-electric pumps

$$AEP_i = (EF_i + DP_i) \times LF_i \times hp_i \times AA$$

Variable	Variable Definition	Units
AEP_i	Annual emissions	g/yr
EF_i	Zero hour emission factor[6]	g/yr
DP_i	Hour-based deterioration product	g/yr
LF	Load Factor	unitless
hp	Maximum rated horsepower of equipment	hp
Usage	Annual Activity	hours/yr
i	Baseline or project non-electric pump	unitless

Equation 11 is used to determine the hour-based deterioration product in the baseline and replacement scenarios, using the deterioration rate and the total equipment activity calculated in Equation 12.

Equation 11. Hour-Based Deterioration Product for Baseline and Project Equipment

$$DP_i = DR_i \times TEA_i$$

Variable	Variable Definition	Units
DP_i	Hour-based deterioration product for the equipment	g/bhp-hr
DR_i	Deterioration rate for the equipment[6]	g/bhp-hr-hr
TEA_i	Total equipment activity for the pump motor from Equation 12	hours
i	Baseline or replacement	

Equation 12 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life, which is calculated in Equation 13 for baseline equipment and Equation 14 for the replacement equipment.

Equation 12: Total Equipment Activity for Baseline and Replacement Equipment

$$TEA_i = AA \times DL_i$$

Variable	Variable Definition	Units
TEA_i	Total equipment activity for the pump motor	hr
AA	Annual activity of the pump motor	hr/yr
DL_i	Deterioration life of the equipment from Equation 13	yr
i	Baseline or replacement	

Equation 13. Deterioration Life for the Baseline Equipment

$$DL_{baseline} = YR_{replacement} - MY_{baseline} + \frac{Useful\ Life}{2}$$

Variable	Variable Definition	Units
$DL_{baseline}$	Deterioration life of the baseline equipment	yr
$YR_{replacement}$	Expected first year of operation of the project (replacement) equipment	yr
$MY_{baseline}$	Baseline engine model year	yr
Useful Life	Useful life of the project equipment (quantification period)[5]	yr

Equation 14. Deterioration Life for the Replacement Equipment

$$DL_{replacement} = \frac{Useful\ Life}{2}$$

Variable	Variable Definition	Units
$DL_{replacement}$	Deterioration life of the replacement equipment	yr
Useful Life	Useful life of the project equipment (quantification period)[5]	yr

For projects that replace pumps with electric pumps, Equation 15 calculates the annual criteria and toxic air pollutant emissions from operation of the equipment based on the electricity consumed measured from energy meters, when available.[10] If unavailable, prospective estimates of energy use from Equation 6, or retrospective estimates of energy use from Equation 7 may also be used.

Equation 15. Annual Criteria and Toxic Air Pollutant Emissions

$$AEP_i = Energy_i \times EF_{electricity} \times \frac{1}{454}$$

Variable	Variable Definition	Units
AEP_i	Annual emissions of project pump equipment	lb/yr
$Energy_i$	Annual energy usage for baseline or replacement equipment from energy meter readings, if available. If unavailable, use Equation 6 (for prospective estimates), or Equation 7 (for retrospective estimates)	kWh/yr
$EF_{electricity}$	Pollutant-specific emission factor for grid electricity[6]	lbs/kWh
1/454	Conversion unit from grams to pounds	lb/g
i	Baseline or replacement	

B. Emission Reductions from VFD Installation

The emission reductions from installation of a VFD is estimated using the annual unit energy savings from the California Energy Efficiency Measure Data in the California Electronic Technical Reference Manual (eTRM).[16]

Table 2. VFD Unit Energy Savings

Pump Type	Pump Size (Hp)	Peak Demand Reduction (kW)	Electricity Use Reductions (kWh/yr)
Booster	<= 75	0.112	264
Booster	> 75 to <= 150	0.108	257
Well	<= 75	0.120	284
Well	> 75 to <= 600	0.177	276

1. GHG Equations

The GHG emission reductions from VFD installation is calculated using Equation 16 as the annual estimated electricity use reductions from Equation 17multiplied by the useful life of the equipment.

Equation 16. GHG Emission Reductions from VFD Installations (Quantification Period)

$$ER_{VFD} = GHG_{VFD} \times Useful\ Life$$

Variable	Variable Definition	Units
ER_{VFD}	Emission reductions from VFD Installation	$MTCO_2e$
GHG_{VFD}	Annual GHG emission reductions from replacing baseline equipment with replacement equipment	$MTCO_2e/yr$
Useful Life	Useful life of the replacement equipment (quantification period)[4]	yr

[16] California Electronic Technical Reference Manual (eTRM). *Enhanced Variable Frequency Drive on Irrigation Pump, Annual Unit Energy Savings*.

Equation 17. Annual GHG Emission Reductions from VFD Installations

$$GHG_{VFD} = Energy_{VFD} \times FSEF \times \frac{1\ MTCO2e}{1{,}000{,}000\ gCO2e}$$

Variable	Variable Definition	Units
GHG_{VFD}	Annual estimated emission reductions from VFD installation	$MTCO_2e$/yr
$Energy_{VFD}$	Annual energy savings from VFD installation, from Table 2. VFD Unit Energy Savings	kWh/yr
FSEF	Fuel-specific emission factor[6]	gCO2e/kWh
Useful Life	Useful life of the replacement equipment (quantification period)	yr
1/1,000,000	Conversion unit from metric tons of carbon dioxide equivalent to grams of carbon dioxide equivalent	MTCO2e/ gCO2e

2. Criteria and Toxic Air Pollutant Equations

The criteria and toxic air pollutant emission reductions from VFD installations are estimated as the annual estimated electricity use reductions multiplied by the useful life of the equipment, using Equation 15. The calculations are performed for each air pollutant: NOx, ROG, and $PM_{2.5}$.

C. Emission Reductions from Solar PV Electricity Generation

The emission reductions from grid-connected solar PV projects are calculated as the emission reductions from avoided fossil fuel-based electricity generation, using Equation 18. The annual electricity generation estimated using the PVWatts calculator is summed over the project life of 30 years after applying an annual degradation rate of 0.5% per year.[17,18] The estimated avoided energy use is then multiplied by the emission factor for California grid electricity.

[17] The 30-year quantification period (useful life) was obtained from the National Renewable Energy Laboratory "*Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics*" fact sheet.
[18] Jordan, D.C., Kurtz, S.R., VanSant, K., and J. Newmiller (2016). *Compendium of photovoltaic degradation rates*.

Updated light-induced degradation rate from the above source should be used to overwrite the default value from an earlier reference for PVWatts:
Pingel, S., Koshnicharov, D., Frank, O., Geipel, T., Zemen, Y., Striner, B., Berghold, J. *Initial degradation of industrial silicon solar cells in solar panels*. 25th EU PVSEC, 2010.

Equation 18. Emission Reductions from Solar PV

$$ER_{PV} = \sum_{n=1}^{30} (1 - Degradation)^{n-1} \times Production \times EF_{electricity}$$

Variable	Variable Definition	Units
ER_{PV}	Total GHG or criteria and toxic air pollutant emission reductions for useful life of solar PV system (30 years)[19]	$MTCO_2e$ or lbs
Degradation	Annual rate of system degradation (0.5%)[20]	%/yr
Production	Annual electricity generation estimated using PVWatts Calculator	kWh/yr
$EF_{electricity}$	Emission factor for California grid electricity[6]	$MTCO_2e$ /kWh or lbs/kWh

[19] The 30-year quantification period (useful life) was obtained from the National Renewable Energy Laboratory "*Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics*" fact sheet.

[20] Jordan, D.C., Kurtz, S.R., VanSant, K., and J. Newmiller (2016). *Compendium of photovoltaic degradation rates.*

D. Emission Reductions from Energy Efficiency Retrofits

Emission reductions from energy efficiency retrofits are estimated from total energy savings using Equation 19. Equation 19 estimates the annual energy use of each pre-existing and newly installed measure. Based on the difference between the project scenario and baseline scenario calculated in Equation 20, Equation 21 is used to determine total energy savings over the quantification period (useful life of the project).[21] The total estimated energy savings is then multiplied by the emission factor for California grid electricity, using Equation 22.

Equation 19. Equipment-specific Energy Use

$$Energy\ Use = \frac{Watts}{1000} \times Hours \times\ Quantity$$

Variable	Variable Definition	Units
Energy Use	Annual energy consumption of pre-existing or installed equipment	kWh/yr
Watts	Watts per pre-existing or installed equipment	Watts
Hours	Hours of annual use	hr
Quantity	Number of pre-existing or installed equipment	Units

[21] All deemed energy savings and useful life values must be those that are supported by the Department of Community Services and Development Low-income Weatherization Program Quantification Methodology. For example, the 15-year useful life (quantification period) for lighting fixtures was obtained from the California Municipal Utilities Association (2017) *Energy Efficiency Technical Reference Manual*.

Equation 20. Annual Energy Savings

$$Annual\ Energy\ Savings = Baseline\ Energy\ Use - Project\ Energy\ Use$$

Variable	Variable Definition	Units
Annual Energy Savings	Annual reduction in energy use of all installed equipment over all baseline equipment	kWh/yr
Baseline Energy Use	Annual energy consumption of all pre-existing equipment, summed from Equation 19	kWh/yr
Project Energy Use	Annual energy consumption of all installed equipment, summed from Equation 19	kWh/yr

Equation 21. Lifetime Energy Savings

$$Total\ Energy\ Savings = Annual\ Energy\ Savings \times Useful\ Life$$

Variable	Variable Definition	Units
Total Energy Savings	Total energy use reductions over the useful life of all installed equipment	kWh
Annual Energy Savings	Annual reduction in energy use of installed equipment over pre-existing measures, from Equation 20	kWh/yr
Useful Life	Estimated useful life of installed measures. For lighting fixtures, enter "15". Useful life of other energy efficiency measures must be from a method approved by CARB[22].	yr

[22] All deemed energy savings and useful life values must be those that are supported by the Department of Community Services and Development Low-income Weatherization Program Quantification Methodology. For example, the 15-year useful life (quantification period) for lighting fixtures was obtained from the California Municipal Utilities Association (2017) *Energy Efficiency Technical Reference Manual*.

Equation 22. Emission Reductions from Energy Efficiency Retrofits

$$ER_{EE} = Total\ Energy\ Savings \times EF_{electricity}$$

Variable	Variable Definition	Units
ER_{EE}	Total GHG or criteria and toxic air pollutant emission reductions for the useful life of all installed measures	$MTCO_2e$ or lbs
Total Energy Savings	Total energy use reductions over the useful life of all installed equipment, from Equation 21	kWh
$EF_{electricity}$	Emission factor for California grid electricity[6]	$MTCO_2e$ /kWh or lbs/kWh

E. Emission Estimates from Interim Water Provision

1. GHG Equations

GHG and air pollutant emission estimates from interim water provision are estimated as the emissions from interim water provision delivery vehicles determined from the vehicle miles traveled and the emission factors specific to the vehicle types[23] using Equation 23 and Equation 24.

Equation 23 estimates the total GHG emissions from new transportation vehicles.

Equation 23. GHG Emissions from Transportation Vehicles

$$E_{TV} = \left[\sum_{i}\left(\frac{VEF_{GHG,x} \times VMT_{x,D}}{1{,}000{,}000}\right) - \left(\frac{VEF_{GHG,x} \times VMT_{x,P}}{1{,}000{,}000}\right)\right] \times Useful\ Life$$

Variable	Variable Definition	Units
E_{TV}	Total GHG emissions from transportation vehicle within each vehicle type category	$MTCO_2e$
i	Number of applicable vehicle type categories	Unitless
VEF_{GHG}	Vehicle GHG emission factor[6] specific to vehicle type	g CO2e/mi
$VMT_{x,D}$	Total miles traveled per year for the delivery vehicles of identical vehicle type (total annual miles driven for project services by the vehicles within the vehicle type category)	mi/yr
$VMT_{x,P}$	Total avoided miles traveled per year for the passenger vehicles of identical vehicle type (total avoided annual miles driven to get bottled water)	mi/yr
1,000,000	Conversion factor from g to MT	g/MT
Useful Life	Useful Life (quantification period)	yr

[23] See the Appendix of the User Guide for the State Water Board SADW Benefits Calculator Tool for a description of vehicle type categories.

2. Criteria and Toxic Air Pollutant Equations

Equation 24 estimates the total emissions of criteria and toxic air pollutants from new transportation vehicles.

Equation 24. Criteria and Toxic Air Pollutant Emissions from Transportation Vehicles

$$E_{TV} = \sum_{i} \left(\left(\frac{VEF_{CT,x} \times VMT_{x,D}}{454} \right) - \left(\frac{VEF_{CT,x} \times VMT_{x,P}}{454} \right) \right) \times Useful\ Life$$

Variable	Variable Definition	Units
E_{TV}	Total criteria or toxic air pollutant emissions from transportation vehicle	lb
I	Number of identical vehicles	Unitless
VEF_{CT}	Vehicle criteria or toxic air pollutant emission factors (ROG, NO_x, $PM_{2.5}$, Diesel PM)[6]	lb/mi
$VMT_{x,D}$	Total miles traveled per year for the delivery vehicles of identical vehicle type (total annual miles driven for project services by the vehicles within the vehicle type category)	mi/yr
$VMT_{x,P}$	Total avoided miles traveled per year for the passenger vehicles of identical vehicle type (total avoided annual miles driven to get bottled water)	mi/yr
x	Vehicle type category	
454	Conversion factor from g to lb	g/lb
Useful Life	Duration of the project in years (quantification period)	yr

F. Net Emission Reduction Estimates

Equation 25 estimates the GHG and criteria and toxic air pollutant net benefits associated with SADW project components, including pump motor replacements and fuel conversions; installation of VFDs; avoided emissions from solar PV installations; emission reductions from energy efficiency updates; and emissions from interim water delivery.

Equation 25. Net GHG or Criteria Air Pollutant Emission Reductions Benefit

$$ER = ER_{MR} + ER_{VFD} + ER_{PV} + ER_{EE} - E_{TV}$$

Variable	Variable Definition	Units
ER	Total GHG or criteria and toxic air pollutant emission reductions	MT CO2e or lb
ER_{MR}	GHG or criteria and toxic air pollutant emission reductions from pump motor replacement (calculated from Equation 1)	MT CO2e or lb
ER_{VFD}	GHG or criteria and toxic air pollutant emission reductions from installation of a VFD (calculated from Equation 16)	MT CO2e or lb
ER_{PV}	GHG or criteria and toxic air pollutant emission reductions from solar PV installation (calculated from Equation 18)	MT CO2e or lb
ER_{EE}	GHG or criteria and toxic air pollutant emission reductions from energy efficiency updates (calculated from Equation 22)	MT CO2e or lb
ER_{TV}	GHG emissions (calculated from Equation 23) or criteria and toxic air pollutant emissions (calculated from Equation 24) from interim water delivery	MT CO2e or lb

Section C. References

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

California Air Resources Board (2021). *California Climate Investments Quantification Methodology Emission Factor Database*.

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