California Air Resources Board

Quantification Methodology

California Air Resources Board
Funding Agricultural Replacement Measures for Emission Reductions Program

California Climate Investments

FINAL
March 24, 2025
(updated July 15, 2025)

Disclaimer:

- This tool is designed to calculate emission reductions, cost-effectiveness, and maximum grant amounts. While every effort has been exhausted and made to ensure that the calculations are accurate and consistent with applicable program guidelines, determining final project eligibility and verifying outputs generated by the tool is the responsibility of district staff.

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List of Acronyms and Abbreviations

Acronym	Term
bhp	brake horsepower
CARB	California Air Resources Board
CCI	California Climate Investments
DGE	diesel gallon equivalent
Diesel PM	diesel particulate matter
EER	energy efficiency ratio
FARMER	Funding Agricultural Replacement Measures for Emissions Reductions
g	gram
gal	gallon
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
HHD	heavy-heavy duty trucks
hp	horsepower
kWh	kilowatt-hour
lbs	pounds
MHD	medium-heavy duty trucks
mi	mile
MJ	megajoule
$MTCO_2e$	metric tons of carbon dioxide equivalent
NO_x	oxides of nitrogen
PM	particulate matter
$PM_{2.5}$	particulate matter with a diameter less than 2.5 micrometers
PM_{10}	particulate matter with a diameter less than 10 micrometers
ROG	reactive organic gas
scf	standard cubic foot
UTV	utility terrain vehicles
VMT	vehicle miles traveled
yr	year

List of Definitions

Term	Definition
Activity	Annual operation of the equipment, measured in annual average hours of use.
Baseline Equipment	Engine technology applied under normal business practices, such as the existing engine in a vehicle or equipment for replacements and repowers. In other words, the equipment that is currently owned/in operation that will be repowered, or scrapped and replaced with a newer, cleaner piece of equipment.
Co-benefit	A social, economic, or environmental benefit as a result of the proposed project in addition to the GHG reduction benefit.
Cost-effectiveness	A measure of the dollars provided to a project for each ton of covered emission reduction.
Cost-effectiveness Limit	The maximum amount of funds the FARMER Program will pay per weighted ton of emission reductions.
Deterioration	The increased exhaust emissions over time taking into account wear and tear on engines and emissions control devices.
Deterioration Life	A factor calculated from the period of time the engine has deteriorated, plus half the project life, used to estimate deterioration over the entire project life.
Deterioration Product	The result of multiplying the deterioration rate, equipment activity, and the deterioration life for a technology.
Deterioration Rate	Rates that estimate increased air pollutant emissions from engine wear and tear and other variables that increase engine emissions over time. On-road deterioration rates are established by weight class and engine model year, based on values in CARB's on-road emission inventory model. Off-road deterioration rates are established by horsepower and either Tier or model year, based on values in CARB category-specific inventory models.
Energy and Fuel Cost Savings	Changes in energy and fuel costs to the farmer or agricultural operation as a result of the project. Savings may be achieved by changing the quantity of energy or fuel used, conversion to an alternative energy or fuel source/vehicle, or renewable energy or fuel generation to displace existing fuel purchases.

Term	Definition
Intended Service Class	The service weight class that the vehicle will be used for. This is often, but not always, the same as the Gross Vehicle Weight Rating.
Key Variable	Project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., fossil fuel use reductions).
Load Factor	Average operational level of an engine in a given application as a fraction or percentage of the engine manufacturer's maximum rated horsepower.
Project Life	Number of years that the equipment will provide GHG emission reductions that can reasonably be achieved and assured. Sometimes referred to as " Quantification Period" or "Useful Life."
Project Type	For the purposes of the FARMER Quantification Methodology, eligible projects fall into five project types that meet the objectives program and for which there are methods to quantify GHG emission reductions.
Replacement Equipment	The new or repowered equipment(s) that replaces the use of the baseline equipment(s).
Repower	Replacement of the existing engine with an electric motor or a newer emission-certified engine instead of rebuilding the existing engine to its original specifications.

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating GHG emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low- income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

CARB is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the GGRF. This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project types eligible for funding by each administering agency, as reflected in the program expenditure records available on the CARB Expenditure Records webpage.

For CARB's FARMER Program, CARB developed this FARMER Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project type. This methodology uses calculations to estimate GHG emission reductions from replacing older, higher- emitting agricultural equipment or vehicles with newer, more efficient or cleaner equipment or vehicles; and GHG emissions associated with the implementation of FARMER projects.

The FARMER 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 FARMER Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds awarded. The FARMER Benefits Calculator Tool is available for download on the California Climate Investments Resources webpage.

Using many of the same inputs required to estimate GHG emission reductions, the FARMER Benefits Calculator Tool estimates the following co-benefits and key variables from FARMER Program projects: $PM_{2.5}$ Reductions (lbs), NO_x Reductions (lbs), ROG Reductions (lbs), Diesel PM Reductions (lbs), Fossil Fuel Use Reductions (gallons), Fossil Fuel Based Energy Use Reductions (kWh), and Fuel Savings (dollars). Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., criteria pollutant emission reductions, fuel use reductions). Additional co-benefits for which CARB assessment methodologies were not incorporated into the FARMER Benefits Calculator Tool may also be applicable to the project. Applicants should consult the 2024 FARMER Guidelines, solicitation materials, and agreements to ensure they are meeting FARMER programmatic requirements. The FARMER Guidelines are available on the CARB FARMER webpage.

Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability. CARB developed this FARMER 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 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 FARMER project types. CARB also determined 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 FARMER Quantification Methodology and Draft FARMER Benefits Calculator Tool for public comment in March 2025. This Final FARMER Quantification Methodology and accompanying FARMER Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the 2024 FARMER Program 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. As they become available, co-benefit assessment methodologies are posted on the California Climate Investments Co-benefits webpage.

Tools

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

The FARMER Benefits Calculator Tool must be used to estimate the GHG emission reductions and co-benefits of the proposed project. The FARMER Benefits Calculator Tool can be downloaded from the California Climate Investments Resources webpage.

Updates

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

- Updating air pollutant emission factors, load factors, and cost-effectiveness and funding limits per the 2024 FARMER Program Guidelines.
- Consolidating and aligning the calculations for Moyer and FARMER on-road heavy-duty trucks.
- Consolidating and aligning the calculations for zero-emission off-road, irrigation pumps, and ZEV agricultural UTV with the off-road agricultural equipment category.
- Consolidating and aligning the calculations for zero-emission agricultural equipment, irrigation pump engines, and ZEV agricultural UTV with the off-road agricultural equipment category.
- Consolidating and aligning the calculations for Off-road Ag Equipment: 2 (or more)-for-1 and Irrigation Pump Engines: 2 (or more)-for-1.
- Removing Ag Trade-Up and Infrastructure project types.
- Updating “Equipment Type” options to match new categories in 2024 FARMER Program Guidelines.
- Adding optional efficiency factor input for replacement equipment that can perform additional work per hour.
- Updating fuel carbon intensity values to 2023 volume-weighted averages.
- Updating fuel and energy costs to 2023 averages.
- Removing ‘Project Profile’ tab inputs for “Carl Moyer Guidelines Version” and “Carl Moyer Mailout or Advisory Date”.
- Adding ‘Project Profile’ tab input for “Implementing Air District”.
- Removing ‘Quantification Inputs’ tab inputs for “Is project eligible for Carl Moyer 2-Step Calculation?”, “Number of vehicles in Fleet”, “Quantification Period II”, and “Baseline Vehicle Odometer Reading”.
- Combining inputs for “Annual Miles Traveled” and “Annual average Hours of Operation” into “Annual usage (hrs/yr for off-road, mi/yr for on-road)”.
- Removing “Retrofit” as eligible option in “Type of Off-Road Project”.
- Renaming “Engine Cycle Type” column to “Engine Cycle/Induction Type”.
- Consolidating state and federal funding sources into “Other State/Federal

Funding".
- Consolidating interest-based sources into "Interest (FARMER)".
- Removing AQIP, ARFVTF, and Tire Fund funding sources.

Section B. Methods

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

Project Type

CARB developed the following project types that meet the objectives of the FARMER Program and for which there are methods to quantify GHG emission reductions:

1. On-road heavy-duty truck replacement and repower projects
    a. **Heavy-Duty On-Road Trucks:** One-for-one transaction where a single baseline vehicle is scrapped and a single new or used replacement vehicle is procured
2. Off-road equipment replacement and repower projects
    a. **Off-Road Agricultural Equipment:** One-for-one transaction where a single baseline equipment is scrapped and a single new replacement equipment is procured
    b. **Used Agricultural Equipment**: One-for-one transaction where a single baseline equipment is scrapped and a single used replacement equipment is procured
    c. **Off-Road Ag Equipment: 2 (or-more)-for-1**: In some cases, the replacement equipment is no longer available at similar horsepower ratings to the baseline equipment so the procurement of the higher horsepower equipment is allowed (additionally, multiple pieces of equipment may be scrapped to make the project more cost-effective, also referred to as "2 (or more)-for-1")
3. Zero-emission utility terrain vehicles
    a. **Zero-Emission Ag UTV:** Rebates for the purchase of zero-emission utility terrain vehicles (UTV)

General Approach

Methods used in the FARMER Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by project type are provided in this section. The Emission Factor Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated. These methods account for GHG emission reductions from replacing older farm equipment with newer, more efficient equipment. In general, the GHG emission reductions are estimated in the FARMER Benefits Calculator Tool using the approaches in Figure 1. The FARMER 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.

Figure 1. General Approach to Quantification by Project Type

Single Transaction Project Types (1a, 2a, 2b, 3a)
Emission Reductions = Baseline Equipment/Vehicle Emissions – Replacement Equipment/Vehicle Emissions
2 (or-more)-for-1 Transaction Project Types (2c)
Emission Reductions = $\sum_{i=1}^{N} Baseline\ Equipment/Vehicle\ Emissions - Replacement\ Equipment/Vehicle\ Emissions$ *N = # of baseline equipment/vehicles being scrapped*

More specifically, the FARMER Benefits Calculator Tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits using two methods for each of the project types:

1. Equations and methods from the FARMER Program.
2. Equations and methods from previously existing CARB methodologies or Calculator Tools.

For all calculations, there are two pieces of equipment of interest:

1. The equipment/vehicle in use – i.e., the “baseline” vehicle/equipment.
2. The newer, replacement equipment/vehicle. Replacement and repowered equipment/vehicles are collectively referred to as the “replacement” in the equations listed in this document.

A. Weighted Emissions Reductions and Maximum Grant Amount of FARMER Projects

1. Determine the weighted air pollutant emission reductions

Total weighted air pollutant emission reductions from FARMER projects are determined by taking the sum of the project's annual air pollutant emission reductions using Equation 1. While NO_x and ROG emissions are given equal weight; emissions of combustion PM_{10} (such as diesel exhaust PM_{10} emissions) have been identified as a toxic air contaminant and thus carry a greater weight in the calculation, consistent with the FARMER Program Guidelines (2024).

Equation 1: Weighted Emission Reductions

$$WER = ER_{NOx} + ER_{ROG} + 20 \times ER_{PM}$$

Table 1. Variables of Equation 1: Weighted Emission Reductions

Variable	Variable Definition	Units
WER	Annual weighted emissions reductions	US tons/yr
ER_{NOx}	Annual NOx emission reductions	US tons/yr
ER_{ROG}	Annual ROG emission reductions	US tons/yr
ER_{PM}	Annual PM emission reductions	US tons/yr

2. Determine the maximum grant amount

The maximum grant amount is determined to be the lowest result of the two following equations: Equation 2 and Equation 4. Moreover, additional funding caps are applicable to different project types. Please refer to the FARMER Program Guidelines for more information regarding funding caps and cost-effectiveness limits. Please refer to the FARMER Program Guidelines for more information regarding applicability.

Equation 2: Potential Grant Amount at Applicable Cost-Effectiveness Limit

$$PGA = CL \times WER \times \frac{1}{CRF}$$

Table 2. Variables of Equation 2: Potential Grant Amount at Applicable Cost-Effectiveness Limit

Variable	Variable Definition	Units
PGA	Potential grant amount, based on cost-effectiveness limit	$
CL	Cost-effectiveness limit	$/ton
WER	Weighted emissions reduction of replacing the baseline equipment	US tons/yr
CRF	Capital Recovery Factor	Unitless

Equation 3: Capital Recovery Factor

$$CRF = \frac{(1 + DR)^{PL} \times DR}{(1 + DR)^{PL} - 1}$$

Table 3. Variables of Equation 3: Capital Recovery Factor

Variable	Variable Definition	Units
CRF	Capital Recovery Factor	Unitless
DR	Discount rate	%
PL	Project life	years

FARMER projects are typically evaluated at a 1% discount rate and a 10 year project life.

Equation 4: Potential Grant Amount at Maximum Percentage of Eligible Cost

$$PGA = C_{replacement} \times PE$$

Table 4. Variables of Equation 4: Potential Grant Amount at Maximum Percentage of Eligible Cost

Variable	Variable Definition	Units
PGA	Potential grant amount, based on maximum percentage of eligible cost	$
$C_{replacement}$	Cost of replacement technology	$
PE	Maximum percentage of eligible cost as specified in the FARMER Program Guidelines	%

B. Emissions Reductions from On-Road Heavy-Duty Truck Replacement and Repower Projects

The FARMER Benefits Calculator tool calculates estimates of GHG emissions reductions and air pollutant emission co-benefits for each of the project types. The following subsections presents the equations and methods from the FARMER Program and existing CARB methodologies or Calculator Tools used for On-Road Heavy-Duty Truck Replacement and Repower Projects (Trucks).

1. GHG Equations

Equation 5 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 6, the GHG emission reductions from on-road heavy-duty truck replacement and repower projects are estimated as the difference between the baseline and replacement scenarios. Equation 7 is used to determine the estimated annual fuel consumption in the baseline and replacement scenarios based on annual vehicle miles traveled. For electric vehicle replacements, Equation 8 is used to determine the estimated annual energy consumption based on annual vehicle miles traveled.

Gross Vehicle Weight Rating, Model Year, and Calendar Year are used as lookup inputs to ascertain fuel economy from CARB's EMission FACtors (EMFAC) model.

Equation 5: GHG Emission Reductions from On-Road Heavy-Duty Truck Projects (Quantification Period)

$$QPER_{GHG} = QP \times ER_{GHG}$$

Table 5. Variables of Equation 5: GHG Emission Reductions from On-Road Heavy-Duty Truck Projects

Variable	Variable Definition	Units
$QPER_{GHG}$	GHG emission reductions over quantification period	$MTCO_2e$
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years
ER_{GHG}	Annual GHG emission reductions of replacing the baseline truck with the replacement truck	$MTCO_2e$/yr

Equation 6: Annual GHG Emission Reductions from On-Road Heavy-Duty Truck Projects

$$ER_{GHG} = ((FC_{baseline} \times CC_{baseline\ fuel}) - (FC_{replacement} \times CC_{replacement\ fuel})) \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

Table 6. Variables of Equation 6: Annual GHG Emission Reductions from On-Road Heavy-Duty Truck Projects

Variable	Variable Definition	Units
ER_{GHG}	Annual GHG emission reductions of replacing the baseline truck with the replacement truck	$MTCO_2e$/yr
$FC_{baseline}$	Fuel consumption of the baseline truck	gal/yr
$CC_{baseline\ fuel}$	Carbon content of baseline fuel type	gCO_2e/DGE
$FC_{replacement}$	Fuel consumption of the replacement truck	gal/yr
$CC_{replacement\ fuel}$	Carbon content of replacement fuel type	gCO_2e/DGE

If the baseline or replacement fuel type is CNG, LNG, or RNG, its carbon content is converted to diesel gallon equivalent (DGE) for the GHG emissions calculations step.

Equation 7: Fuel Consumption for the Baseline and Replacement Truck

$$FC_i = \frac{AA}{MPG_i}$$

Table 7. Variables of Equation 7: Fuel Consumption for the Baseline and Replacement Truck

Variable	Variable Definition	Units
FC	Fuel consumption	gallons/yr
AA	Annual activity	miles/yr
MPG	Fuel economy	miles/gallon
i	Baseline or Replacement	

Equation 8: Fuel Consumption for Replacement Electric Trucks

$$FC_{replacement,elec} = \frac{AA}{MPkWh_{replacement,elec}} \times \frac{ED_{elec}}{ED_{diesel}} \times \frac{1}{EER}$$

Table 8. Variables of Equation 8: Fuel Consumption for Replacement Electric Trucks

Variable	Variable Definition	Units
$FC_{replacement,\ elec}$	Fuel consumption of electric vehicle	DGE/yr
AA	Annual activity	miles/yr
MPkWh	Energy economy	miles/kWh
ED_{elec}	Energy density of electricity	MJ/kWh
ED_{Diesel}	Energy density of diesel	MJ/DGE
EER	Energy economy ratio of electricity relative to diesel.	Unitless

2. Criteria and Toxic Air Pollutant Equations

Estimates of individual air pollutant emission reductions from on-road heavy-duty truck replacement and repower projects are calculated. Equation 9 shows the air pollutant emission reductions that occur over the project's entire quantification period. Based upon FARMER Program methods, individual air pollutant emission reductions are estimated as the difference between the baseline and replacement scenarios using Equation 10.

Intended Service Class, Model Year, and NO_x standards are used as lookup inputs to ascertain emission factors and deterioration rates from the FARMER Program Guidelines. The following calculations are repeated for each type of pollutant – i.e., NO_x, ROG, and PM_{10}.

Equation 9: Air Pollutant Emission Reductions from On-Road Heavy-Duty Truck Projects (Quantification Period)

$$QPER_{pollutant} = QP \times ER_{pollutant} \times OP_{CA} \times 2{,}000\ \frac{lbs}{US\ ton}$$

Table 9. Variables of Equation 9: Air Pollutant Emission Reductions from On-Road Heavy-Duty Truck Projects

Variable	Variable Definition	Units
$QPER_{pollutant}$	Emission reductions over quantification period	lbs
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years
$ER_{pollutant}$	Annual emission reductions of replacing the baseline truck with the replacement truck	US tons/yr
OP_{CA}	Percent operation in California	%

Equation 10: Annual Air Pollutant Emission Reductions from On-Road Heavy-Duty Truck Projects

$$ER_{pollutant} = \mathrm{AEP}_{baseline} - \mathrm{AEP}_{replacement}$$

Table 10. Variables of Equation 10: Annual Air Pollutant Emission Reductions from On-Road Heavy-Duty Truck Projects

Variable	Variable Definition	Units
$ER_{pollutant}$	Annual emission reductions of replacing the baseline truck with the replacement truck	US tons/yr
$AEP_{baseline}$	Annual emissions for the baseline truck	US tons/yr
$AEP_{replacement}$	Annual emissions for the replacement truck	US tons/yr

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

Equation 11: Annual Air Pollutant Emissions for Baseline and Replacement Truck

$$AEP_i = (EF_i + DP_i) \times AA \times \frac{1\ US\ ton}{907{,}200\ g}$$

Table 11. Variables of Equation 11: Annual Air Pollutant Emissions for Baseline and Replacement Truck

Variable	Variable Definition	Units
AEP_i	Annual air pollutant emissions for the truck	US tons/yr
EF_i	Zero-mile emission factor for the truck	gram/mile
DP_i	Mile-based deterioration product for the truck	gram/mile
AA	Annual activity	miles/yr
i	Baseline or Replacement	

Equation 12 is used to determine the mile-based deterioration product in the baseline and replacement scenarios, using respective values for deterioration rate and total equipment activity. Depending on the engine category and model year, the total equipment activity may be limited to an upper bound, as specified in the FARMER Program Guidelines.

Equation 12: Mile-Based Deterioration Product for Baseline and Replacement Truck

$$DP_i = \frac{DR_i \times TEA_i}{10{,}000}$$

Table 12. Variables of Equation 12: Mile-Based Deterioration Product for Baseline and Replacement Truck

Variable	Variable Definition	Units
DP_i	Mile-based deterioration product for the truck	gram/mile
DR_i	Deterioration rate for the truck	g/mi-10,000 mi
TEA_i	Total equipment activity of the truck	miles
i	Baseline or Replacement	

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

Equation 13: Total Equipment Activity for the Baseline and Replacement Truck

$$TEA_i = AA_i \times DL_i$$

Table 13. Variables of Equation 13: Total Equipment Activity for the Baseline and Replacement Truck

Variable	Variable Definition	Units
TEA	Total equipment activity of the truck	miles
AA_i	Annual activity	miles/yr
DL_i	Deterioration life of the truck	years
i	Baseline or Replacement	

Equation 14 is a modified equation for Total Equipment Activity and is used in the case where the truck is used and not brand new. This formula is used when the current odometer reading is >10,000 miles – the criteria used for defining a used truck.

Equation 14: Total Equipment Activity for Used Truck

$$TEA_i = AA_i \times DL_i + COR$$

Table 14. Variables of Equation 14: Total Equipment Activity for Used Truck

Variable	Variable Definition	Units
TEA_i	Total equipment activity of the truck	miles
AA_i	Annual activity	miles/yr
DL_i	Deterioration life of the truck	years
COR	Current Odometer Reading	miles
i	Baseline or Replacement	

Equation 15 is used to determine the deterioration life in the baseline scenario.

Equation 15: Deterioration Life for the Baseline Truck

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

Table 15. Variables of Equation 15: Deterioration Life for the Baseline Truck

Variable	Variable Definition	Units
$DL_{baseline}$	Deterioration life of the baseline truck	years
$YR_{replacement}$	Expected first year of operation of the replacement truck	year
$MY_{baseline}$	Baseline engine model year	year
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years

Equation 16 is used to determine the deterioration life in the replacement scenario. If the replacement truck is not brand new, but is instead used, then Equation 17 is applied to calculate deterioration life.

Equation 16: Deterioration Life for the Replacement Truck

$$DL_{replacement} = \frac{QP}{2}$$

Table 16. Variables of Equation 16: Deterioration Life for the Replacement Truck

Variable	Variable Definition	Units
$DL_{replacement}$	Deterioration life of the replacement truck	years
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years

Equation 17: Deterioration Life for the Truck if it is Used

$$DL_i = YR_i - MY_i + \frac{QP}{2}$$

Table 17. Variables of Equation 17: Deterioration Life for the Truck if it is Used

Variable	Variable Definition	Units
DL_i	Deterioration life of the truck	years
YR_i	Expected first year of operation of the truck	year
MY_i	Engine model year	year
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years

C. Emissions Reductions from Off-Road Equipment Replacement and Repower Projects

The FARMER Benefits Calculator Tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits for each of the eligible project types. The following subsections present the equations and methods from the FARMER Program and existing CARB methodologies or Calculator Tools used for Off-Road Equipment Replacement and Repower Projects.

1. GHG Equations

Equation 18 shows the GHG emission reductions that occur over the project's entire quantification period. For off-road agricultural equipment and 2 (or more)-for-1 projects, the quantification period is assumed to be 10 years.

Equation 18: GHG Emission Reductions from Off-Road Equipment Replacement and Repower Projects (Quantification Period)

$$QPER_{GHG} = QP \times ER_{GHG}$$

Table 18. Variables of Equation 18: GHG Emission Reductions from Off-Road Equipment Replacement and Repower Projects

Variable	Variable Definition	Units
$QPER_{GHG}$	GHG emission reductions over quantification period	$MTCO_2e$
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years
ER_{GHG}	Annual GHG emission reductions of replacing the baseline equipment with the replacement equipment	$MTCO_2e/yr$

Using Equation 19, the GHG emission reductions from off-road equipment replacement and repower projects are estimated as the difference between the emissions from the baseline and replacement equipment. To determine GHG emissions for off-road equipment, fuel consumption is calculated for the baseline and replacement equipment and multiplied by the fuel's carbon content using Equation 20.

Equation 19: Annual GHG Emission Reductions from Off-Road Equipment Replacement and Repower Projects

$$ER_{GHG} = GHG_{baseline} - GHG_{replacement}$$

Table 19. Variables of Equation 19: Annual GHG Emission Reductions from Off-Road Equipment Replacement and Repower Projects

Variable	Variable Definition	Units
ER_{GHG}	Annual GHG emission reductions of replacing the baseline equipment with the replacement equipment	$MTCO_2e/yr$
$GHG_{baseline}$	Annual GHG emissions for the baseline equipment	$MTCO_2e/yr$
$GHG_{replacement}$	Annual GHG emissions for the replacement equipment	$MTCO_2e/yr$

Equation 20: GHG Emissions from Off-Road Equipment Replacement and Repower Projects

$$GHG_i = FC_i \times CC_{fuel} \times \frac{1\ MTCO2e}{1{,}000{,}000\ g}$$

Table 20. Variables of Equation 20: GHG Emissions from Off-Road Equipment Replacement and Repower Projects

Variable	Variable Definition	Units
GHG_i	Annual greenhouse gas emissions	MTCO2e/yr
FC_i	Fuel consumption	gal/yr, scf/yr
CC_{fuel}	Carbon content (depends on fuel type)	gCO2e/gal, gCO2e/scf
i	Baseline or replacement	

Equation 21 is used to determine the estimated annual fuel consumption in the baseline and replacement scenarios, using respective values for brake specific fuel consumption, maximum rated horsepower, load factor, and fuel efficiency factor.

The BSFC values used are as follows: 1) compression-ignited engines <= 100 hp: 0.408 lb/hp-hr, 2) compression-ignited engines >100 hp: 0.367 lb/hp-hr, 3) spark-ignited engines using CNG: 0.507 lb/hp- hr, and 4) 4-stroke spark-ignited engines using gasoline: 0.605 lb/hp-hr.

Equation 21: Fuel Consumption for the Baseline and Replacement Equipment

$$FC_i = BSFC_i \times HP_{max,i} \times LF_i \times AA_i \times FEF_i$$

Table 21. Variables of Equation 21: Fuel Consumption for the Baseline and Replacement Equipment

Variable	Variable Definition	Units
FC_i	Fuel consumption of the equipment	gallon/yr
$BSFC_i$	Brake specific fuel consumption	gal/bhp-hr
$HP_{max,i}$	Maximum rated horsepower of the equipment	bhp
LF_i	Load factor of the equipment	Unitless
AA_i	Annual Activity	hours/year
FEF_i	Fuel efficiency factor	Unitless
i	Baseline or Replacement	

Some off-road replacement projects may include replacement equipment that can perform additional work per hour, which can be verified through physical characteristics, such as harvesters that can operate across more rows per pass or a sprayer with a wider applicator. For these projects, an efficiency factor may be applied to the baseline annual activity to calculate the adjusted annual activity for the replacement equipment, as described in Equation 22 and Equation 23 below. For projects that do not provide an efficiency improvement, the efficiency factor is one and the replacement annual activity is the same as the baseline annual activity.

For example, a baseline harvester that operates 600 hours per year and picks 4 rows of a commodity per pass is replaced with a new harvester that picks 6 rows per pass. This project would have an efficiency factor of 1.5 and the adjusted annual activity for the replacement would be 400 hours per year. Another example is a sprayer with a total boom width of 90 feet and operates 800 hours per year that is replaced with a sprayer with a total boom width of 120 feet. This project would have an efficiency factor of 1.33 and the adjusted annual activity for the replacement would be 600 hours per year.

Equation 22: Adjusted Annual Activity for the Replacement Equipment

$$AA_{replacement} = \frac{AA_{baseline}}{Eff}$$

Table 22. Variables of Equation 22: Adjusted Annual Activity for the Replacement Equipment

Variable	Variable Definition	Units
$AA_{replacement}$	Annual Activity for the replacement equipment	hours/year
$AA_{baseline}$	Annual Activity for the baseline equipment	hours/year
Eff	Efficiency factor	Unitless

Equation 23: Efficiency Factor

$$Eff = \frac{C_{replacement}}{C_{baseline}}$$

Table 23. Variables of Equation 23: Efficiency Factor

Variable	Variable Definition	Units
Eff	Efficiency factor	Unitless
$C_{replacement}$	Characteristic of the replacement equipment	Unit of measure
$C_{baseline}$	Characteristic of the baseline equipment	Unit of measure

Fuel efficiency factor is determined Using Equation 24 – Equation 25.

Equation 24: Fuel Efficiency Factor of the Baseline Equipment

$$FEF_{baseline} = 1$$

Table 24. Variables of Equation 24: Fuel Efficiency Factor of the Baseline Equipment

Variable	Variable Definition	Units
$FEF_{baseline}$	Fuel efficiency factor of the baseline equipment	Unitless

Equation 25: Fuel Efficiency Factor of the Replacement Equipment

$$FEF_{replacement} = 1 - (MY_{replacement} - MY_{baseline}) \times AFEF_{year}$$

Table 25. Variables of Equation 25: Fuel Efficiency Factor of the Replacement Equipment

Variable	Variable Definition	Units
$FEF_{replacement}$	Fuel efficiency factor of the replacement equipment	Unitless
$MY_{replacement}$	Model year of the replacement equipment	year
$MY_{baseline}$	Model year of the baseline equipment	year
$AFEF_{year}$	Annual fuel efficiency factor, dependent on year	Unitless

According to work by Grisso et al. (2014), tractor models tested in 2000 were 10-15% more efficient than tractors tested in 1980. Grisso et al. presented no data before 1980 and no data after 2007. McCullough et. al. (2022) expanded upon this work, measuring an average improvement in fuel efficiency of 0.55% per year across all tractor tiers from 1987 – 2021. Therefore, no efficiency losses are assumed for models before 1980 and no efficiency gains are gained after 2021. Thus, the annual fuel efficiency factor ($AFEF_{year}$) = 10% gains/20 years = 0.5%/year = 0.005 for 1980 – 1987 models, and 0.55% = 0.0055 for 1987 – 2021 models.

As seen in Equation 26, the load factor of the replacement equipment is varied up to a certain percentage per data from CARB's diesel agricultural equipment inventory survey and discussed in Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower. Refer to the document to see what standard deviation value applies to a given equipment type.

Equation 26: Load Factor of the Replacement Equipment for GHG Calculations

$$LF_{replacement} = \left(LF_{baseline} \times \frac{HP_{max,baseline}}{HP_{max,replacement}}\right)\Bigg|_{LF_{baseline} - LF_{stdev}}^{LF_{baseline} + LF_{stdev}}$$

Table 26. Variables of Equation 26: Load Factor of the Replacement Equipment for GHG Calculations

Variable	Variable Definition	Units
$LF_{replacement}$	Load factor of the replacement equipment	Unitless
$HP_{max,\ baseline}$	Maximum rated horsepower of the baseline equipment	bhp
$LF_{baseline}$	Load factor of the baseline equipment	Unitless
$HP_{max,\ replacement}$	Maximum rated horsepower of the replacement equipment	bhp
LF_{stdev}	Load factor standard deviation used as adjustment bounds (0.208)	Unitless

In the case where the replacement equipment is electric, Equation 21 – Equation 25 and their respective parameters are not applicable. As such, the GHG emissions for these replacement equipment are based on electricity consumed using Equation 27. Electricity consumed is calculated using Equation 28 and is based on the fuel consumption of the baseline equipment, but with an appropriate energy efficiency ratio (EER) applied.

Equation 27: Annual GHG Emissions from Zero-Emission Replacement Equipment

$$GHG_{ZEV\ replacement} = EU_{ZEV\ replacement} \times CC_{electricity} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

Table 27. Variables of Equation 27: Annual GHG Emissions from Zero-Emission Replacement Equipment

Variable	Variable Definition	Units
$GHG_{ZEV\ replacement}$	Greenhouse gas emissions for the zero-emission replacement equipment	$MTCO_2e$/yr
$EU_{ZEV\ replacement}$	Electricity use of the zero-emission replacement equipment	kWh/yr
$CC_{electricity}$	Carbon content of electricity	gCO_2e/kWh

Equation 28: Electricity Usage for Zero-Emission Replacement Equipment

$$EU_{replacement} = \frac{FC_{baseline} \times ED_{baseline\ fuel}}{ED_{electricity} \times EER_{electricity}}$$

Table 28. Variables of Equation 28: Electricity Usage for Zero-Emission Replacement Equipment

Variable	Variable Definition	Units
$EU_{replacement}$	Electricity use of the zero-emission replacement	kWh/year
$FC_{baseline}$	Fuel consumption of the baseline equipment	gallon/year, scf/year
$ED_{baseline\ fuel}$	Energy density of the baseline equipment's fuel type	MJ/gal, MJ/scf
$ED_{electricity}$	Energy density of electricity	MJ/kWh
$EER_{electricity}$	Energy Efficiency Ratio relative to baseline equipment's fuel type	Unitless

2. Criteria and Toxic Air Pollutant Equations

Equation 29 shows the individual air pollutant emission reductions that occur over the project's entire quantification period. The individual air pollutant emission reductions from off-road equipment replacement and repower projects are estimated, based upon methods outlined in the FARMER Program Guidelines, as the difference between the baseline and replacement scenarios using Equation 30.

Horsepower, Engine Tier, and Model Year are used as lookup inputs to ascertain emission factors and deterioration rates from the FARMER Program Guidelines. The following calculations are repeated for each type of pollutant – i.e., NO_X, ROG, and PM_{10}.

Equation 29: Air Pollutant Emission Reductions from Off-Road Equipment Replacement and Repower Projects (Quantification Period)

$$QPER_{pollutant} = QP \times ER_{pollutant} \times OP_{CA} \times 2{,}000\ \frac{lbs}{US\ ton}$$

Table 29. Variables of Equation 29: Air Pollutant Emission Reductions from Off-Road Equipment Replacement and Repower Projects

Variable	Variable Definition	Units
$QPER_{pollutant}$	Emission reductions over quantification period	lbs
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years
$ER_{pollutant}$	Annual emission reductions	US tons/yr
OP_{CA}	Percent operation in California	%

Equation 30: Annual Air Pollutant Emission Reductions from Off-Road Equipment Replacement and Repower Projects

$$ER_{pollutant} = \text{AEP}_{baseline} - \text{AEP}_{replacement}$$

Table 30. Variables of Equation 30: Annual Air Pollutant Emission Reductions from Off-Road Equipment Replacement and Repower Projects

Variable	Variable Definition	Units
$ER_{pollutant}$	Annual emission reductions	US tons/yr
$AEP_{baseline}$	Annual emissions for the baseline equipment	US tons/yr
$AEP_{replacement}$	Annual emissions for the replacement equipment	US tons/yr

Equation 31 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.

Equation 31: Annual Air Pollutant Emissions for Baseline and Replacement Equipment

$$AEP_i = (EF_i + DP_i) \times LF_i \times HP_i \times \frac{AA_i}{907{,}200\ (g/US\ ton)}$$

Table 31. Variables of Equation 31: Annual Air Pollutant Emissions for Baseline and Replacement Equipment

Variable	Variable Definition	Units
AEP_i	Annual emissions for the equipment	US tons/yr
EF_i	Zero-mile emission factor for the equipment	g/bhp-hr
DP_i	Hour-based deterioration product for the equipment	g/bhp-hr
LF_i	Equipment Load Factor	Unitless
HP_i	Maximum rated horsepower of the equipment	bhp
AA_i	Annual Activity	hours/year
i	Baseline or Replacement	

Equation 32 is used to determine the hour-based deterioration product in the baseline and replacement scenarios, using respective values for deterioration rate and total equipment activity.

Equation 32: Hour-Based Deterioration Product for Baseline and Replacement Equipment

$$DP_i = DR_i \times TEA_i$$

Table 32. Variables of Equation 32: Hour-Based Deterioration Product for Baseline and Replacement Equipment

Variable	Variable Definition	Units
DP_i	Hour-based deterioration product for the equipment	g/bhp-hr
DR_i	Deterioration rate for the equipment	g/bhp-hr-hr
TEA_i	Total equipment activity of the equipment	hours
i	Baseline or Replacement	

Equation 33 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life.

Equation 33: Total Equipment Activity for the Baseline and Replacement Equipment

$$TEA_i = AA_i \times DL_i$$

Table 33. Variables of Equation 33: Total Equipment Activity for the Baseline and Replacement Equipment

Variable	Variable Definition	Units
TEA_i	Total equipment activity of the equipment	hours
AA_i	Annual Activity	hours/year
DL_i	Deterioration life of the equipment	years
i	Baseline or Replacement	

If the replacement equipment is not brand new, but is instead used, then Equation 34 is applied to calculate total equipment activity.

Equation 34: Total Equipment Activity for the Replacement Equipment if it is Used

$$TEA_{replacement} = (AA_{replacement} \times DL_{replacement}) + HR$$

Table 34. Variables of Equation 34: Total Equipment Activity for the Replacement Equipment if it is Used

Variable	Variable Definition	Units
$TEA_{replacement}$	Total equipment activity of the replacement equipment	hours
$AA_{replacement}$	Annual Activity of the replacement equipment	hours/year
$DL_{replacement}$	Deterioration life of the replacement equipment	years
HR	Hour reading of the equipment	hours
i	Baseline or Replacement	

Equation 35 is used to determine the deterioration life in the baseline scenario.

Equation 35: Deterioration Life for the Baseline Equipment

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

Table 35. Variables of Equation 35: Deterioration Life for the Baseline Equipment

Variable	Variable Definition	Units
$DL_{baseline}$	Deterioration life of the baseline equipment	years
$YR_{replacement}$	Expected first year of operation of the replacement equipment	year
$MY_{baseline}$	Baseline engine model year	year
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years

Equation 36 is used to determine the deterioration life in the replacement scenario.

Equation 36: Deterioration Life for the Replacement Equipment

$$DL_{replacement} = \frac{QP}{2}$$

Table 36. Variables of Equation 36: Deterioration Life for the Replacement Equipment

Variable	Variable Definition	Units
$DL_{replacement}$	Deterioration life of the replacement equipment	years
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years

D. Emissions Reductions from Zero-Emission Utility Terrain Vehicles Rebates

The FARMER Benefits Calculator tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits for each of the project types. The following subsections present the equations and methods from the FARMER Program and existing CARB methodologies or Calculator Tools used for rebates for the purchase of Zero-Emission Utility Terrain Vehicles.

1. GHG Equations

Equation 37 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 38 – Equation 42, GHG emissions are calculated based on fuel usage. Fuel usage for baseline vehicles and electricity usage for replacement vehicles are determined using Equation 40 and Equation 42, respectively.

Equation 37: GHG Emission Reductions from Rebates for the Purchase of Zero-Emission Utility Terrain Vehicles (Quantification Period)

$$QPER_{GHG} = QP \times ER_{GHG}$$

Table 37. Variables of Equation 37: GHG Emission Reductions from Rebates for the Purchase of Zero- Emission Utility Terrain Vehicles

Variable	Variable Definition	Units
$QPER_{GHG}$	GHG emission reductions over quantification period	$MTCO_2e$
QP	Quantification period (this is essentially the project life as denoted in the FARMER Program Guidelines)	years
ER_{GHG}	Annual GHG emission reductions	$MTCO_2e/yr$

Equation 38: Annual GHG Emission Reductions from Rebates for the Purchase of Zero-Emission Utility Terrain Vehicles

$$ER_{GHG} = GHG_{baseline} - GHG_{replacement\ UTV}$$

Table 38. Variables of Equation 38: Annual GHG Emission Reductions from Rebates for the Purchase of Zero-Emission Utility Terrain Vehicles

Variable	Variable Definition	Units
ER_{GHG}	Annual emission reductions	$MTCO_2e/yr$
$GHG_{baseline}$	Annual GHG emissions for the baseline equipment (fuel type dependent)	$MTCO_2e/yr$
$GHG_{replacement\ UTV}$	Annual GHG emissions for the replacement equipment (fuel type dependent)	$MTCO_2e/yr$

Equation 39: GHG Emissions for Baseline Vehicle/Equipment (diesel, gasoline, or alternative fuels)

$$GHG_{baseline} = FC_{baseline} \times CC_{baseline\ fuel} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

Table 39. Variables of Equation 39: GHG Emissions for Baseline Vehicle/Equipment (diesel, gasoline, or alternative fuels)

Variable	Variable Definition	Units
$GHG_{baseline}$	Annual greenhouse gas emissions for the baseline UTV	$MTCO_2e$/yr
$FC_{baseline}$	Fuel consumption of the baseline UTV	gal/yr, scf/yr
$CC_{baseline\ fuel}$	Carbon content of the baseline fuel (depends on fuel type)	gCO_2e/gal, gCO_2e/scf

Equation 40: Fuel Usage for Baseline Vehicle/Equipment (diesel, gasoline, or alternative fuels)

$$FC_{baseline} = BSFC \times HP \times LF \times AA \times GC$$

Table 40. Variables of Equation 40: Fuel Usage for Baseline Vehicle/Equipment (diesel, gasoline, or alternative fuels)

Variable	Variable Definition	Units
$FC_{baseline}$	Fuel consumption of the baseline UTV	gal/yr, scf/yr
BSFC	Brake specific fuel consumption (fuel specific)	lb/bhp-hr
HP	Maximum rated horsepower of the equipment	bhp
LF	Load factor	Unitless
AA	Annual activity	hours/year
GC	Gallon conversion (fuel specific)	gal/lb, gal/scf

On a case-by-case basis, applicants may have the option of scrapping a baseline tractor being operated and used as a UTV, in lieu of a baseline UTV, and replacing that equipment with the ZEV UTV. Each case will be at the discretion of CARB and the air districts.

Equation 41: GHG Emissions from Zero-Emission Utility Terrain Vehicles

$$GHG_{replacement\ UTV} = EU_{replacement\ UTV} \times CC_{electricity} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

Table 41. Variables of Equation 41: GHG Emissions from Zero-Emission Utility Terrain Vehicles

Variable	Variable Definition	Units
$GHG_{replacement\ UTV}$	Annual greenhouse gas emissions for the replacement ZEV UTV	$MTCO_2e$/yr
$EU_{replacement\ UTV}$	Electricity use of the replacement ZEV UTV	kWh/year
$CC_{electricity}$	Carbon content of electricity	gCO_2e/kWh

Equation 42: Electricity Usage for Zero-Emission Utility Terrain Vehicles

$$EU_{replacement\ UTV} = \frac{FC_{baseline\ UTV} \times ED_{baseline\ fuel}}{ED_{electricity} \times EER_{electricity}}$$

Table 42. Variables of Equation 42: Electricity Usage for Zero-Emission Utility Terrain Vehicles

Variable	Variable Definition	Units
$EU_{replacement\ UTV}$	Electricity use of the replacement ZEV UTV	kWh/yr
$FC_{baseline\ tractor}$	Fuel consumption of the baseline tractor	gal/yr, scf/yr
$ED_{baseline\ fuel}$	Energy density of the baseline tractor's fuel type	MJ/gal, MJ/scf
$ED_{electricity}$	Energy density of electricity	MJ/kWh
$EER_{electricity}$	Energy Efficiency Ratio relative baseline tractor's fuel type	Unitless

2. Criteria and Toxic Air Pollutant Equations

Please refer to the equations and methods described in the "Criteria and Toxic Air Pollutant Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized.

E. Emissions Reductions from 2 (or-more)-for-1 Off-Road Equipment Replacement and Repower Projects

This project category is essentially the same as the Off-Road Equipment Replacement/Repower. However, this category allows an applicant to procure a replacement at a different horsepower rating than their baseline if the given horsepower rating is no longer available. Additionally, this category allows for an applicant to scrap more than one baseline equipment to increase cost-effectiveness. The modified equations in this section are also applicable to Agricultural Irrigation Pumps.

For the first year of the FARMER Program, staff developed a conservative GHG quantification methodology for 2 (or-more)-for-1 projects that mirrors the assumptions made in the Carl Moyer Program and does not account for vehicle or equipment efficiency improvements. Staff intends to fund this project category initially using AB 118 funds and will collect and analyze usage data from the implemented projects to inform and develop future quantification methodologies that incorporate efficiency improvements.

1. GHG Equations

Please refer to the equations and methods described in the “GHG Equations” subsection of the “Emissions Reductions from Off-Road Equipment Replacement and Repower Projects” section. The same equations and methods are utilized. However, a notable difference is that rather than scrapping one baseline equipment/vehicle, the applicant could opt to scrap multiple pieces of equipment/vehicles to improve the cost-effectiveness. This is reflected by modifying Equation 19 to be a summation - i.e., Equation 43. Note that for fuel consumption and carbon content, units vary depending of fuel type of baseline and/or replacement equipment, respectively.

Equation 43: Annual GHG Emission Reductions from 2 (or-more)-for-1 Off-Road Equipment Projects

$$ER_{GHG} = \left(\sum_{j=1}^{N} GHG_{baseline,j} - GHG_{replacement} \right) \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

Table 43. Variables of Equation 43: Annual GHG Emission Reductions from 2 (or-more)-for-1 Off-Road Equipment Projects

Variable	Variable Definition	Units
ER_{GHG}	Annual GHG emission reductions of replacing the baseline equipment	$MTCO_2e/yr$
$GHG_{baseline,\,j}$	Annual GHG emissions for the baseline equipment	$MTCO_2e/yr$
$GHG_{replacement}$	Annual GHG emissions for the replacement equipment	$MTCO_2e/yr$
N	Number of baseline equipment applicant is scrapping	

Moreover, the fuel efficiency factor applied to off-road equipment was also modified for the case where the applicant is scrapping more than one baseline equipment to increase the cost-effectiveness. The fuel efficiency is calculated by determining how much newer the replacement is relative to the baseline equipment as seen in Equation 25.

However, when multiple baselines are being scrapped, the average model year across all of the baselines is used as demonstrated in Equation 44.

Equation 44: Fuel Efficiency Factor of the Replacement Equipment

$$FEF_{replacement} = 1 - \left(MY_{replacement} - \frac{\sum_{j=1}^{N} MY_{baseline,j}}{N} \right) \times AFEF_{year}$$

Table 44. Variables of Equation 44: Fuel Efficiency Factor of the Replacement Equipment

Variable	Variable Definition	Units
$FEF_{replacement}$	Fuel efficiency factor of the replacement equipment	Unitless
$MY_{replacement}$	Model year of the replacement equipment	Year
$MY_{baseline,\,j}$	Model year of the baseline equipment	Year
$AFEF_{year}$	Annual fuel efficiency factor, dependent on year	Unitless
N	Number of baseline equipment applicant is scrapping	

According to work by Grisso et al. (2014), tractor models tested in 2000 were

10-15% more efficient than tractors tested in 1980. Grisso et al. presented no data before 1980 and no data after 2007. McCullough et. al. (2022) expanded upon this work, measuring an average improvement in fuel efficiency of 0.55% per year across all tractor tiers from 1987 – 2021. Therefore, no efficiency losses are assumed for models before 1980 and no efficiency gains are gained after 2021. Thus, the annual fuel efficiency factor ($AFEF_{year}$) = 10% gains/20 years = 0.5%/year = 0.005 for 1980 – 1987 models, and 0.55% = 0.0055 for 1987 – 2021 models.

As seen in Equation 45, the load factor of the replacement equipment is varied up to a certain percentage per data from CARB's diesel agricultural equipment inventory survey and discussed in Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower. Refer to the document to see what standard deviation value applies to a given equipment type.

Equation 45: Load Factor of the Replacement Equipment for GHG Calculations

$$LF_{replacement} = \frac{\frac{\sum_{j=1}^{N}\left(HP_{max,baseline,j} \times AA_j\right)}{\sum_{j=1}^{N} AA_j} \times LF_{baseline}}{HP_{max,replacement}} \Bigg|_{LF_{baseline}-LF_{stdev}}^{LF_{baseline}+LF_{stdev}}$$

Table 45. Variables of Equation 45: Load Factor of the Replacement Equipment for GHG Calculations

Variable	Variable Definition	Units
$LF_{replacement}$	Load factor of the replacement equipment	Unitless
$HP_{max,\ baseline}$	Maximum rated horsepower of the baseline equipment	bhp
$LF_{baseline}$	Load factor of the baseline equipment	Unitless
$HP_{max,\ replacement}$	Maximum rated horsepower of the replacement equipment	bhp
LF_{stdev}	Load factor standard deviation used as adjustment bounds (0.208)	Unitless

2. Criteria and Toxic Air Pollutant Equations

Please refer to the equations and methods described in the "Criteria and Toxic Air Pollutant Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized. However, one notable difference is that rather than scrapping one baseline equipment/vehicle, the applicant could opt to scrap multiple pieces of equipment/vehicles to improve the cost-effectiveness. This is reflected by modifying Equation 30 to be a summation – i.e., Equation 46.

Equation 46: Annual Emission Reductions from Off-Road Equipment Replacement and Repower Projects

$$ER_{pollutant} = \sum_{j=1}^{N} \mathrm{AEP}_{baseline,j} - \mathrm{AEP}_{replacement}$$

Table 46. Variables of Equation 46: Annual Emission Reductions from Off-Road Equipment Replacement and Repower Projects

Variable	Variable Definition	Units
$ER_{pollutant}$	Annual emission reductions	US tons/yr
$AEP_{baseline, j}$	Annual emissions for the baseline equipment	US tons/yr
$AEP_{replacement}$	Annual emissions for the replacement equipment	US tons/yr
N	Number of baseline equipment applicant is scrapping	

Section C. References

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

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