AGR I ENV AI

# DairyCarbon v1.0

Scientific methodology, parameter provenance, uncertainty, assumptions, and limitations

| | |
|---|---|
| Model scope | United States · dairy cattle, dairy goats, dairy sheep |
| Boundary | Annual farm-gate; direct animal/manure sources plus on-farm energy, refrigerants, and optional purchased-feed total |
| Methods | IPCC 2019 Refinement Tier 2 equations with U.S. activity-data orientation |
| Primary use | Screening, hotspot identification, scenario comparison, and data-quality improvement |
| Not designed for | Regulatory verification, offset issuance, product labeling, or full life-cycle assessment |

## Prepared for AgriEnv AI

Methodology release 1.0 · 2026-08-25 · Companion to the DairyCarbon web application and Python package.

## IMPORTANT INTERPRETATION

DairyCarbon is a transparent calculation framework. Its reliability depends primarily on the quality and representativeness of farm inputs. Measured intake, annual average populations, milk shipped, manure-system fractions, storage duration, and local electricity factors should replace defaults whenever available. Results are estimates with material uncertainty, especially for methane conversion in manure systems.

# Contents



## Terminology

$CH_4$ = methane; $N_2O$ = nitrous oxide; $CO_2e$ = carbon-dioxide equivalent; DMI = dry-matter intake; GE = gross energy intake; DE = digestible energy; VS = volatile solids; $B_0$ = maximum methane-producing capacity; MCF = methane conversion factor; $EF_3$ = direct manure $N_2O$ emission factor; FPCM/ECM = fat- and protein/energy-corrected milk; $GWP_{100}$ = 100-year global warming potential.

# 1. Purpose, boundary, and accounting principles

DairyCarbon estimates the annual greenhouse-gas footprint of a U.S. dairy operation using animal-group activity data. The model is organized to show where emissions arise and to preserve the quantities and factors used in every calculation. It follows IPCC source categories but is intended for farm decisions rather than national inventory reporting.

## 1.1 Included sources

• Enteric $CH_4$ from dairy cattle, dairy goats, and dairy sheep.

• $CH_4$ from manure deposited or handled in lagoons, liquid/slurry systems, solid storage, dry lots, daily spread, deep bedding, composting, anaerobic digestion, and pasture/range/paddock.

• Direct $N_2O$ from manure management and indirect $N_2O$ associated with volatilization and leaching/runoff.

• $CO_2$ from annual on-farm diesel, gasoline, propane, and purchased electricity.

• Refrigerant leakage, represented as leaked mass multiplied by a user-entered refrigerant GWP.

• Optional purchased-feed emissions entered as an externally calculated annual t $CO_2e$ value. DairyCarbon does not calculate feed-crop production.

## 1.2 Excluded unless supplied externally

• Feed production detail, fertilizer used on feed crops, soil-carbon stock change, land-use change, capital goods, buildings, machinery manufacture, veterinary products, purchased animals, outbound milk processing, packaging, retail, and consumer stages.

• Biogenic $CO_2$ exhaled by animals and $CO_2$ from manure decomposition are not counted as fossil $CO_2$, consistent with inventory convention.

## 1.3 Boundary rule

Farm total (kg $CO_2e$ $yr^{-1}$) = enteric $CH_4$ × $GWPCH_4$ + manure $CH_4$ × $GWPCH_4$ + manure $N_2O$ × $GWPN_2O$ + fuel/electricity $CO_2e$ + refrigerant $CO_2e$ + optional purchased-feed $CO_2e$

No downstream displacement credit is automatically granted for captured biogas. A separate, documented avoided-energy calculation would require the quantity and use of recovered gas, conversion efficiency, parasitic energy, flare destruction, leakage, and the displaced marginal energy source.

# 2. Calculation architecture and units

The model uses a bottom-up inventory. Each animal group is calculated separately and then summed. This is essential because lactating cows, dry animals, replacements, calves/kids/lambs, and breeding males differ in body weight, intake, diet, nitrogen balance, and milk output.

## 2.1 Annual-average population

Users should enter annual-average head count, not only a peak inventory. If inventories change materially, a time-weighted mean should be used: Σ(head in period × days in period)/365.

## 2.2 Gas conversion

| Gas | $GWP_{100}$ used | Interpretation |
|---|---|---|
| Biogenic $CH_4$ | 27.2 | IPCC AR6 100-year value for biogenic methane |
| $N_2O$ | 273 | IPCC AR6 100-year value |
| Fossil $CO_2$ | 1 | By definition |

Users comparing results with a corporate inventory must confirm whether that program requires AR5, AR6, or another prescribed assessment report. Changing GWPs changes $CO_2e$ but not the underlying mass of $CH_4$ or $N_2O$.

## 2.3 Core constants

| Constant | Value | Use |
|---|---|---|
| Gross energy density of dry matter | 18.45 MJ $kg^{-1}$ DM | DMI-to-GE conversion |
| Energy content of methane | 55.65 MJ $kg^{-1}$ $CH_4$ | IPCC enteric equation |
| Methane density | 0.67 kg $CH_4$ $m^{-3}$ | Manure methane |
| N in crude protein | CP / 6.25 | Feed nitrogen intake |
| $N_2O$-N to $N_2O$ | 44 / 28 | Molecular-weight conversion |

# 3. Animal characterization

## 3.1 Supported populations

| Species | Animal classes | Example breeds |
|---|---|---|
| Dairy cattle | Lactating cow; dry cow; replacement heifer; calf; breeding bull | Holstein, Jersey, Brown Swiss, Ayrshire, Guernsey, Milking Shorthorn, crossbred |
| Dairy goats | Lactating doe; dry doe; replacement kid; buck | Alpine, Saanen, Nubian, LaMancha, Toggenburg, crossbred |
| Dairy sheep | Lactating ewe; dry ewe; replacement lamb; ram | East Friesian, Lacaune, Awassi, crossbred |

## 3.2 How genetics are represented

Breed selection changes starting values for mature body weight and, for lactating animals, typical milk yield. Those values propagate through DMI, GE intake, enteric methane, VS, nitrogen intake, nitrogen excretion, and milk intensity. This is not a direct breed emission coefficient. Genetic effects are mediated through measurable performance and intake because evidence for a stable, universal breed multiplier is insufficient.

The model therefore follows a hierarchy: (1) farm measurement; (2) ration or herd-management records; (3) breed/class default. Selecting Jersey instead of Holstein is useful for initializing a scenario, but recorded Jersey intake and production should always replace the default.

## 3.3 Editable activity data

| Input | Why it matters | Preferred evidence |
|---|---|---|
| Annual average head | Scales every animal source | Monthly herd records |
| Body weight | Supports plausibility checks and defaults | Scale or herd average |
| DMI | Primary driver of enteric $CH_4$, VS, and N intake | Ration delivery minus refusals, corrected to DM |
| Milk/day and lactation days | Annual output and cattle Ym class | Milk shipped and herd records |
| Diet digestibility | Controls fecal organic matter/VS | Feed analysis or nutrition model |
| Crude protein | Controls N intake and excretion | Laboratory ration analysis |
| N retention | Subtracts milk/growth/pregnancy retention | Validated farm/nutrition model |

Defaults are transparent placeholders, not breed standards, genetic evaluations, or production forecasts.

# 4. Enteric methane

## 4.1 Tier 2 energy-balance equation

Enteric $CH_4$ (kg head$^{-1}$ yr$^{-1}$) = GE (MJ head$^{-1}$ d$^{-1}$) × 365 × Ym / 55.65 GE = DMI (kg DM d$^{-1}$) × 18.45 MJ kg$^{-1}$ DM

The calculation is performed for each animal group and multiplied by annual-average head. Ym is the fraction of gross feed energy converted to methane.

## 4.2 Resolved Ym values

| Group | Condition | Ym (% GE) |
|---|---|---|
| Dairy cattle | High production (>8,500 kg milk head$^{-1}$ yr$^{-1}$) | 5.7 |
| Dairy cattle | Medium production (5,000–8,500 kg yr$^{-1}$) | 6.3 |
| Dairy cattle | Low/nonlactating screening default | 6.5 |
| Dairy goats | All classes screening default | 5.5 ± 1.0 |
| Dairy sheep | All classes screening default | 6.7 ± 0.9 |

Sources: IPCC 2019 Refinement Tables 10.12 and 10.13. The web/Python implementation uses annual milk production to assign the high- or medium-producing cattle value; nonlactating cattle use a conservative 6.5% screening value. The sheep and goat defaults reflect the IPCC multi-study analyses.

## 4.3 Diet and management

DMI and diet composition can change both total $CH_4$ and methane yield. The model allows the user to modify DMI and to enter a verified enteric-reduction percentage. It deliberately does not apply universal automatic credits for fat, forage quality, monensin, tannins, seaweed, or genetic selection because effects depend on dose, diet, duration, species, and measurement method.

## 4.4 3-NOP scenario

The control is represented as a percent reduction applied to baseline enteric $CH_4$. Hristov et al. (2015) reported about 30% reduction in high-producing Holstein cows at 40–80 mg 3-NOP kg$^{-1}$ feed DM over 12 weeks. Dijkstra et al. (2018) and Kebreab et al. (2023) show that response depends on dose, dietary fiber, and cattle type. Users must enter a value supported for their actual product, ration, animal class, and period.

# 5. Manure volatile solids and methane

## 5.1 Volatile-solids screening equation

$$VS\ (\text{kg head}^{-1}\ \text{d}^{-1}) = DMI \times [1 - \text{digestibility fraction}] \times 0.92$$

The factor 0.92 removes an assumed 8% ash fraction from undigested fecal dry matter. This simplified VS equation is used when direct VS measurements or a complete IPCC Tier 2 urinary energy calculation are unavailable. It should be replaced for high-accuracy projects using measured manure characteristics or a validated nutrition/manure model.

## 5.2 Methane potential and management

$$\text{Manure } CH_4 = \text{head} \times VS \times 365 \times B_0 \times 0.67 \times \Sigma(\text{system fraction} \times MCF_{\text{system, climate}})$$

| Species | North America $B_0$ ($m^3$ $CH_4$ $kg^{-1}$ VS) | Source |
|---|---|---|
| Dairy cattle | 0.24 | IPCC 2019 Table 10.16A |
| Dairy goats | 0.18 | IPCC 2019 Table 10.16A |
| Dairy sheep | 0.19 | IPCC 2019 Table 10.16A |
| Pasture deposit (all) | 0.19 | Use with IPCC PRP MCF |

## 5.3 Default methane conversion factors

| System | Cool | Temperate | Warm | Notes |
|---|---|---|---|---|
| Uncovered lagoon | 60% | 67% | 76% | Selected U.S.-relevant IPCC climate columns |
| Liquid/slurry, 6 months | 21% | 26% | 41% | Retention time materially affects MCF |
| Solid storage | 2% | 4% | 5% | Dry/aerobic pathway |
| Dry lot | 1% | 1.5% | 2% | Broad default |
| Daily spread | 0.1% | 0.5% | 1% | Storage only; soil emissions separate |
| Deep bedding <1 month | 2.75% | 6.5% | 18% | Cattle/deep-pack default |
| Intensive windrow compost | 0.5% | 1% | 1.5% | Frequent turning |
| Pasture/range/paddock | 0.47% | 0.47% | 0.47% | Use $B_0$ = 0.19 |
| Digester scenario | 21% | 26% | 41% | Pre-capture slurry potential; capture applied separately |

Source: IPCC 2019 Refinement Table 10.17. DairyCarbon uses one primary managed system plus a grazing fraction. Complex serial systems, solids separation, crust dynamics, and monthly retention-time modeling require a more detailed mass-flow model.

# 6. Manure nitrogen and nitrous oxide

## 6.1 Nitrogen balance

N intake (kg N head$^{-1}$ d$^{-1}$) = DMI × crude-protein fraction / 6.25 N excreted (kg N yr$^{-1}$) = head × N intake × [1 − N-retention fraction] × 365

The retention input represents nitrogen exported in milk or retained in growth and pregnancy. A farm-specific nutrient balance is preferable. Unrealistic crude protein or retention assumptions can dominate the $N_2O$ result.

## 6.2 Direct $N_2O$

Direct $N_2O$ (kg yr$^{-1}$) = N excreted × Σ(system fraction × $EF_3$) × 44/28

| System | $EF_3$, kg $N_2O$-N kg$^{-1}$ N |
|---|---|
| Daily spread / uncovered lagoon / slurry without crust | 0 |
| Solid storage / covered solid / deep bedding without mixing | 0.010 |
| Dry lot | 0.020 |
| Slurry with crust | 0.005 |
| Anaerobic digester | 0.0006 |
| Intensive windrow compost | 0.005 |
| Pasture/range/paddock screening value | 0.004 |

Source: IPCC 2019 Refinement Table 10.21. Pasture-deposited N is conceptually a managed-soils source; it is retained in DairyCarbon's farm boundary and identified as such in the audit logic.

## 6.3 Indirect $N_2O$

Indirect $N_2O$ = N excreted × [(FracGas × $EF_4$) + (FracLeach × $EF_5$)] × 44/28 Default $EF_4$ = 0.01 kg $N_2O$-N kg$^{-1}$ volatilized N; $EF_5$ = 0.011 kg $N_2O$-N kg$^{-1}$ leached N

FracGas and FracLeach vary by system. Examples used in the model include dairy lagoon 0.40/0, uncovered slurry 0.48/0, solid storage 0.22/0, dry lot 0.30/0.035, daily spread 0.07/0, and a screening pasture allocation 0.20/0.24. Table 10.22 ranges are wide; therefore indirect $N_2O$ should be treated as uncertain.

# 7. Location, reporting year, and climate

Users may enter latitude/longitude directly or enter a county/nearby city. The client queries the Open-Meteo geocoding and historical archive services. The arithmetic mean of available daily 2-m air temperature for the selected calendar year is calculated and stored as the reporting-year mean.

## 7.1 Climate bins

| Model class | Reporting-year mean temperature | Use |
|---|---|---|
| Cool | <10 °C | Cool MCF column |
| Temperate | 10 to <20 °C | Temperate MCF column |
| Warm | ≥20 °C | Warm MCF column |

The original IPCC table contains finer moist/dry and regional combinations. DairyCarbon collapses these to three transparent, U.S.-oriented screening classes because the current interface does not run a monthly storage process model or calculate a full IPCC ecological climate zone. This is an important simplification.

## 7.2 Weather data behavior

• The web calculation remains usable if the weather service is unavailable; the user enters mean temperature manually.

• Weather data influence manure MCF, not enteric Ym, unless the user separately changes intake or production to reflect heat stress.

• The reporting year and coordinates are activity-data metadata. Long-term climate normals can be used for planning, but inventory calculations should use conditions representative of the reporting period.

## 7.3 Recommended enhancement for verification work

For a verified project, calculate monthly manure temperature, storage loading, removal schedule, crust/cover status, and retention time using the IPCC MCF calculation workbook or a validated country-specific model. Compare multiple years and quantify uncertainty rather than relying on a single annual temperature bin.

# 8. Farm energy, refrigerants, and purchased feed

## 8.1 Stationary and mobile energy

$$\text{Energy } CO_2e = \text{diesel gal} \times 10.21 + \text{gasoline gal} \times 8.78 + \text{propane gal} \times 5.75 + \text{electricity kWh} \times \text{electricity factor}$$

| Input | Default factor | Model treatment |
| --- | --- | --- |
| Diesel | 10.21 kg $CO_2$ $gal^{-1}$ | Annual gallons |
| Gasoline | 8.78 kg $CO_2$ $gal^{-1}$ | Annual gallons |
| Propane | 5.75 kg $CO_2$ $gal^{-1}$ | Annual gallons |
| Electricity | 0.386 kg $CO_2e$ $kWh^{-1}$ | Editable screening default; use local eGRID/utility value |

Fuel factors represent combustion $CO_2$ screening factors. A full corporate inventory may additionally require $CH_4$ and $N_2O$ from combustion, upstream fuel emissions, renewable-energy certificates, location- and market-based Scope 2 reporting, and consistent organizational boundaries.

## 8.2 Refrigerants

$$\text{Refrigerant } CO_2e = \text{refrigerant leaked (kg)} \times \text{refrigerant-specific } GWP_{100}$$

The user must enter actual top-up/leak mass and the correct refrigerant GWP. The interface example of 1,430 is a placeholder commonly associated with R-134a under older assessment conventions; it is not automatically valid for the farm's refrigerant or reporting program.

## 8.3 Purchased feed

Purchased feed is outside the direct animal/manure computation and is optional. A user may enter an annual cradle-to-farm-gate feed footprint from a supplier EPD, LCA, or consistent feed model. The value should not be added if the same upstream emissions are counted elsewhere. Because DairyCarbon does not simulate crops, feed mitigation is represented only by changing that externally supplied value or by changes in measured DMI.

# 9. Mitigation scenarios

A scenario holds herd structure and all unchanged activity data constant, then modifies selected controls. Avoided emissions equal baseline less alternative. Negative values are not reported as avoided emissions.

$$\text{Avoided } CO_2e = \text{baseline farm } CO_2e - \text{alternative farm } CO_2e$$

## 9.1 Enteric control

Enteric reduction is applied multiplicatively to calculated enteric $CH_4$. The user is responsible for evidence supporting the entered percentage, duration, animal coverage, and continued efficacy.

## 9.2 Anaerobic digestion

$$\text{Residual manure } CH_4 = \text{pre-capture manure } CH_4 \times [1 - \text{capture efficiency} \times \text{destruction efficiency}]$$

DairyCarbon’s digester pathway begins with the climate-specific six-month liquid/slurry methane potential, then applies user-entered capture and destruction efficiencies. This makes the avoided-emissions comparison explicit. It is not a substitute for metered biogas, destruction records, digestate-storage emissions, flare uptime, or project-protocol equations. For project accounting, replace this screening calculation with a complete methane balance.

## 9.3 Lagoon cover

A verified lagoon-cover reduction can reduce the selected lagoon MCF. IPCC notes that solid covers may reduce methane, but the range is broad and performance depends on construction, rain, crust, solids, leakage, and gas treatment. The interface caps the generic input at 50%.

## 9.4 Productivity and intensity

Increasing milk yield may reduce emissions intensity even when absolute farm emissions rise. DairyCarbon reports both totals and per-kg milk intensity so that a reduction in intensity is not misrepresented as a reduction in atmospheric emissions.

Mitigation results are conditional estimates. They do not establish additionality, permanence, leakage control, ownership of environmental attributes, or eligibility for carbon credits.

# 10. Outputs and audit trail

| Output | Unit | Interpretation |
|---|---|---|
| Annual farm footprint | t $CO_2e$ $yr^{-1}$ | Sum of included sources |
| Enteric $CH_4$ | kg $CH_4$ $yr^{-1}$ and t $CO_2e$ | Mass retained alongside $CO_2e$ |
| Manure $CH_4$ | kg $CH_4$ $yr^{-1}$ and t $CO_2e$ | After modeled capture |
| Manure $N_2O$ | kg $N_2O$ $yr^{-1}$ and t $CO_2e$ | Direct + indirect |
| Per head | kg $CO_2e$ $head^{-1}$ $yr^{-1}$ | Total divided by all entered animals |
| Per kg milk | kg $CO_2e$ $kg^{-1}$ milk | Total divided by uncorrected annual milk |
| Avoided emissions | t $CO_2e$ $yr^{-1}$ | Baseline minus scenario |
| Audit CSV | structured fields | Inputs, factors, units, sources, and results |

## 10.1 Milk denominator

Version 1.0 uses uncorrected milk mass because milk fat and protein are not collected. For comparison among breeds or farms, FPCM or ECM is preferred. A later version should request fat and protein and implement a cited correction equation.

## 10.2 Interpretation order

- First inspect absolute farm emissions and gas mass.
- Then inspect the source breakdown to identify dominant drivers.
- Use intensity only with a clearly stated denominator and boundary.
- Compare scenarios only when activity data and accounting boundaries are consistent.
- Archive the audit CSV with source documents and calculation date.

## 10.3 Rounding

The calculation engine retains floating-point values; the interface rounds only for display. CSV and Python results provide higher precision. Reported precision should not imply accuracy beyond the input data and factors.

# 11. Uncertainty, sensitivity, and accuracy

## 11.1 What accuracy means here

DairyCarbon can reproduce its own equations exactly, but agreement with measured farm emissions is limited by model form, temporal variability, animal heterogeneity, measurement error, and default-factor uncertainty. IPCC Tier 2 is more responsive than Tier 1 because it uses intake and management data; it is not a direct measurement.

## 11.2 Expected high-sensitivity inputs

| Input | Direction of effect | Priority |
|---|---|---|
| DMI | Raises enteric $CH_4$, VS, manure $CH_4$, and N intake | Very high |
| Ym | Directly proportional to enteric $CH_4$ | Very high |
| Manure MCF / storage duration / temperature | Directly proportional to manure $CH_4$ | Very high for liquid systems |
| Digestibility | Higher digestibility lowers simplified VS | High |
| Crude protein and N retention | Control N excretion and manure $N_2O$ | High |
| Manure-system fraction and grazing | Redistribute $CH_4$ and $N_2O$ pathways | High |
| Annual milk | Changes intensity; also selects cattle Ym class | High |
| Electricity factor | Directly proportional to electricity $CO_2e$ | Moderate to high |
| Mitigation efficacy | Directly controls avoided emissions | Project-specific |

## 11.3 Suggested uncertainty analysis

For material decisions, run at least low/base/high values. Example ranges: DMI ±5–10%; Ym using IPCC uncertainty or measured confidence intervals; $B_0$ ±15% (IPCC table note); manure MCF using the appropriate IPCC range and storage-duration alternatives; N excretion ±15–30%; electricity factor by reporting method; mitigation efficacy using trial or supplier confidence bounds. Monte Carlo simulation should use distributions and correlations rather than adding all worst cases.

## 11.4 Model checks

- Mass and energy units are explicit and tested in both TypeScript and Python.
- Warm-lagoon scenarios must exceed cool-lagoon manure $CH_4$ for identical activity data.
- A positive enteric control must lower enteric $CH_4$ by the entered proportion.
- Category totals must sum to the reported farm total.
- Zero head or zero milk is handled without division errors.

# 12. Data quality, validation, and limitations

## 12.1 Data-quality hierarchy

| Tier | Example | Recommended use |
|---|---|---|
| A | Metered fuel/electricity, milk shipped, measured DMI, lab diet analysis, monthly herd counts | Primary inventory input |
| B | Farm records, ration software, manure engineering design and documented operating schedule | Good screening input |
| C | Regional or breed/class defaults | Gap filling; flag in audit |
| D | Unverified assumptions or generic mitigation claims | Scenario exploration only |

## 12.2 Validation plan

• Reconcile annual milk output with processor statements and herd days.

• Compare estimated cattle enteric $CH_4$ per head with U.S. EPA/IPCC ranges for the same productivity class.

• Compare VS and N excretion with manure nutrient-management records.

• Reconcile energy inputs with invoices; use eGRID subregion or supplier factors.

• For digesters, reconcile captured gas, methane concentration, engine/flaring hours, parasitic energy, and leakage.

• Where possible, compare against a second accepted tool while matching boundaries, GWP set, and allocation rules.

## 12.3 Principal limitations

• Annual bins do not represent daily or monthly temperature and storage kinetics.

• One managed manure system plus grazing cannot describe all serial manure pathways.

• The VS equation is simplified and omits urinary energy detail.

• Goat and sheep defaults are less data-rich than dairy-cattle parameters.

• Breed defaults do not represent within-breed genetics or herd-specific selection.

• Milk is not fat/protein corrected in v1.0.

• No soil-carbon, feed-crop, land-use, or full supply-chain model is included.

• The model does not determine regulatory compliance or credit eligibility.

# 13. Parameter register

| Parameter | Value/rule | Primary source |
|---|---|---|
| Cattle Ym | 5.7%, 6.3%, or 6.5% by productivity | IPCC 2019 Table 10.12 |
| Goat Ym | 5.5% ±1.0 | IPCC 2019 Table 10.13 |
| Sheep Ym | 6.7% ±0.9 | IPCC 2019 Table 10.13 |
| GE density | 18.45 MJ $kg^{-1}$ DM | IPCC 2019 Ch. 10 |
| $CH_4$ energy | 55.65 MJ $kg^{-1}$ | IPCC Eq. 10.21 |
| $B_0$ cattle/goat/sheep | 0.24 / 0.18 / 0.19 $m^3$ $kg^{-1}$ VS | IPCC 2019 Table 10.16A |
| MCF | System × climate table | IPCC 2019 Table 10.17 |
| $EF_3$ | System-specific | IPCC 2019 Table 10.21 |
| FracGas / FracLeach | System-specific screening values | IPCC 2019 Table 10.22 |
| $EF_4$ / $EF_5$ | 0.01 / 0.011 | IPCC managed-soils guidance |
| $CH_4$ $GWP_{100}$ | 27.2 biogenic | IPCC AR6 WGI |
| $N_2O$ $GWP_{100}$ | 273 | IPCC AR6 WGI |
| Fuel $CO_2$ | 10.21 diesel; 8.78 gasoline; 5.75 propane kg $gal^{-1}$ | U.S. EPA factors |
| Electricity | 0.386 kg $CO_2e$ $kWh^{-1}$ default; editable | U.S. screening value; replace with eGRID/utility |
| 3-NOP | No automatic factor; user-entered evidence value | Hristov 2015; Dijkstra 2018; Kebreab 2023 |
| Weather | Daily mean temperature averaged for selected year | Open-Meteo historical archive |

## Parameter governance

All default changes should be versioned with source, publication date, applicable species/class/diet/climate, units, uncertainty, and rationale. A parameter must not be changed merely because a newer value exists; the boundary and methodology must remain internally consistent.

# 14. References

Authoritative methods and primary literature used to define the calculation framework are listed below. Access dates should be recorded when the model is used in a formal inventory.


1. IPCC. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4, Chapter 10: Emissions from Livestock and Manure Management. Corrected July 2023. https://www.ipcc-nggip.iges.or.jp/public/2019rf/vol4.html
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12. U.S. EPA AgSTAR. Practices to Reduce Methane Emissions from Livestock Manure Management. https://www.epa.gov/agstar/practices-reduce-methane-emissions-livestock-manure-management
13. U.S. EPA. Emission Factors for Greenhouse Gas Inventories and eGRID resources. https://www.epa.gov/climateleadership/ghg-emission-factors-hub and https://www.epa.gov/egrid
14. Open-Meteo. Historical Weather API documentation. https://open-meteo.com/en/docs/historical-weather-api
15. GHG Protocol. Corporate Standard and Scope 2 Guidance. https://ghgprotocol.org/standards-guidance


## Release statement

DairyCarbon v1.0 was designed as an inspectable decision-support model. The web application and Python implementation use the same constants and equations. Users should cite the IPCC and EPA methods—not DairyCarbon—as the scientific authority for inventory factors, and should document any substitutions made for project use.