AGRIENV AI

MixedFarmCarbon v1.0

Scientific methodology for linked U.S. crop and dairy greenhouse-gas accounting

Model scope	United States mixed crop and dairy farms
Enterprises	Ten field crops; dairy cattle, goats, and sheep
Boundary	Annual farm gate; direct sources plus shared energy, refrigerants, and optional purchased-feed total
Linking principle	Physical manure-N, farm-grown feed, and shared energy flows are entered once
Primary use	Screening, hotspot analysis, scenario comparison, and data-quality improvement
Not designed for	Regulatory verification, offset issuance, nutrient-management compliance, or product labeling

Prepared for AgriEnv AI

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

IMPORTANT INTERPRETATION

MixedFarmCarbon is a transparent screening framework. Its result is not more accurate than its activity data and factors. Measured fertilizer, yield, intake, animal populations, milk shipped, manure-system fractions, storage losses, exported manure, and utility factors should replace examples or defaults. Emission factors are uncertain and spatially variable; do not present a single result as a measured quantity.

Contents

Terminology

CH4 = methane; N2O = nitrous oxide; CO2e = carbon-dioxide equivalent; DMI = dry-matter intake; GE = gross energy; VS = volatile solids; B0 = maximum methane-producing capacity; MCF = methane conversion factor; EF3 = direct manure N2O emission factor; FracGas = nitrogen volatilization fraction; FracLeach = nitrogen leaching/runoff fraction; GWP100 = 100-year global warming potential.

1. Purpose and accounting boundary

MixedFarmCarbon estimates annual greenhouse-gas emissions for one U.S. farm containing both crop fields and dairy animals. The defining feature is a physical-flow ledger connecting enterprises. Animal manure is not entered again as unrelated purchased organic fertilizer, farm-grown feed is not added as a purchased-feed footprint, and shared farm energy is entered once.

1.1 Included sources

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

• CH_4 and direct/indirect N_2O from manure storage and treatment.

• Direct and indirect N_2O from synthetic fertilizer, on-farm and purchased manure applied to fields, crop residues, and manure deposited while grazing.

• Rice-cultivation CH_4 and CO_2 from limestone and urea application.

• CO_2e from shared diesel, gasoline, propane, purchased electricity, refrigerant leakage, optional purchased feed, and documented other sources.

1.2 Excluded unless documented externally

• Soil-organic-carbon stock change, land-use change, fertilizer manufacture, pesticides, seed, machinery and building capital, veterinary inputs, water infrastructure, purchased animals, downstream processing, packaging, retail, and consumer stages.

• Biogenic CO_2 from animal respiration and routine manure decomposition is not treated as fossil CO_2.

1.3 Boundary equation

Whole-farm CO_2e = enteric CH_4 + manure CH_4 + manure-storage N_2O + field-soil N_2O + grazing-deposition N_2O + rice CH_4 + lime/urea CO_2 + shared energy + refrigerants + optional purchased feed + other documented sources

All gas terms are converted to kg CO_2e before summation. The model uses AR6 GWP100 values of 27.2 for biogenic CH_4 and 273 for N_2O. Corporate programs may prescribe different values.

2. Integrated architecture and anti-double-counting rules

Independent crop and livestock calculators cannot simply be added. The same manure, feed, or fuel can appear in both. MixedFarmCarbon uses linked mass and activity flows.

2.1 Manure-N flow

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Animal N excreted -> grazing deposit + managed manure Managed manure -> storage N losses + N available after storage Available N -> exported manure + retained manure Retained manure -> normalized allocation among farm fields
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Storage CH_4 and N_2O remain farm emissions even if manure is later exported. Field N_2O from exported manure is outside the farm boundary. Purchased manure enters only at field application; its off-farm production and storage are not counted unless entered under Other.

2.2 Feed flow

Each crop field records the fraction of harvested yield used as farm feed. That quantity is reported as a linkage metric but does not add a new emission category because the field's fertilizer, residues, rice, amendment, and shared energy sources are already represented. Only an externally calculated footprint for feed purchased from outside the farm is added.

2.3 Energy flow

Diesel, gasoline, propane, and electricity are entered once for the whole farm. This avoids adding separate crop and dairy energy totals that may include the same tractor, pump, shop, feed handling, refrigeration, or utility meter.

2.4 Allocation caution

MixedFarmCarbon reports whole-farm intensities per acre, per head, and per kg of milk as descriptive ratios. It does not allocate shared emissions among milk, animals, feed, crops sold, or co-products. Product carbon footprints require a documented physical, economic, or biophysical allocation method and downstream boundary.

3. Crop-field inputs and residue nitrogen

The model supports multiple crop fields. Each field has crop, area, harvested yield, farm-feed fraction, synthetic N, purchased manure N, share of retained farm manure, residue removal, irrigation, fertilizer form, inhibitor status, limestone, urea, and rice management when applicable.

3.1 Crop-specific residue equation

Harvested dry matter = harvested fresh yield x dry fraction Above-ground residue DM (AGR) = harvested dry matter x RAG Below-ground residue DM (BGR) = (harvested dry matter + AGR) x RS Residue N returned = AGR x NAG x (1 - removal fraction) + BGR x NBG

Crop	NAG	NBG	RAG	RS	Dry fraction
Corn grain	0.006	0.007	1.0	0.22	0.87
Soybean	0.008	0.008	2.1	0.19	0.91
Winter wheat	0.006	0.009	1.3	0.23	0.89
Cotton*	0.008	0.009	1.0	0.22	0.85
Sorghum*	0.007	0.006	1.4	0.22	0.89
Rice	0.007	0	1.4	0.16	0.89
Barley	0.007	0.014	1.2	0.22	0.89
Oats	0.007	0.008	1.3	0.25	0.89
Alfalfa hay	0.027	0.019	0	0.40	0.90
Potato	0.019	0.014	0.4	0.20	0.22

Source: IPCC 2019 Refinement, Volume 4, Chapter 11, Table 11.1a. *Generic assumptions are used where a complete crop-specific row is unavailable. Measured residue biomass and N concentration are preferable.

3.2 Field-level manure allocation

Farm manure N allocated to field i = retained available manure N x share_i / sum(all positive field shares)

Shares are relative weights. They are normalized so the sum of farm-manure N applied equals retained N. Purchased manure is a separate field input in lb N and is not part of that normalization.

4. Managed-soil N2O, fertilizer, irrigation, and amendments

4.1 Direct N2O

Direct N2O = [synthetic N x EF1synthetic + (farm manure N + purchased manure N + residue N) x EF1other] x 44/28

Wet-climate screening values are EF1 = 0.016 for synthetic N and 0.006 for organic/residue N. Dry-climate value is 0.005. Rice uses water-regime factors of 0.003 under continuous flooding and 0.005 under drainage. Source: IPCC 2019 Table 11.1.

4.2 Volatilization and leaching

Indirect N2O = {[(synthetic N x FracGASF) + (applied manure N x 0.21)] x EF4 + [(all field N inputs) x FracLeach x EF5]} x 44/28

Condition	EF4	FracLeach	EF5
Humid/wet	0.014	0.24	0.011
Dry, rainfed or drip	0.005	0	0.011
Dry, sprinkler or surface irrigated	0.005	0.24	0.011

4.3 Fertilizer form

Form	FracGASF	Automatic direct-EF treatment
Urea	0.15	Climate EF
UAN / ammonium nitrate	0.05	Climate EF
Anhydrous ammonia / ammonium sulfate	0.08	Climate EF
Controlled-release fertilizer	0.15	Climate EF x 0.65
Nitrification inhibitor	By fertilizer	Direct EF x 0.62

The 0.65 and 0.62 scenario multipliers are screening values informed by Akiyama et al. (2010). They are not product guarantees. Timing, placement, soil, weather, and dose can change results.

4.4 Lime and urea CO2

CO2 = [(limestone product kg x 0.12 C fraction) + (urea product kg x 0.20 C fraction)] x 44/12

5. Rice methane

Rice CH_4 = area (ha) x flooded cultivation days x 1.30 kg CH_4 ha^{-1} day^{-1} x water-regime scaling

Water regime	Scaling
Continuous flooding	1.00
Single drainage	0.60
Multiple drainage	0.52
Rainfed regular	0.28

The baseline and scaling are Tier 1 screening values from IPCC 2006 Volume 4 Chapter 5. Organic-amendment timing and rate scaling is not automated because the current input set is insufficient.

6. Animal populations, breed, diet, and production

Species	Classes	Major breed options
Dairy cattle	Lactating, dry, replacement, calf, bull	Holstein, Jersey, Brown Swiss, Ayrshire, Guernsey, Milking Shorthorn, crossbred
Dairy goats	Lactating, dry, replacement, buck	Alpine, Saanen, Nubian, LaMancha, Toggenburg, crossbred
Dairy sheep	Lactating, dry, replacement, ram	East Friesian, Lacaune, Awassi, crossbred

Breed selection supplies editable starting values for mature body weight and lactating milk yield. Genetics are not represented by a direct emission multiplier. Breed affects emissions only through measurable traits such as intake, body size, diet, production, and nitrogen balance. Farm records supersede defaults.

6.1 Required animal-group data

- Annual-average head, species, class, and breed.
- Body weight, DMI, milk yield, lactation days, diet digestibility, crude protein, and N retention.
- A time-weighted population is preferred when inventory changes during the year.

7. Enteric methane

GE (MJ head-1 day-1) = DMI (kg DM head-1 day-1) x 18.45 Enteric CH4 (kg yr-1) = head x GE x 365 x Ym / 55.65

Animal group	Ym, % GE
High-producing dairy cattle (>8,500 kg milk/head/year)	5.7
Other lactating dairy cattle	6.3
Nonlactating cattle screening value	6.5
Dairy goats	5.5
Dairy sheep	6.7

Sources: IPCC 2019 Tables 10.12 and 10.13. DMI is the principal activity driver. Heat stress, ration composition, forage quality, fat, additives, and genetics can affect DMI and methane yield; their effects should be represented through measured inputs or a verified reduction percentage.

7.1 Enteric mitigation

The scenario control applies a user-entered reduction to baseline enteric CH4. Evidence for 3-NOP and other interventions depends on animal type, dose, ration, duration, and measurement method. Hristov et al. (2015), Dijkstra et al. (2018), Niu et al. (2018), and Kebreab et al. (2023) provide evidence but not a universal farm value.

8. Manure volatile solids and methane

8.1 Volatile solids

VS (kg head-1 day-1) = DMI x (1 - digestibility fraction) x 0.92

The 0.92 factor removes an assumed ash fraction. This simplified VS equation is used when direct VS or a complete Tier 2 urinary-energy calculation is unavailable.

8.2 Manure methane

Manure CH4 = head x VS x 365 x B0 x 0.67 x [managed fraction x MCFsystem,climate + grazing fraction x 0.0047]

Species	B0, m3 CH4/kg VS
Dairy cattle	0.24
Dairy goats	0.18
Dairy sheep	0.19

System	Cool MCF	Temperate	Warm
Uncovered lagoon	60%	67%	76%
Slurry, 6 months	21%	26%	41%
Solid storage	2%	4%	5%
Dry lot	1%	1.5%	2%
Daily spread	0.1%	0.5%	1%
Deep bedding	2.75%	6.5%	18%
Windrow compost	0.5%	1%	1.5%
Digester pre-capture potential	21%	26%	41%

Sources: IPCC 2019 Tables 10.16A and 10.17. The digester calculation starts with pre-capture slurry potential and then applies capture x destruction efficiency. This avoids granting both a low default MCF and a full capture credit.

9. Manure nitrogen, storage N2O, and the linked N ledger

9.1 Nitrogen excretion

N intake = DMI x crude-protein fraction / 6.25 N excreted = head x N intake x (1 - N-retention fraction) x 365

9.2 Storage direct and indirect N2O

Direct storage N2O = managed excreted N x EF3 x 44/28 Indirect storage N2O = managed excreted N x [(FracGas x 0.01) + (FracLeach x 0.011)] x 44/28

System	EF3	FracGas	FracLeach
Lagoon	0	0.40	0
Slurry	0	0.48	0
Solid	0.010	0.22	0
Dry lot	0.020	0.30	0.035
Daily spread	0	0.07	0
Deep bedding	0.010	0.30	0.02
Compost	0.005	0.30	0.02
Digester	0.0006	0.10	0

9.3 Available N after storage

Available stored N = managed excreted N x (1 - FracGas - FracLeach - EF3) Exported N = available N x export fraction Retained N = available N - exported N

This is a simplified conservation ledger. It treats EF3 as N2O-N loss and does not separately model organic-N mineralization, ammonia capture, solids separation, bedding additions, crust N, denitrification to N2, or multi-stage manure processing. Use measured manure analyses for nutrient-management decisions.

9.4 Grazing deposition

Grazing N2O = pasture-deposited N x [0.004 + 0.20 x 0.01 + wet-climate leaching fraction x 0.011] x 44/28

Grazing-deposition N2O is shown as a linked land source. It is not also counted in manure storage.

10. Climate and reporting-year weather

The web application accepts county/nearest-city or latitude/longitude and reporting year. It retrieves daily mean temperature, precipitation, and FAO reference evapotranspiration from the Open-Meteo historical archive. Users may enter validated climate summaries manually if the service is unavailable.

Thermal label	Annual mean temperature
Cold	<5 C
Cool	5 to <10 C
Temperate	10 to <18 C
Warm	18 to <24 C
Hot	>=24 C

Moisture index = annual precipitation / annual reference ET Humid/wet if moisture index > 1; otherwise dry

The thermal bin selects the cool, temperate, or warm manure MCF column. The wet/dry class resolves managed-soil N_2O and leaching factors. This transparent classification is a screening approximation, not a full IPCC ecological-zone map or monthly manure-temperature model.

Recommended verification upgrade

Use local station or accepted gridded data, monthly manure temperature and storage loading, site-specific soil and hydrology, and a validated Tier 2/3 crop model. Review unusual reporting years against a multi-year normal.

11. Shared energy, refrigerants, and feed

11.1 Shared energy

Energy CO_2e = diesel gal x 10.21 + gasoline gal x 8.78 + propane gal x 5.75 + electricity kWh x selected kg CO_2e/kWh

Fuel factors are U.S. EPA screening values. Electricity is editable because eGRID subregions, suppliers, and market-based reporting differ. Enter total farm activity once.

11.2 Refrigerants

Refrigerant CO_2e = leaked refrigerant kg x refrigerant GWP100

Use equipment service records and the correct refrigerant-specific GWP required by the reporting program.

11.3 Purchased and farm-grown feed

Purchased feed is optional and entered as an externally calculated annual t CO_2e total. The model does not invent a feed factor. Farm-grown feed quantity is reported from field yield x farm-feed fraction but receives no additional emissions because those fields are already in the inventory.

A complete feed life-cycle assessment would require ingredient masses, origins, fertilizer and manure attribution, land-use change, processing, transport, co-product allocation, storage loss, and uncertainty. The optional input should be supported by a supplier-specific environmental product declaration or a documented LCA.

12. Mitigation scenarios

The same farm can be evaluated before and after selected controls. Avoided emissions equal baseline minus scenario emissions for the affected pathways. The model does not predict crop yield, milk response, cost, adoption, or rebound effects.

Control	Calculation	Guardrail
Synthetic N reduction	Scale field synthetic N; recalculate direct and indirect N2O	No yield or nutrient-balance prediction
Enteric reduction	Scale baseline enteric CH4	Use product/diet/species evidence
Energy reduction	Scale shared fuel and electricity CO2e	Enter operationally achievable value
Anaerobic digester	Pre-capture manure CH4 x capture x destruction	No automatic displaced-energy credit
Lagoon cover	Scale lagoon MCF by verified reduction	No universal default credit
Manure export	Remove exported retained N from farm field application	Storage emissions remain on farm

Interaction warning: scenario effects are not necessarily additive in reality. A change in diet can alter DMI, digestibility, milk, N excretion, manure VS, crop-feed demand, and land use. The current controls change only their explicitly stated pathways.

13. Outputs, audit trail, and implementation parity

13.1 Outputs

• Annual whole-farm kg and t CO_2e by source and subsystem.

• Physical CH_4 and N_2O quantities inside the calculation audit.

• Total acres, head, milk, harvested crop yield, and farm-grown feed quantity.

• Descriptive whole-farm intensities per acre, per head, and per kg milk.

• Avoided emissions under selected scenarios.

13.2 CSV audit

The browser export includes model version, climate class, manure-N balance, field inputs and allocated manure N, animal-group activity, resolved factors, category results, units, and source notes. Store the CSV with source records and the methodology version.

13.3 Web and Python parity

The TypeScript web engine and downloadable Python module use the same crop tables, manure-system factors, gas conversion constants, equations, and anti-double-counting logic. Automated Python tests verify positive totals, manure-N conservation, purchased-feed addition, farm-grown-feed non-addition, and scenario direction.

13.4 Interpretation

Per-acre and per-head ratios divide the complete farm total by acres or head. Per-milk ratio divides the complete farm total by uncorrected milk mass. These are whole-farm indicators, not allocated crop or dairy product footprints.

14. Uncertainty, sensitivity, and validation

Accuracy cannot be summarized by one percentage. Mathematical code can reproduce an equation exactly while emissions remain uncertain because activity data, factor representativeness, weather, management, and boundary choices are uncertain.

Component	Main uncertainty	Priority improvement
Soil N_2O	Episodic, nonlinear, spatially variable	Site-specific Tier 2/3 model or measurements
Residue N	Biomass and N fractions vary	Measured residues and lab N
Enteric CH_4	DMI and Ym	Measured DMI, ration data, validated model
Manure CH_4	MCF, storage time, temperature	Monthly system and retention-time data
Manure N	CP, retention, storage losses	Whole-farm nutrient balance and manure analysis
Feed linkage	Purchased-feed footprint boundary	Supplier-specific documented LCA
Shared energy	Meter/fuel allocation and factor	Invoices, meters, eGRID/supplier factor
Mitigation	Real-world persistence and interactions	Farm-specific measured evidence

14.1 Recommended sensitivity analysis

• Vary crop EF1, manure MCF, Ym, DMI, digestibility, CP, N retention, FracGas, and electricity factors over documented ranges.

• Test manure allocation and export records against annual nutrient imports, exports, and inventory change.

• Recalculate with and without optional purchased feed and other sources to show boundary sensitivity.

• Compare reporting-year weather with a 10-year normal and investigate incomplete or anomalous data.

14.2 Validation sequence

First check units and arithmetic with hand calculations. Second compare representative fields and herds with IPCC worksheets. Third compare whole-farm totals with USDA COMET-Farm or another recognized model using matched boundaries. Fourth reconcile farm N and feed mass balances. Fifth seek independent review before external claims.

15. Data collection protocol and limitations

15.1 Minimum annual records

Area	Records
Fields	Field areas, crop, yield, residue handling, fertilizer/manure N, lime/urea, irrigation, rice water
Animals	Monthly head, DMI/rations, milk shipped, class/breed, digestibility, CP, body weight
Manure	System fractions, storage duration, grazing, manure analyses, exports/imports, digester/cover data
Energy	Fuel invoices, meters, electricity factor, refrigerant service logs
Climate	Coordinates, reporting year, station or accepted gridded annual summaries
Boundary	Purchased-feed method, other sources, exclusions, scenario evidence

15.2 Important limitations

- The model does not perform soil-carbon stock-change accounting or simulate crop/milk response.
- One primary managed manure system plus grazing is used; serial systems are simplified.
- Available manure N is a screening mass balance, not a nutrient-management recommendation.
- Farm-grown feed is linked by quantity, not nutritional composition or land allocation.
- No co-product allocation, land-use change, capital-goods, or downstream processing is included.
- Breed defaults initialize inputs; they are not genetic emission coefficients.
- Weather retrieval is a point estimate, not a county-area average or station measurement.

For regulatory, carbon-market, lender, or public product claims, use the required protocol, verifier, boundary, GWPs, uncertainty treatment, and evidence. MixedFarmCarbon can organize inputs and identify hotspots but does not replace those requirements.

16. Parameter register

Parameter	Value / rule	Primary basis
CH4 GWP100	27.2, biogenic	IPCC AR6
N2O GWP100	273	IPCC AR6
GE density	18.45 MJ/kg DM	IPCC Ch. 10
CH4 energy	55.65 MJ/kg CH4	IPCC Ch. 10
CH4 density	0.67 kg/m3	IPCC Ch. 10
B0 cattle/goat/sheep	0.24 / 0.18 / 0.19	IPCC Table 10.16A
Ym cattle	5.7%, 6.3%, 6.5%	IPCC Tables 10.12-10.13
Ym goat/sheep	5.5% / 6.7%	IPCC Table 10.13
Crop residue coefficients	Crop-specific table	IPCC Table 11.1a
Wet/dry field EF1	0.016/0.006; 0.005	IPCC Table 11.1
EF4 / EF5	0.014 or 0.005 / 0.011	IPCC Table 11.3
Manure FracGASM	0.21	IPCC Table 11.3
Fuel factors	10.21, 8.78, 5.75 kg CO2/gal	U.S. EPA factors
N inhibitor sensitivity	0.62 multiplier	Akiyama et al. 2010
Controlled release sensitivity	0.65 multiplier	Akiyama et al. 2010

The complete crop and manure-system tables are embedded in both software engines and exported where relevant. Factor updates require a new model version and methodology revision.

17. References

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Document status: MixedFarmCarbon v1.0. Review and update the factor register when IPCC, EPA, USDA, GHG Protocol, or the cited peer-reviewed evidence changes.