Package 'gleam'

May 8, 2026

Type Package

Title Global Livestock Environmental Assessment Model (GLEAM-X)

Version 0.8.0

Description The official implementation of the Global Livestock Environmental Assessment Model (GLEAM) of the Food and Agriculture Organization of the United Nations (FAO) in R. GLEAM-X provides a modular, transparent framework for simulating livestock production systems and quantifying their environmental impacts.
Methodological background: MacLeod et al. (2017) ``Invited review: A position on the Global Livestock Environmental Assess-
ment Model (GLEAM)" <doi:10.1017/S1751731117001847>. Further
information: <https://www.fao.org/gleam/en/>.

License AGPL-3

URL https://github.com/un-fao/GLEAM/, https://www.fao.org/gleam/en/

BugReports https://github.com/un-fao/GLEAM/issues

Encoding UTF-8

RoxygenNote 7.3.3

Imports cli (>= 3.0.0), data.table (>= 1.16.0)

Suggests knitr, rmarkdown, testthat (>= 3.2.0)

VignetteBuilder knitr

Config/testthat/edition 3

Depends R (>= 4.4.0)

NeedsCompilation no

Author Ahmed Jou [aut, cre] (ORCID: <https://orcid.org/0009-0002-2309-4583>,
https://applitics.fr),
Yassine Elaouni [aut] (https://applitics.fr),
Dominik Wisser [aut] (ORCID: <https://orcid.org/0000-0001-8368-3801>,
GLEAM team lead, FAO),
Lydia Lanzoni [aut] (ORCID: <https://orcid.org/0000-0002-4488-4368>,
Livestock and climate change specialist, FAO),
Giuseppe Tempio [aut] (ORCID: <https://orcid.org/0009-0004-2272-0794>,
Livestock environmental impact analyst, FAO),

Phyllis Ndungu' [ctb] (Livestock and climate change specialist, FAO),
Yushan Li [ctb] (Livestock and sustainability specialist, FAO),
Manling Xu [ctb] (Livestock data intern, FAO),
Zixin Wang [ctb] (Livestock data intern, FAO),
Narindra Rakotovao [ctb] (Livestock policy officer, FAO),
Stewart Chikoloma [ctb] (Livestock data specialist, FAO),
David OBrien [ctb] (ORCID: <https://orcid.org/0009-0007-0339-0517>,
https://applitics.fr),
Food and Agriculture Organization of the United Nations FAO [cph]
(Original GLEAM model framework),
Federal Ministry of Agriculture, Food and Regional Identity of Germany
BMELH [fnd] (Funding support)

Maintainer Ahmed Jou <ahmed@applitics.fr>

Repository CRAN

Date/Publication 2026-04-16 18:30:08 UTC

Contents

`assign_allocation_shares` *Assign allocation shares to emission variables by commodity*

Description

Expands commodity-level allocation shares across emission sources and applies predefined allocation rules for excluded emission sources.

Usage

```
assign_allocation_shares(
  allocation_herd_long,
  emissions_vars,
  commodities,
  non_allocated_emission_sources,
  commodity_col,
  allocation_col
)
```

Arguments

`allocation_herd_long`	Long-format `data.table` containing herd-level emissions and allocation information. Each row represents an emission source–commodity combination or an unallocated emission source prior to allocation.
`emissions_vars`	Character. Names of emission variables to which allocation should be applied (e.g., "ch4_enteric","ch4_manure_pasture","ch4_manure_burned","ch4_manure_other", "n2o_manure_pasture_direct","n2o_manure_burned_direct","n2o_manure_other_direct", "n2o_manure_burned_indirect","n2o_manure_pasture_indirect","n2o_manure_other_indirect", "co2_ration_fertilizer", "co2_ration_pesticides", "co2_ration_crop_activities", "co2_ration_luc_nopeat", "co2_ration_luc_peat", "n2o_ration_fertilizer", "n2o_ration_manure_applied", "n2o_ration_crop_residues", "ch4_ration_rice").
`commodities`	Character. List of commodity categories to which emissions may be allocated. For example: c("None","Milk","Meat","Fibre","Work","Eggs").
`non_allocated_emission_sources`	Character. Emission variables that should not be allocated across commodities, even if they appear in emissions_vars (e.g., "ch4_manure_pasture", "ch4_manure_burned").
`commodity_col`	Character. Name of the column in `allocation_herd_long` identifying the commodity category.
`allocation_col`	Character. Name of the column in `allocation_herd_long` containing the allocation share to be applied.

Details

The function assigns commodity allocation shares to emission sources while also allowing for the implementation of specific allocation rules. Emission sources listed in `non_allocated_emission_sources` (e.g., emissions from manure burned as fuel or manure deposited on pasture) are treated as not attributable to livestock commodities under the chosen goal and scope. Consequently, these emissions are allocated entirely to the residual commodity category `"None"` and are not distributed across milk, meat, fibre, work, or egg outputs.

The following methodological rules apply to emission sources listed in `non_allocated_emission_sources`:

- **Manure burned for fuel** — Emissions are considered outside the life cycle assessment system boundaries under the defined goal and scope and are therefore not attributed to livestock commodities. A cut-off approach is applied, consistent with the IDF (2022) standard and LEAP guidelines (LEAP 2016a, 2016b, 2016c).
- **Manure deposited on pastures** — Emissions are not allocated to livestock commodities in order to avoid double counting. When upstream feed production is included in the inventory, emission factors of feed items already account for this source.

This function is part of the `run_allocation_module()`.

Value

A `data.table` equal to `allocation_herd_long` expanded over all `emissions_vars`, with enforced allocation rules:

Non-allocated emission sources `allocation_col` = `1` when `commodity_col == "None"`, else `0`.

Allocated emission sources `allocation_col` = `0` when `commodity_col == "None"` (others unchanged).

References

IDF. (2022). *The IDF Global Carbon Footprint Standard for the Dairy Sector*. Bulletin of the IDF No. 520/2022. International Dairy Federation, Brussels.

FAO. (2016a). *Environmental performance of large ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016b). *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016c). *Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

See Also

`run_allocation_module()`

`calc_allocated_emissions` *Calculate allocated greenhouse gas emissions (GHG)*

Description

Calculates the greenhouse gas emissions (GHG) attributable to specific commodities by applying allocation shares to total herd-level emissions.

Usage

```
calc_allocated_emissions(value, allocation_share)
```

Arguments

`value`	Numeric. Total herd-level emissions by source before allocation to commodities (kg gas).
`allocation_share`	Numeric. Allocation share assigned to the commodity for the corresponding emission source (fraction).

Details

Allocation shares represent the fraction of total emissions assigned to each commodity (e.g., meat, milk, fibre). See `run_allocation_module()` for additional details.

Allocated emissions are calculated as:

$$value\_allocated = value \times allocation\_share$$

This function is part of the `run_aggregation_module()`.

Value

Numeric. Allocated emissions for each commodity–emission combination (kg gas).

See Also

`run_aggregation_module()`, `run_allocation_module()`

`calc_allocation_shares` *Calculate allocation shares for livestock commodities*

Description

Calculates biophysical allocation shares for commodities (meat, milk, fibre, work, eggs) based on their total energy requirements.

Usage

```
calc_allocation_shares(
  species_short,
  meat_allocation_energy,
  milk_allocation_energy,
  fibre_allocation_energy,
  work_allocation_energy,
  egg_allocation_energy
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`meat_allocation_energy`
: Numeric. Energy required by a given sex–age cohort for total meat output by cohort during the assessment period, equal to the energy needed to produce all live-weight gain to reach the target slaughter weight (MJ/cohort/assessment period).

`milk_allocation_energy`
: Numeric. Energy required to produce total milk output by cohort (MJ/cohort/assessment period). Non-zero values are applicable only to milk-producing species and cohorts (species=CTL, BFL, CML, SHP, GTS; cohorts=FA). All other species–cohort combinations are assigned a value of 0.

`fibre_allocation_energy`
: Numeric. Energy required to produce all fibre output by cohort (MJ/cohort/assessment period).

`work_allocation_energy`
: Numeric vector. Energy required to provide all draught power (traction/work) by cohort (MJ/cohort/assessment period).

`egg_allocation_energy`
: Numeric vector. Energy required to produce all eggs during the assessment period (MJ/cohort/assessment period).

Details

These fractions represent the proportions of total environmental burdens (e.g., GHG emissions) that will be allocated to each commodity in subsequent steps of the assessment.

This function is part of the `run_allocation_module()` of the Global Livestock Environmental Assessment Model (GLEAM), which incorporates a biophysical allocation approach, aligned with the IDF Global Carbon Footprint Standard for the Dairy Sector (IDF, 2022), and adapted from Thoma and Nemecek (2020), and is consistent with FAO LEAP livestock LCA guidelines (FAO, 2016a, 2016b, 2016c). This approach also aligns with ISO 14044:2006 (Section 4.3.4.2, Step 2) by using underlying physical (energy-based) relationships to assign shared inputs and outputs in multifunctional livestock production systems.

In accordance with ISO 14044:2006 (Section 4.3.4.2, Step 2), known processing or biophysical relationships may be used to assign shared inputs and outputs of a single production unit to individual products or sub-units. In livestock systems, this includes apportioning shared feed and energy use according to physiological energy requirements (e.g., net energy for lactation, growth..etc.). If the resulting process remains multifunctional, these energy terms may subsequently be used to derive allocation factors among co-products.

This function calculates biophysical allocation fractions for commodities (meat, milk, fibre, work, eggs) for all species. The allocation is based on commodity-specific energy requirements calculated using `calc_meat_allocation_energy`, `calc_milk_allocation_energy`, `calc_fibre_allocation_energy`, `calc_work_allocation_energy`, and `calc_eggs_allocation_energy`.

Pig species (`PGS`): allocation is not based on energy partitioning because pig production is treated as functionally single-output (edible meat). Consequently, 100% of the allocation is assigned to the meat commodity (meat share = 1; all other commodity shares = 0), independent of the energy inputs.

This function is part of the `run_allocation_module()`.

Value

A named list of numeric vectors with same length as input, containing:

meat_share_allocation Numeric. Allocation share assigned to meat (fraction).

milk_share_allocation Numeric. Allocation share assigned to milk (fraction).

fibre_share_allocation Numeric. Allocation share assigned to fibre (fraction).

work_share_allocation Numeric. Allocation share assigned to work (fraction).

eggs_share_allocation Numeric. Allocation share assigned to eggs (fraction).

References

ISO. (2006). *Environmental management — Life cycle assessment — Requirements and guidelines (ISO 14044:2006)*. International Organization for Standardization, Geneva.

IDF. (2022). *The IDF Global Carbon Footprint Standard for the Dairy Sector*. Bulletin of the IDF No. 520/2022. International Dairy Federation, Brussels.

Thoma, G., and Nemecek, T. (2020). Allocation between milk and meat in dairy LCA: Critical discussion of the IDF's standard methodology. In *Proceedings of the 12th International Conference on Life Cycle Assessment of Food (LCAFood 2020)* (pp. 83–89), 13–16 October, Berlin, Germany.

FAO. (2016a). *Environmental performance of large ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016b). *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016c). *Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

See Also

`run_allocation_module`, `calc_meat_allocation_energy`, `calc_milk_allocation_energy`, `calc_fibre_allocation_energy`, `calc_work_allocation_energy`, `calc_eggs_allocation_energy`

`calc_avg_weights` *Calculate average and final live weights by cohort*

Description

Calculates the average and final live weight for a given sex–age cohort based on initial weight, potential final weight, slaughter weight, and the offtake rate.

Usage

```
calc_avg_weights(
  live_weight_cohort_initial,
  live_weight_cohort_potential_final,
  live_weight_cohort_at_slaughter,
  offtake_rate
)
```

Arguments

`live_weight_cohort_initial`	Numeric. Live weight at the beginning of the cohort stage (kg).
`live_weight_cohort_potential_final`	Numeric. Potential final live weight attainable at the end of the cohort stage in the absence of offtake (kg). (For juveniles: equals weaning weight; For subadults: equals adult live weight; For adults: equals adult live weight)
`live_weight_cohort_at_slaughter`	Numeric. Live weight at slaughter for animals removed from the cohort (kg).
`offtake_rate`	Numeric. Annual proportion of animals removed from the herd for each sex-age cohort (fraction).

Details

The calculation of `live_weight_cohort_average` and `live_weight_cohort_final` is performed considering that a fraction of animals is removed (offtake) during the cohort stage, while the remaining animals reach the potential final live weight.

The final live weight is computed as:

$$live\_weight\_cohort_final = (1 - offtake\_rate) \times live\_weight\_cohort\_potential\_final + offtake\_rate \times live\_weight\_$$

The average live weight over the stage is approximated as:

$$live\_weight\_cohort\_average = (live\_weight\_cohort\_initial + live\_weight\_cohort\_final)/2$$

This function is part of the `run_weights_module()`.

Value

A named list with:

live_weight_cohort_average Numeric. Average live weight over the cohort stage. Computed by accounting for the share of offtaken animals within the cohort, using their slaughter weight, and the potential final weight of animals that remain in the cohort (kg).

live_weight_cohort_final Numeric. Live weight at the end of the cohort stage, accounting for both surviving and offtaken animals. Computed as a weighted average of the potential final weight of surviving animals and the slaughter weight of offtaken animals, based on the offtake rate (kg).

See Also

`run_weights_module`

`calc_ch4_enteric` *Calculate daily enteric methane emissions*

Description

Calculates daily enteric methane emissions (kg CH4/head/day) based on gross energy intake, methane conversion factor (ym), and dry matter intake.

Usage

```
calc_ch4_enteric(
  species_short,
  ch4_conversion_factor_ym,
  ch4_mitigation_factor,
  ration_gross_energy,
  ration_intake
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`ch4_conversion_factor_ym`
Numeric. Methane (CH4) conversion factor (ym), representing the percentage of gross energy of the feed ration that is converted to CH4 (percentage).

`ch4_mitigation_factor`
Numeric. Optional. Multiplicative mitigation factor applied to baseline enteric methane (CH4) emissions (dimensionless). If not provided, a default value of 1 (no mitigation) is used. Values lower than 1 represent proportional reductions (e.g., `0.90` = 10% reduction). This factor can represent mitigation measures with a direct effect on enteric methane emissions, such as the use of feed additives or methane inhibitors.

`ration_gross_energy`
Numeric. Average gross energy content of the diet (MJ/kg DM).

`ration_intake` Numeric. Average daily dry matter intake of feed (kg DM/head/day).

Details

The formula used to estimate daily enteric methane emissions is:

$$CH_4 = \frac{ration\_gross\_energy \times ration\_intake \times ch4\_conversion\_factor\_ym}{55.65 \times 100}$$

where 55.65 MJ/kg is the energy content of methane.

`ration_gross_energy` and `ration_intake` can be calculated with `calc_ration_gross_energy` and `calc_ration_intake` (see also `run_ration_quality_module` and `run_metabolic_energy_req_module`).

This function is part of the `run_emissions_enteric_module()`.

Value

Numeric. Average daily enteric methane (CH4) emissions (kg CH4/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.21.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.21.

See Also

run_emissions_enteric_module, calc_ration_gross_energy, calc_ration_intake, run_ration_quality_module
run_metabolic_energy_req_module

`calc_ch4_manure` *Calculate methane (CH4) emissions from manure management systems*

Description

Calculates daily methane emissions from manure management using IPCC-based parameters and separates emissions from manure deposited on pasture, manure burned for fuel, and all other manure management systems.

Usage

```
calc_ch4_manure(ratio_m3CH4_to_kgCH4 = 0.67, volatile_solids, ...)
```

Arguments

`ratio_m3CH4_to_kgCH4`
: Numeric. Conversion factor used to convert methane (CH4) from volumetric unit (m3) to a mass unit (kg). This value represents the density of methane. It defaults to 0.67 kg/m3.

`volatile_solids`
: Numeric. Total volatile solids (VS) excreted per animal per day, representing the organic material in livestock manure and consisting of both biodegradable and non-biodegradable fractions (kg VS/head/day).

`...`
: A variable number of manure management system (MMS) arguments. Each MMS must be provided as a named numeric vector with exactly the following fields:

  manure_management_system_fraction Numeric. Fraction of total manure excreted by animals in a given herd and cohort that is handled in a specific manure management system. Values ranges from 0 to 1. The sum of all fractions for each herd_id must equal 1.

  methane_conversion_factor_mcf Numeric. Methane conversion factor represents the portion or degree of the maximum methane producing capacity (B_0) that is effectively achieved within a specific manure management system. It represents the extent to which the theoretical methane yield is realized based on management practices and environmental conditions, specifically the temperature of the system, the retention time of the organic material, and the degree of anaerobic conditions present. The value theoretically ranges from 0 to 100 percent. Default values can be selected from Table 10.17 of the IPCC guidelines (IPCC 2006, 2019).

ch4_max_producing_capacity_bo Numeric. Maximum methane producing capacity (B_0) for all manure management systems (m3 CH4 / kg VS). The value is region- and species-specific, and represents the theoretical maximum methane yield per unit of volatile solids.. Default values may be selected from Table 10.16 (IPCC, 2019) or from Tables 10A-4 to 10A-9 (IPCC, 2006).

Two MMS names are treated explicitly when present:

`mms_pasture` Manure deposited on pasture.

`mms_burned` Manure burned for fuel.

All remaining MMS arguments are grouped and treated as other manure management systems.

Details

This calculation follows the structure of IPCC Equation 10.23 for methane (CH4) emission factors from manure management.

In the IPCC formulation, emissions are determined by combining:

- daily volatile solids excretion (`volatile_solids`) - see `calc_volatile_solids`,
- the maximum methane-producing capacity (`b0`),
- the methane conversion factor (`mcf`) for each manure management system,
- and the fraction of manure handled in each system (`manure_management_system_fraction`).

Applying the IPCC conversion factor from m3 CH4 to kg CH4 (0.67), daily methane emissions are calculated as:

$$CH4 = volatile\_solids \times b0 \times 0.67 \times \sum \left(\frac{mcf}{100} \times manure\_management\_system\_fraction \right)$$

The summation is taken over all manure management systems included in the calculation. Results are expressed at daily resolution (kg CH4/head/day), consistent with Equation 10.23 after adapting the original annual formulation to a daily basis.

This function is part of the `run_emissions_manure_module()`.

Value

A named list with the following elements:

ch4_manure_pasture Numeric. Methane (CH4) emissions from manure deposited on pasture (kg CH4/head/day).

ch4_manure_burned Numeric. Methane (CH4) emissions from manure burned for fuel (kg CH4/head/day).

ch4_manure_other Numeric. Methane (CH4) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg CH4/head/day).

ch4_manure_all_noburn Numeric. Methane (CH4) emissions from manure management systems, excluding manure burned for fuel (kg CH4/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.23.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.23.

See Also

run_emissions_manure_module, calc_volatile_solids

run_emissions_manure_module, calc_volatile_solids

Examples

```
calc_ch4_manure(
  ratio_m3CH4_to_kgCH4 = 0.67,
  volatile_solids   = 2.024,
  mms_burned = c(
    manure_management_system_fraction = 0.020,
    methane_conversion_factor_mcf = 10,
    ch4_max_producing_capacity_bo = 0.13
  ),
  mms_drylot = c(
    manure_management_system_fraction = 0.264,
    methane_conversion_factor_mcf = 2,
    ch4_max_producing_capacity_bo = 0.13
  ),
  mms_pasture = c(
    manure_management_system_fraction = 0.310,
    methane_conversion_factor_mcf = 0.47,
    ch4_max_producing_capacity_bo = 0.19
  ),
  mms_solid = c(
    manure_management_system_fraction = 0.406,
    methane_conversion_factor_mcf = 5,
    ch4_max_producing_capacity_bo = 0.13
  )
)
```

---

calc_ch4_ration_rice *Calculate a ration component's contribution to methane (CH4) emissions from rice cultivation*

Description

Calculates the contribution of an individual feed component to methane (CH4) emissions from rice cultivation in feed production, using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_ch4_ration_rice(feed_ration_fraction, ch4_feed_rice)
```

Arguments

feed_ration_fraction	Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.
ch4_feed_rice	Numeric. Methane (CH4) emission factor of a feed component, representing CH4 emissions from rice cultivation in feed production, expressed per kg of dry matter intake (g CH4/kg DM).

Details

The contribution is computed as:

$$diet\_ch4\_feed\_rice = feed\_ration\_fraction \times ch4\_feed\_rice$$

This function is part of the run_emissions_ration_module().

Value

Numeric. Contribution of an individual feed component to the diet-level average methane (CH4) emission factor from rice cultivation in feed production (g CH4/kg DM).

See Also

run_emissions_ration_module

---

calc_co2eq *Convert methane (CH4) and nitrous oxide (N2O) emissions to CO2-equivalents (CO2eq) using Global Warming Potentials (GWP) factors*

Description

Calculates CO2-equivalent (CO2eq) emissions for CH4 and N2O based on 100-year Global Warming Potentials (GWP) reported in IPCC assessment reports.

Usage

```
calc_co2eq(gas, value_allocated, global_warming_potential_set)
```

Arguments

`gas` Character. Gas type for each observation. Supported values:

- `"CH4"`: methane (CH4)
- `"N2O"`: nitrous oxide (N2O)
- `"CO2"`: carbon dioxide (CO2)

`value_allocated` Numeric. Allocated emissions for each commodity–emission combination (kg gas).

`global_warming_potential_set` Character. Settings for the 100-year Global Warming Potential (GWP-100) conversion factors used to express CH4 and N2O emissions as CO2eq. Must be one of:

- `"AR6"`: IPCC Sixth Assessment Report (IPCC, 2021) — CH4 = 27, N2O = 273
- `"AR5_excluding_carbon_feedback"`: IPCC Fifth Assessment Report (excluding climate–carbon feedbacks) (IPCC, 2013) — CH4 = 28, N2O = 265
- `"AR5_including_carbon_feedback"`: IPCC Fifth Assessment Report (including climate–carbon feedbacks) (IPCC, 2013) — CH4 = 34, N2O = 298
- `"AR4"`: IPCC Fourth Assessment Report (IPCC, 2007) — CH4 = 25, N2O = 298

Details

CO2-equivalent emissions are calculated as:

$$value\_co2eq = value\_allocated \times gwp$$

where `gwp` is the gas-specific 100-year Global Warming Potential factor from the selected IPCC assessment report.

This function is part of the `run_aggregation_module()`.

Value

List with elements:

value_co2eq Numeric vector. Emissions expressed as CO2-equivalents (kg CO2eq).

gwp Numeric vector. Global Warming Potential factor applied to each observation (kg CO2eq/kg gas).

References

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

See Also

run_aggregation_module(),

---

calc_co2_ration_crop_activities

Calculate a ration component's contribution to carbon dioxide (CO2) emissions from on-field agricultural activities

---

Description

Calculates the contribution of an individual feed component to carbon dioxide (CO2) emissions from on-field agricultural activities in feed production (e.g., energy use for tillage and machinery operations), using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_co2_ration_crop_activities(feed_ration_fraction, co2_feed_crop_activities)
```

Arguments

feed_ration_fraction
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

co2_feed_crop_activities
: Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from on-field agricultural activities in feed production, expressed per kilogram of dry matter intake (kg CO2/kg DM).

Details

The contribution is computed as:

$$diet\_co2\_feed\_crop\_operations = feed\_ration\_fraction \times co2\_feed\_crop\_operations$$

This function is part of the run_emissions_ration_module().

Value

Numeric. Contribution of an individual feed component to the diet-level average carbon dioxide (CO2) emission factor from on-field agricultural activities in feed production (g CO2/kg DM).

See Also

run_emissions_ration_module

`calc_co2_ration_fertilizer` *Calculate a ration component's contribution to carbon dioxide (CO2) emissions from fertilizer manufacture*

Description

Calculates the contribution of an individual feed component to carbon dioxide (CO2) emissions from fertilizer manufacture in feed production, using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_co2_ration_fertilizer(feed_ration_fraction, co2_feed_fertilizer)
```

Arguments

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration,as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`co2_feed_fertilizer`
: Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from fertilizer manufacture in feed production, expressed per kilogram of dry matter intake (g CO2/kg DM).

Details

The contribution is computed as:

$$diet\_co2\_feed\_fertilizer = feed\_ration\_fraction \times co2\_feed\_fertilizer$$

This function is part of the `run_emissions_ration_module()`.

Value

Numeric. Contribution of an individual feed component to the diet-level average carbon dioxide (CO2) emission factor from fertilizer manufacture in feed production (g CO2/kg DM).

See Also

`run_emissions_ration_module`

`calc_co2_ration_luc_nopeat` *Calculate a ration component's contribution to carbon dioxide (CO2) emissions from land-use change (excluding peatland drainage)*

Description

Calculates the contribution of an individual feed component to carbon dioxide (CO2) emissions from land-use change in feed production (excluding peatland drainage), using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_co2_ration_luc_nopeat(feed_ration_fraction, co2_feed_luc_nopeat)
```

Arguments

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`co2_feed_luc_nopeat`
: Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from land-use change in feed production (excluding peatland drainage), expressed per kilogram of dry matter intake (g CO2/kg DM).

Details

The contribution is computed as:

$$diet\_co2\_feed\_luc\_nopeat = feed\_ration\_fraction \times co2\_feed\_luc\_nopeat$$

This function is part of the `run_emissions_ration_module()`.

Value

Numeric. Contribution of an individual feed component to the diet-level average carbon dioxide (CO2) emission factor from land-use change (excluding peatland drainage) in feed production (g CO2/kg DM).

See Also

`run_emissions_ration_module`

`calc_co2_ration_luc_peat` *Calculate a ration component's contribution to carbon dioxide (CO2) emissions from peatland drainage*

Description

Calculates the contribution of an individual feed component to carbon dioxide (CO2) emissions from peatland drainage in feed production, using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_co2_ration_luc_peat(feed_ration_fraction, co2_feed_luc_peat)
```

Arguments

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`co2_feed_luc_peat`
: Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from peatland drainage in feed production, expressed per kilogram of dry matter intake (g CO2/kg DM).

Details

The contribution is computed as:

$$diet\_co2\_feed\_luc\_peat = feed\_ration\_fraction \times co2\_feed\_luc\_peat$$

This function is part of the `run_emissions_ration_module()`.

Value

Numeric. Contribution of an individual feed component to the diet-level average carbon dioxide (CO2) emission factor from peatland drainage in feed production (g CO2/kg DM).

See Also

`run_emissions_ration_module`

`calc_co2_ration_pesticides` *Calculate a ration component's contribution to carbon dioxide (CO2) emissions from pesticide manufacture*

Description

Calculates the contribution of an individual feed component to carbon dioxide (CO2) emissions from pesticide manufacture in feed production, using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_co2_ration_pesticides(feed_ration_fraction, co2_feed_pesticides)
```

Arguments

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`co2_feed_pesticides`
: Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from pesticide manufacture in feed production, expressed per kilogram of dry matter intake (g CO2/kg DM).

Details

The contribution is computed as:

$$diet\_co2\_feed\_pesticides = feed\_ration\_fraction \times co2\_feed\_pesticides$$

Value

Numeric. Contribution of an individual feed component to the diet-level average carbon dioxide (CO2) emission factor from pesticide manufacture in feed production (g CO2/kg DM).

`calc_cohort_totals` *Calculate totals by cohort*

Description

Calculates the total value for each variable at the cohort level over the full assessment period. Values are harmonized to a common unit (`kg/cohort/assessment duration`) by accounting for cohort stock size and simulation duration.

Usage

```
calc_cohort_totals(
  value,
  cohort_stock_size,
  ration_intake,
  feed_emissions_list,
  simulation_duration,
  variable_name,
  variable_type
)
```

Arguments

`value`	Numeric. Variable value expressed as (unit)/head/day for non-production variables and (unit)/cohort/assessment duration for production variables. Production variables can be explored from the list 'gleam_production_meta'.
`cohort_stock_size`	Numeric. Average population size in each of the 6 sex–age cohorts (# heads). (cohorts=FJ, FS, FA, MJ, MS, MA).
`ration_intake`	Numeric. Average daily dry matter intake of feed (kg DM/head/day).
`feed_emissions_list`	List of emission-source definitions for feed-related emissions. Each element is a list with two character fields: **emissions_source** List of variables = "co2_ration_fertilizer", "co2_ration_pesticides", "co2_ration_crop_activities", "co2_ration_luc_nopeat", "co2_ration_luc_peat", "n2o_ration_fertilizer", "n2o_ration_manure_applied", "n2o_ration_crop_residues", "ch4_ration_rice" **label** Human-readable output label.
`simulation_duration`	Numeric. Length of the assessment period (days).
`variable_name`	Character. Names of emission variables to which allocation should be applied (e.g., "ch4_enteric", "ch4_manure_pasture", "ch4_manure_burned", "ch4_manure_other", "n2o_manure_pasture_direct", "n2o_manure_burned_direct", "n2o_manure_other_direct", "n2o_manure_burned_indirect", "n2o_manure_pasture_indirect", "n2o_manure_other_indirect", "co2_ration_fertilizer", "co2_ration_pesticides", "co2_ration_crop_activities", "co2_ration_luc_nopeat",

"co2_ration_luc_peat", "n2o_ration_fertilizer", "n2o_ration_manure_applied", "n2o_ration_crop_residues", "ch4_ration_rice")

`variable_type` Character. Variable group classification. Supported values include:

- `"Production"`: variables already expressed at the cohort level for the full assessment duration
- `"Emissions"`: variables expressed per head per day
- `"Feed"`: variables expressed per head per day
- `"NitrogenBalance"`: variables expressed per head per day

Details

Production variables are already expressed at the cohort level for the entire assessment duration and are therefore returned unchanged. All other variables (emissions, feed, and nitrogen balance) are expressed per head per day and are scaled by cohort stock size and simulation duration to obtain cohort-level totals.

For production variables:

$$value\_total = value$$

For emissions (except emissions from feed), feed, and nitrogen balance variables:

$$value\_total = value \times cohort\_stock\_size \times simulation\_duration$$

For feed emissions variables:

$$value\_total = value \times ration\_intake \times cohort\_stock\_size \times simulation\_duration/1000$$

This function is part of the `run_aggregation_module()`.

Value

Numeric. Variable value expressed as (unit)/cohort/assessment duration for all variables.

See Also

`run_aggregation_module()`

`calc_cohort_to_herd_aggregation`

Aggregate cohort-level to herd-level data

Description

This function aggregates a dataset from cohort level to herd level by summing specified variables over the defined 'id' columns.

Usage

```
calc_cohort_to_herd_aggregation(
  data_cohort,
  id_cols,
  vars_to_sum,
  cohort_short
)
```

Arguments

`data_cohort`	Cohort-level dataset containing energy allocation variables and herd identifiers. Each row corresponds to a single sex–age cohort within a herd.
`id_cols`	Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.
`vars_to_sum`	Character vector. Names of numeric cohort-level variables to be summed across cohorts to produce herd-level totals (e.g., meat_allocation_energy, milk_allocation_energy, fibre_allocation_energy, work_allocation_energy, egg_allocation_energy)
`cohort_short`	Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include: • `FA`: adult females (from age at first parturition) • `FS`: sub-adult females (from weaning to age at first parturition) • `FJ`: juvenile females (from birth to weaning) • `MA`: adult males (from age at first breeding) • `MS`: sub-adult males (from weaning to age at first breeding) • `MJ`: juvenile males (from birth to weaning)

Value

A `data.table` at herd scale, in which selected cohort-level variables have been summed across all cohorts belonging to the same herd, as defined by id_herd.

This function is part of the `run_allocation_module()` and `run_aggregation_module()`.

See Also

`run_allocation_module()`, `run_aggregation_module()`

---

calc_cohort_weights *Calculate live weights by cohort and life stage*

Description

Determines the initial, potential final, and slaughter live weights for a given sex–age cohort based on species-specific biological parameters. The function assigns weights according to the animal's life stage (juvenile, subadult, adult) and the sex of the cohort.

Usage

```
calc_cohort_weights(
  cohort_short,
  live_weight_female_adult = NA_real_,
  live_weight_male_adult = NA_real_,
  live_weight_at_birth = NA_real_,
  live_weight_female_at_slaughter = NA_real_,
  live_weight_male_at_slaughter = NA_real_,
  live_weight_at_weaning = NA_real_
)
```

Arguments

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`live_weight_female_adult`
Numeric. Live weight of adult females (kg)

`live_weight_male_adult`
Numeric. Live weight of adult males (kg)

`live_weight_at_birth`
Numeric. Live weight of the animal at birth (kg).

`live_weight_female_at_slaughter`
Numeric. Slaughter weight of female sub-adult animals (kg).

`live_weight_male_at_slaughter`
Numeric. Slaughter weight of male sub-adult animals (kg).

`live_weight_at_weaning`
Numeric. Live weight of the animal at weaning (kg)

Details

The function attributes weights according to cohort and animal type:

- **Juveniles** (`"FJ"`, `"MJ"`):
  - `live_weight_cohort_initial` = `live_weight_at_birth`
  - `live_weight_cohort_potential_final` = `live_weight_at_weaning`
  - `live_weight_cohort_at_slaughter` = `live_weight_at_weaning`
- **Subadults** (`"FS"`, `"MS"`):
  - `live_weight_cohort_initial` = `live_weight_at_weaning`

  - `live_weight_cohort_potential_final` = adult weight for the cohort sex (`live_weight_female_adult` for `"FS"`, `live_weight_male_adult` for `"MS"`)
  - `live_weight_cohort_at_slaughter` = subadult slaughter weight for the cohort sex (`live_weight_female_at_slaughter` for `"FS"`, `live_weight_male_at_slaughter` for `"MS"`)
- **Adults** (`"FA"`, `"MA"`):
  - `live_weight_cohort_initial` = `live_weight_female_adult` for `"FA"`, and `live_weight_cohort_initial` = `live_weight_male_adult` for `"MA"`
  - `live_weight_cohort_potential_final` = adult weight for the cohort sex
  - `live_weight_cohort_at_slaughter` = adult weight for the cohort sex

This function is part of the `run_weights_module()`.

Value

A named list with:

live_weight_cohort_initial Numeric. Live weight at the beginning of the cohort stage (kg).

live_weight_cohort_potential_final Numeric. Potential final live weight attainable at the end of the cohort stage in the absence of offtake (kg). (For juveniles: equals weaning weight; For subadults: equals adult live weight; For adults: equals adult live weight)

live_weight_cohort_at_slaughter Numeric. Live weight at slaughter for animals removed from the cohort (kg).

live_weight_mature_stage Numeric. Mature (adult) live weight that the animal can attain under given biological and management conditions (kg).

See Also

`run_weights_module`

---

calc_conversion_factor_ym

Calculate methane conversion factor (ym)

Description

Calculates the methane conversion factor (ym, % of dietary gross energy in feed converted to methane) for a given species and cohort based on diet digestibility. Implements species- and cohort-specific rules consistent with IPCC Tier 2 approach.

Usage

```
calc_conversion_factor_ym(
  species_short,
  cohort_short,
  ration_digestibility_fraction
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`ration_digestibility_fraction`
Numeric. Average digestibility of the feed ration, expressed as ratio of digestible (or metabolizable, for poultry) to gross energy content (fraction).

Details

ym is computed using species- and cohort-specific default relationships with diet digestibility (Opio et al., 2013).

`ration_digestibility_fraction` can be calculated with `calc_ration_digestibility` - see also `run_ration_quality_module`.

- **For `CTL` and `BFL`:**

$$ym = 9.75 - 0.05 \times (ration\_digestibility\_fraction \times 100)$$

- **For `SHP`, `GTS` and `CML`:**
  - `FA` and `MA` cohorts:

$$ym = 9.75 - 0.05 \times (ration\_digestibility\_fraction \times 100)$$

  - `FS` and `MS` cohorts:

$$ym = 7.75 - 0.05 \times (ration\_digestibility\_fraction \times 100)$$

- **For `PGS`:** ym is assigned fixed values by cohort:
  - `FA` and `MA` cohorts:

$$ym = 1.01$$

  - `FS` and `MS` cohorts:

$$ym = 0.39$$

ym is returned as 0 for juvenile cohorts (`FJ`, `MJ`), assuming negligible enteric methane production before weaning/rumen development.

This function is part of the `run_emissions_enteric_module()`.

Value

Numeric. Methane (CH4) conversion factor (ym), representing the percentage of gross energy of the feed ration that is converted to CH4 (percentage).

References

Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B. & Steinfeld, H. (2013). *Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment*. Food and Agriculture Organization of the United Nations (FAO), Rome.

Jørgensen, H., Theil, P. K. & Knudsen, K. E. B. (2011). *Enteric methane emission from pigs*. In: Planet Earth 2011 – Global Warming Challenges and Opportunities for Policy and Practice (p. 610; Table 2). InTech.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.21.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.21.

See Also

`run_emissions_enteric_module`, `calc_ration_digestibility`, `run_ration_quality_module`

`calc_daily_weight_gain`

Calculate daily weight gain by cohort

Description

Calculates average daily weight gain for a given sex–age cohort based on the difference between potential final and initial live weights.

Usage

```
calc_daily_weight_gain(
  live_weight_cohort_potential_final,
  live_weight_cohort_initial,
  cohort_duration_days
)
```

Arguments

`live_weight_cohort_potential_final`	Numeric. Potential final live weight attainable at the end of the cohort stage in the absence of offtake (kg). (For juveniles: equals weaning weight; For subadults: equals adult live weight; For adults: equals adult live weight)
`live_weight_cohort_initial`	Numeric. Live weight at the beginning of the cohort stage (kg).
`cohort_duration_days`	Numeric. Amount of time that each animal spends in a specific cohort (days).

Details

Daily live weight gain is calculated as the difference between the potential final live weight and the initial live weight, divided by the duration of the cohort stage:

$$daily\_weight\_gain = (live\_weight\_cohort\_potential\_final - live\_weight\_cohort\_initial)/cohort\_duration\_days$$

This function is part of the `run_weights_module()`.

Value

Numeric. Average live weight gain of the cohort over the cohort stage (kg/head/day).

See Also

`run_weights_module`

`calc_fecundity_rates` *Calculate daily fecundity rates*

Description

Calculates the daily number of male and female offspring produced per adult female.

Usage

```
calc_fecundity_rates(parturition_rate, litter_size, birth_fraction_female)
```

Arguments

`parturition_rate`	Numeric. Average annual number of parturitions per female animal (# parturitions/adult female/year). A herd-level reproductive performance indicator calculated as the total number of parturitions (deliveries) occurring during a year divided by the number of adult females potentially able to give birth during that year.
`litter_size`	Numeric. Average number of offspring born per parturition (# offspring/parturition). This value can be calculated as the total number of offspring born divided by the total number of parturitions during the year.
`birth_fraction_female`	Numeric. Female birth fraction, defined as the probability that a newborn offspring is female (fraction). Can be calculated as the number of female offspring born divided by the total number of offspring born.

Value

A named list with two elements:

fecundity_female Numeric. Daily number of female offspring per adult female (# offspring/day)

fecundity_male Numeric. Daily number of male offspring per adult female (# offspring/day)

This function is part of the `run_demographic_herd_module()`.

See Also

`run_demographic_herd_module()`

Examples

```
calc_fecundity_rates(parturition_rate = 0.8, litter_size = 2, birth_fraction_female = 0.5)
```

---

calc_feed_digestibility_fraction

Calculate feed digestibility fraction

Description

Calculates species-specific feed digestibility fractions by feed component.

Usage

```
calc_feed_digestibility_fraction(
  feed_digestible_energy_ruminant,
  feed_digestible_energy_pigs,
  feed_gross_energy
)
```

Arguments

`feed_digestible_energy_ruminant`
: Numeric. Digestible energy content of a feed component for ruminants, representing the energy absorbed by the animal after fecal losses (MJ/kg DM).

`feed_digestible_energy_pigs`
: Numeric. Digestible energy content of a feed component for pigs, representing the energy absorbed by the animal after fecal losses (MJ/kg DM).

`feed_gross_energy`
: Numeric. Gross energy content of a feed component, representing the total chemical energy released upon complete combustion of the feed (MJ/kg DM).

Details

Digestibility is computed as the ratio of usable energy to gross energy:

$$feed\_digestibility\_fraction = usable\_energy / feed\_gross\_energy$$

For ruminants and pigs, usable energy is represented by `digestible_energy` (DE), which accounts for fecal energy losses.

This function is part of the `run_ration_quality_module()`.

Value

List with elements:

feed_digestibility_fraction_ruminant Numeric. Digestibility of a feed component for ruminants, expressed as the ratio of digestible energy to gross energy content (fraction).

feed_digestibility_fraction_pigs Numeric. Digestibility of a feed component for pigs, expressed as the ratio of digestible energy to gross energy content (fraction).

See Also

`run_ration_quality_module`

---

calc_fibre_allocation_energy

Calculate fibre energy requirements (for biophysical allocation)

Description

Calculates the energy required for fibre production over the assessment period (MJ/cohort/assessment period), based on the daily energy requirement for fibre production, cohort size, and assessment duration.

Usage

```
calc_fibre_allocation_energy(
  species_short,
  cohort_stock_size = NA_real_,
  metabolic_energy_req_fibre_production = NA_real_,
  ratio_me_to_ne = NA_real_,
  simulation_duration = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_stock_size`
: Numeric. Average population size in each of the 6 sex–age cohorts (# heads). (cohorts=FJ, FS, FA, MJ, MS, MA).

`metabolic_energy_req_fibre_production`
: Numeric. Energy required for the synthesis of fibre for SHP, GTS and CML. Assumed to be 0 for other species. (MJ/head/day). Expressed as net energy for SHP and GTS and as metabolizable energy for CML.

`ratio_me_to_ne` Numeric. Ratio of metabolizable energy converted to net energy (fraction). Used for species_short = CML.

`simulation_duration`
: Numeric. Length of the assessment period (days).

Details

This function provides the fibre-related energy term used in a biophysical allocation framework to apportion emissions between milk and other co-products in multifunctional livestock production systems.

The approach implements the IDF (2022) standard, adapted from Thoma and Nemecek (2020), and is consistent with FAO LEAP livestock LCA guidelines (FAO, 2016a, 2016b, 2016c) and with ISO 14044:2006 (Section 4.3.4.2, Step 2).

In accordance with ISO 14044:2006 (Section 4.3.4.2, Step 2), known processing or biophysical relationships may be used to assign shared inputs and outputs of a single production unit to individual products or sub-units. In livestock systems, this includes apportioning shared feed and energy use according to physiological energy requirements (e.g., net energy for lactation, growth, etc.). If the resulting process remains multifunctional, these energy terms may subsequently be used to derive allocation factors among co-products.

Total fibre-related energy over the assessment period is computed for fibre-producing species (`CML`, `SHP`, `GTS`) and applicable cohorts (`"FA"`, `"FS"`, `"MA"`, `"MS"`).

The `fibre_allocation_energy` is calculated as follows:

$$energy\_allocation\_fibre = \frac{energy\_requirement\_fibre\_production}{ratio\_me\_to\_ne} \times simulation\_duration \times cohort\_stock\_size$$

for camels (`CML`), and:

$$energy\_allocation\_fibre = energy\_requirement\_fibre\_production \times simulation\_duration \times cohort\_stock\_size$$

for sheep (`SHP`) and goats (`GTS`).

where `metabolic_energy_req_fibre_production` can be computed using `calc_metabolic_energy_req_fibre` (see also `run_metabolic_energy_req_module`).

This function is part of the `run_allocation_module()`.

Value

Numeric. Energy required to produce all fibre output by cohort (MJ/cohort/assessment period). Non-zero values are expected only for fibre-producing species (CML, SHP, GTS) and applicable cohorts ("FA", "FS", "MA", "MS").

References

ISO. (2006). *Environmental management — Life cycle assessment — Requirements and guidelines (ISO 14044:2006)*. International Organization for Standardization, Geneva.

IDF. (2022). *The IDF Global Carbon Footprint Standard for the Dairy Sector*. Bulletin of the IDF No. 520/2022. International Dairy Federation, Brussels.

Thoma, G., and Nemecek, T. (2020). Allocation between milk and meat in dairy LCA: Critical discussion of the IDF's standard methodology. In *Proceedings of the 12th International Conference on Life Cycle Assessment of Food (LCAFood 2020)* (pp. 83–89), 13–16 October, Berlin, Germany.

FAO. (2016a). *Environmental performance of large ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016b). *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016c). *Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

See Also

`run_allocation_module`, `calc_metabolic_energy_req_fibre`, `run_metabolic_energy_req_module`

`calc_fibre_production` *Calculate fibre production*

Description

Calculates fibre production for producing cohorts (`FA`, `FS`, `MA`, `MS`) of fibre-producing species (`CML`, `SHP`, `GTS`) over the assessment period (kg/cohort/assessment period).

Usage

```
calc_fibre_production(
  species_short,
  cohort_short,
  fibre_yield_year,
  simulation_duration,
  cohort_stock_size
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`fibre_yield_year`
Numeric. Annual production yield of fibre, such as wool, cashmere, mohair (kg/head/year). Required only for species = CML, SHP, and GTS.

`simulation_duration`
Numeric. Length of the assessment period (days).

`cohort_stock_size`
Numeric. Average population size in each of the 6 sex–age cohorts (# heads). (cohorts=FJ, FS, FA, MJ, MS, MA).

Details

Fibre production outputs are computed as follows:

$$fibre\_production = \frac{fibre\_yield\_year}{365} \times simulation\_duration \times cohort\_stock\_size$$

Non-zero fibre outputs are only expected for producing cohorts (`FA`, `FS`, `MA`, `MS`) of fibre-producing species (`CML`, `SHP`, `GTS`).

This function is part of the `run_production_module()`.

Value

Numeric. Total fibre produced over the assessment period by cohort (kg /cohort/assessment period).

See Also

`run_production_module`

`calc_meat_allocation_energy` *Calculate meat energy requirements (for biophysical allocation)*

Description

Calculates the energy required for meat production over the assessment period (MJ/cohort/assessment period), based on total live weight gained by the cohort from birth to slaughter.

Usage

```
calc_meat_allocation_energy(
  species_short,
  cohort_short,
  meat_production_live_weight_cohort,
  live_weight_cohort_at_slaughter = NA_real_,
  live_weight_at_birth = NA_real_,
  ratio_me_to_ne = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`meat_production_live_weight_cohort` Numeric. Total meat produced as live weight over the assessment period by cohort (kg/cohort/assessment period).

`live_weight_cohort_at_slaughter` Numeric. Live weight at slaughter for animals removed from the cohort (kg).

`live_weight_at_birth` Numeric. Live weight of the animal at birth (kg).

`ratio_me_to_ne` Numeric. Ratio of metabolizable energy converted to net energy (fraction). Used for species_short = CML.

Details

This function provides the meat-related energy term used in a biophysical allocation framework to apportion emissions between milk and other co-products in multifunctional livestock production systems.

The approach implements the IDF (2022) standard, adapted from Thoma and Nemecek (2020), and is consistent with FAO LEAP livestock LCA guidelines (FAO, 2016a, 2016b, 2016c) and with ISO 14044:2006 (Section 4.3.4.2, Step 2).

In accordance with ISO 14044:2006, known biophysical relationships may be used to assign shared inputs and outputs of a production system to individual products or sub-units. In livestock systems, this includes apportioning shared feed and energy use according to physiological energy requirements such as growth, lactation, and maintenance. If the resulting process remains multifunctional, these energy terms may subsequently be used to derive allocation factors among co-products.

The `meat_allocation_energy` is calculated as follows:

$$energy\_allocation\_meat = specific\_energy\_meat \times meat\_production\_live\_weight\_cohort$$

where

- `specific_energy_meat` is the average energy required to produce one kilogram of live weight, accounting for species- and cohort-specific growth characteristics (MJ/kg live weight).
- `meat_production_live_weight_cohort` is the total live weight of animals sold for meat over the assessment period. It can be computed using `calc_meat_production` (see also `run_production_module`).

Specific approaches by species:

- **For** `CTL`**,** `BFL`**,** `CML`**,** `SHP`**,** `GTS`:
  Growth energy is calculated using species- and cohort-specific biophysical relationships adapted from established growth energy formulations (further details in `calc_metabolic_energy_req_growth`).
- **For** `PGS`:
  Growth energy is not calculated in this function and `0` is returned. In downstream processing, `calc_allocation_shares` assigns 100% of the allocation to the edible meat commodity for pig systems.

This function is part of the `run_allocation_module()`.

Value

Numeric. Energy required by a given sex–age cohort for total meat output by cohort during the assessment period, equal to the energy needed to produce all live-weight gain to reach the target slaughter weight (MJ/cohort/assessment period). For pigs (`PGS`), the function returns `0` by design.

References

ISO. (2006). *Environmental management — Life cycle assessment — Requirements and guidelines (ISO 14044:2006)*. International Organization for Standardization, Geneva.

IDF. (2022). *The IDF Global Carbon Footprint Standard for the Dairy Sector*. Bulletin of the IDF No. 520/2022. International Dairy Federation, Brussels.

Thoma, G., and Nemecek, T. (2020). Allocation between milk and meat in dairy LCA: Critical discussion of the IDF's standard methodology. In *Proceedings of the 12th International Conference on Life Cycle Assessment of Food (LCAFood 2020)* (pp. 83–89), 13–16 October, Berlin, Germany.

FAO. (2016a). *Environmental performance of large ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016b). *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016c). *Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

See Also

`run_allocation_module`, `calc_meat_production`, `run_production_module`, `calc_allocation_shares`

`calc_meat_production` *Calculate meat production*

Description

Calculates cohort-level meat production outputs over the assessment period based on the number of animals removed from the herd (offtake). The function returns multiple production metrics expressed in live weight, carcass weight, bone-free meat, and meat protein (kg/cohort/assessment period).

Usage

```
calc_meat_production(
  offtake_heads_assessment,
  live_weight_cohort_at_slaughter,
  carcass_dressing_fraction,
  bone_free_meat_fraction,
  meat_protein_fraction
)
```

Arguments

`offtake_heads_assessment`
: Numeric. Total number of animals removed via offtake over the assessment period, aggregated to 6 sex–age cohorts (heads/assessment period) (cohorts = FJ, FS, FA, MJ, MS, MA).

`live_weight_cohort_at_slaughter`
: Numeric. Live weight at slaughter for animals removed from the cohort (kg).

`carcass_dressing_fraction`
: Numeric. Ratio of a slaughtered animal's carcass weight to its live weight (fraction).

`bone_free_meat_fraction`
: Numeric. Ratio of bone-free-meat to carcass weight (fraction).

`meat_protein_fraction`
: Numeric. Protein content of bone-free-meat (kg protein/kg bone-free-meat).

Details

Meat production outputs are computed as follows:

- `meat_production_live_weight_cohort` is computed as:
  $meat\_production\_live\_weight\_cohort = offtake\_heads\_assessment \times live\_weight\_cohort\_at\_slaughter$
- `meat_production_carcass_weight_cohort` is computed as:
  $meat\_production\_carcass\_weight\_cohort = meat\_production\_live\_weight\_cohort \times carcass\_dressing\_fraction$
- `meat_production_bone_free_meat_cohort` is computed as:
  $meat\_production\_bone\_free\_meat\_cohort = meat\_production\_carcass\_weight\_cohort \times bone\_free\_meat\_fraction$
- `meat_production_protein_cohort` is computed as:
  $meat\_production\_protein\_cohort = meat\_production\_bone\_free\_meat\_cohort \times meat\_protein\_fraction$

This function is part of the `run_production_module()`.

Value

A named list with:

meat_production_live_weight_cohort Numeric . Total meat produced as live weight over the assessment period by cohort (kg/cohort/assessment period).

meat_production_carcass_weight_cohort Numeric. Total meat as carcass weight (excluding organs, and other by-products after dressing) produced over the assessment period by cohort (kg/cohort/assessment period).

meat_production_bone_free_meat_cohort Numeric. Total bone-free-meat (excluding bones, organs, and other by-products after dressing and bone removal) produced over the assessment period by cohort (kg/cohort/assessment period).

meat_production_protein_cohort Numeric. Total meat protein (excluding bones, organs, and other by-products after dressing and bone removal) produced over the assessment period by cohort (kg protein/cohort/assessment period).

See Also

`run_production_module`, `run_demographic_herd_module`, `run_weights_module`

`calc_metabolic_energy_req_activity` *Calculate metabolic energy requirements for activity*

Description

Calculates the energy requirement for activity by cohort (MJ/head/day), defined as the amount of energy needed to support animal movement and physical activity.

Usage

```
calc_metabolic_energy_req_activity(
  species_short,
  cohort_short,
  metabolic_energy_req_maintenance,
  live_weight_cohort_average,
  low_activity_fraction,
  high_activity_fraction
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`metabolic_energy_req_maintenance`
Numeric. Energy required for maintenance, defined as the amount of energy needed to keep the animal at equilibrium such that body energy is neither gained nor lost. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

`live_weight_cohort_average`
: Numeric. Average live weight over the cohort stage. Computed by accounting for the share of offtaken animals within the cohort, using their slaughter weight, and the potential final weight of animals that remain in the cohort (kg).

`low_activity_fraction`
: Numeric. Proportion of the assessment period during which the animal performs low-intensity movement typical of stall-feeding or near-field grazing, characterized by minimal walking distances and flat terrain (fraction).

`high_activity_fraction`
: Numeric. Proportion of the assessment period during which the animal engages in sustained locomotion associated with herding or long-distance grazing, typically involving extended walking distances and/or uneven or hilly terrain (fraction).

Details

This approach follows the IPCC Tier 2 energy partitioning method and applies:

$$metabolic\_energy\_req\_activity = cact \times metabolic\_energy\_req\_maintenance$$

For `SHP` and `GTS`, activity energy is calculated as:

$$metabolic\_energy\_req\_activity = cact \times live\_weight\_cohort\_average$$

where

$cact$ is an activity coefficient (dimensionless for `CTL`, `BFL`, `PGS`; MJ/day/kg for `SHP`, `GTS`) that reflects the animal's feeding and management conditions. `metabolic_energy_req_maintenance` can be calculated using `calc_metabolic_energy_req_maintenance()`.

For `CTL`, `BFL`, `SHP` and `GTS`, $cact$ is computed as a *weighted average* of activity levels over the assessment period to account for variation in management and grazing intensity.

Specific coefficients by species and cohort:

CTL, BFL (NRC, 1996; AFRC, 1993):

- `low_activity_fraction`: $cact = 0.17$
- `high_activity_fraction`: $cact = 0.36$

CML (Wardeh, 2004):

- `all activity levels`: $cact = 0.1$

GTS (AFRC, 1993):

- `low_activity_fraction`: $cact = 0.019$
- `high_activity_fraction`: $cact = 0.024$

SHP (AFRC, 1993):

- `low_activity_fraction`: $cact = 0.0107$
- `high_activity_fraction`: $cact = 0.024$

PGS (NRC, 1998):

- `all activity levels`: $cact = 0.125$

This function is part of the `run_metabolic_energy_req_module()`.

Value

Numeric. Energy required for activity, defined as the amount of energy needed to support animal movement and physical activity (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

References

NRC (1998). *Nutrient Requirements of Swine*, 10th Revised Edition. National Academies Press, Washington, DC.

NRC (1996). *Nutrient Requirements of Beef Cattle*, 7th Revised Edition. National Academies Press, Washington, DC.

AFRC (1993). *Energy and Protein Requirements of Ruminants. An Advisory Manual Prepared by the AFRC Technical Committee on Responses to Nutrients.* CAB International, Wallingford, UK.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.4; Table 10.5.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.4; Table 10.5.

Wardeh, M. F. (2004). *The nutrient requirements of the dromedary camel*. Journal of Camel Science, 1(1):37-45. The Camel Applied Research and Development Network (CARDN), Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD).

See Also

`run_metabolic_energy_req_module`, `calc_metabolic_energy_req_maintenance`, `calc_avg_weights`

`calc_metabolic_energy_req_fibre`
Calculate metabolic energy requirements for fibre production

Description

Calculates the energy requirement for fibre production (MJ/head/day), defined as the additional energy required for the synthesis of animal fibre (e.g. wool or hair).

Usage

```
calc_metabolic_energy_req_fibre(
  species_short,
  cohort_short,
  fibre_yield_year = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`fibre_yield_year`
Numeric. Annual production yield of fibre, such as wool, cashmere, mohair (kg/head/year). Required only for species = CML, SHP, and GTS.

Details

This component follows the IPCC Tier 2 partitioning approach and is applied only to fibre-producing species and relevant cohorts, which are assumed to be `FA`, `FS`, `MA`, and `MS`.

Species-specific approach:

- **SHP and GTS** (IPCC, 2006; IPCC, 2019):
  For sheep and goats, fibre production energy is calculated assuming a fixed net energy cost of 24 MJ per kilogram of fibre produced. Annual fibre production is converted to a daily requirement as:

$$metabolic\_energy\_req\_fibre = \frac{24 \times fibre\_yield\_year}{365}$$

  where:
  - $fibre\_yield\_year$ is annual fibre production (kg/head/year),
  - 24 is the net energy requirement per kilogram of fibre (MJ/kg fibre),
  - division by 365 converts annual production to a daily basis.
- **CML** (AFRC, 1998; Cannas et al., 2007):
  For camels, fibre energy requirements are first calculated on a **net energy** basis and then converted to **metabolizable energy** using a net-to-metabolizable energy efficiency coefficient:

$$metabolic\_energy\_req\_fibre = \frac{24}{0.43} \times \frac{fibre\_yield\_year}{365}$$

  where:

  - 24 is the net energy requirement per kilogram of fibre (MJ/kg fibre),
  - 0.43 is the efficiency of conversion from metabolizable energy to net energy for fibre production (fraction),
  - $fibre\_prod$ is annual fibre production per animal (kg/head/year),
  - 365 to convert annual production to a daily basis.

  The efficiency coefficient of 0.43 is adopted by analogy with goats, assuming a dietary metabolizability of approximately 0.55, following AFRC guidance and the synthesis by Cannas et al. (2007).

- **Other species**: Fibre production energy is assumed to be zero.

This function is part of the `run_metabolic_energy_req_module()`.

Value

Numeric. Energy required for the synthesis of fibre for SHP, GTS and CML. Assumed to be 0 for other species. (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

References

AFRC (1998) *The Nutrition of Goats.* CAB International, Wallingford, UK.

AFRC (1993). *Energy and Protein Requirements of Ruminants. An Advisory Manual Prepared by the AFRC Technical Committee on Responses to Nutrients.* CAB International, Wallingford, UK.

Cannas, A., Atzori, A. S., Boe, F., & Teixeira, I. (2007). *Energy and protein requirements of goats*. In: Dairy sheep nutrition (pp. 31-49). CAB International, Wallingford, UK.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.12.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.12.

See Also

`run_metabolic_energy_req_module`,

`calc_metabolic_energy_req_growth`
Calculate metabolic energy requirements for growth

Description

Calculates the energy requirement for growth by cohort (MJ/head/day), defined as the energy required for body tissue accretion, corresponding to the retained energy component of live weight gain.

Usage

```
calc_metabolic_energy_req_growth(
  species_short,
  cohort_short,
  live_weight_cohort_average = NA_real_,
  live_weight_cohort_final = NA_real_,
  live_weight_cohort_initial = NA_real_,
  live_weight_mature_stage = NA_real_,
  daily_weight_gain = NA_real_,
  offtake_rate = NA_real_,
  cohort_duration_days = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`live_weight_cohort_average`
Numeric. Average live weight over the cohort stage. Computed by accounting for the share of offtaken animals within the cohort, using their slaughter weight, and the potential final weight of animals that remain in the cohort (kg).

`live_weight_cohort_final`
Numeric. Live weight at the end of the cohort stage, accounting for both surviving and offtaken animals. Computed as a weighted average of the potential final weight of surviving animals and the slaughter weight of offtaken animals, based on the offtake rate (kg).

`live_weight_cohort_initial`
Numeric. Live weight at the beginning of the cohort stage (kg).

`live_weight_mature_stage`
Numeric. Mature (adult) live weight that the animal can attain under given biological and management conditions (kg).

`daily_weight_gain`
: Numeric. Average live weight gain of the cohort over the cohort stage (kg/head/day).

`offtake_rate`
: Numeric. Annual proportion of animals removed from the herd for each sex-age cohort (fraction).

`cohort_duration_days`
: Numeric. Amount of time that each animal spends in a specific cohort (days).

Details

This function follows the IPCC Tier 2 energy partitioning approach and applies species-specific equations for growth energy requirements.

In general, growth energy is computed only for growing cohorts (`FJ`, `FS`, `MJ`, `MS`); in this implementation, growth is set to 0 for adult cohorts (`FA`, `MA`).

Species-specific approach:

- **CTL and BFL** (NRC, 1996; IPCC, 2006; IPCC, 2019)

  Growth energy is computed using a growth coefficient $cgro$ that differs between castrated and intact males. For male cohorts, $cgro$ is calculated as a weighted average using `offtake_rate`, assuming that animals removed from the herd are castrated and animals remaining in the cohort are intact.

- **SHP and GTS** (Gibbs et al., 2002; AFRC, 1993; IPCC, 2006; IPCC, 2019)

  For sheep and goats, growth energy is calculated using a linear formulation with coefficients a and b (MJ/kg live weight). For male cohorts, the coefficients differ between castrated and intact males; the model computes a weighted average using `offtake_rate`, assuming that offtaken animals are castrated.

- **CML** (Al-Jassim, 2019)

  Growth energy is represented using a simplified linear relationship with daily weight gain.

- **PGS** (NRC, 1998)

  For pigs, growth is assumed to consist exclusively of protein tissue and fat tissue, and growth energy requirements are expressed as metabolizable energy (ME).

  The growth energy coefficient $cgro$ (MJ/kg live weight) is calculated as:

  $cgro = prot\_tissue\_frac \times meat\_protein \times meat\_protein\_energy + (1 - prot\_tissue\_frac) \times fat\_adipose\_tissue_frac \times meat\_fat\_energy$

  Total metabolizable energy required for growth is then:

  $metabolic\_energy\_req\_growth = daily\_weight\_gain \times cgro$

  where:

  - $cgro$ is the growth energy coefficient (MJ/kg live weight),
  - `prot_tissue_frac` = `0.65` is the fraction of protein tissue in daily weight gain,
  - `meat_protein` = `0.23` is the fraction of protein in protein tissue,
  - `meat_protein_energy` = `54.0` is the ME cost of protein deposition (MJ/kg protein),
  - `fat_adipose_tissue_frac` = `0.90` is the fraction of fat in adipose tissue,
  - `meat_fat_energy` = `52.3` is the ME cost of fat deposition (MJ/kg fat).

This function is part of the `run_metabolic_energy_req_module()`.

Value

Numeric. Energy required for growth (i.e., weight gain) (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

References

Al-Jassim, R. (2019). *Metabolisable energy and protein requirements of the Arabian camel (Camelus dromedarius)*. Journal of Camelid Science (12) 33-45

NRC (1998). *Nutrient Requirements of Swine*, 10th Revised Edition. National Academies Press, Washington, DC.

NRC (1996). *Nutrient Requirements of Beef Cattle*, 7th Revised Edition. National Academies Press, Washington, DC.

AFRC (1993). *Energy and Protein Requirements of Ruminants. An Advisory Manual Prepared by the AFRC Technical Committee on Responses to Nutrients.* CAB International, Wallingford, UK.

Gibbs, M.J., Conneely, D., Johnson, D., Lassey, K.R. and Ulyatt, M.J. (2002). *CH4 emissions from enteric fermentation*. In: Background Papers: IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, p 297–320. IPCC-NGGIP, Institute for Global Environmental Strategies (IGES), Hayama, Kanagawa, Japan.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.6 and 10.7; Table 10.6.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.6 and 10.7; Table 10.6.

See Also

`run_metabolic_energy_req_module`, `calc_cohort_weights`, `calc_avg_weights`, `calc_daily_weight_gain`

`calc_metabolic_energy_req_lactation`

Calculate metabolic energy requirements for lactation

Description

Calculates the energy requirement for lactation by cohort (MJ/head/day), defined as the energy needed to support milk production by lactating females.

Usage

```
calc_metabolic_energy_req_lactation(
  species_short,
  cohort_short,
  lactating_females_fraction = NA_real_,
  milk_yield_day = NA_real_,
  milk_fat_fraction = NA_real_,
```

```
  non_productive_duration = NA_real_,
  pregnancy_duration = NA_real_,
  litter_size = NA_real_,
  death_rate_juvenile = NA_real_,
  live_weight_at_birth = NA_real_,
  live_weight_at_weaning = NA_real_,
  lactation_duration = NA_real_,
  parturition_rate = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`lactating_females_fraction`
: Numeric. Proportion of adult females that are lactating during the assessment period (fraction). Required only for species = CML, CTL, BFL, SHP, and GTS.

`milk_yield_day` Numeric. Average milk yield per milk-producing animal during the assessment duration (kg/head/day). This value is calculated as the total quantity of milk produced for human consumption by milk-producing animals during the assessment period, divided by the number of milk-producing animals, and the length of the assessment period (days). Required only for species = CML, CTL, BFL, SHP, and GTS.

`milk_fat_fraction`
: Numeric. Milk fat fraction (kg fat/kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

`non_productive_duration`
: Numeric. Period during which the animal is not performing any productive physiological function such as pregnancy or lactation (days). Required only for PGS.

`pregnancy_duration`
: Numeric. Duration of pregnancy period (days).

`litter_size` Numeric. Average number of offspring born per parturition (# offspring/parturition). This value can be calculated as the total number of offspring born divided by the total number of parturitions during the year.

`death_rate_juvenile`
Numeric. Fraction of deaths in a herd over a year for juvenile cohorts (i.e. FJ and MJ), (fraction).

`live_weight_at_birth`
Numeric. Live weight of the animal at birth (kg).

`live_weight_at_weaning`
Numeric. Live weight of the animal at weaning (kg).

`lactation_duration`
Numeric. Duration of the lactation period, defined as the number of days during which the animal is lactating (days). Required only for PGS.

`parturition_rate`
Numeric. Average annual number of parturitions per female animal (# parturitions/adult female/year). A herd-level reproductive performance indicator calculated as the total number of parturitions (deliveries) occurring during a year divided by the number of adult females potentially able to give birth during that year.

Details

This approach follows the IPCC Tier 2 partitioning method and applies species-specific equations for lactation energy requirements as a function of the quantity of milk produced and a species-specific energy cost per unit of milk.

Requirements are calculated only for cohort = `FA` (adult females) and are scaled by the proportion of lactating animals (`lactating_females_fraction`) or reproducing females (`parturition_rate`) within the cohort.

Species-specific approach:

CTL, BFL, CML, SHP and GTS:

Total milk production includes:

- milk extracted for human consumption (`milk_yield`)
- milk consumed directly by offspring (`milk_for_offspring`)

In general form, lactation energy is computed as:

$$metabolic\_energy\_req\_lactation = (milk\_yield \times lactating\_females\_fraction + milk\_for\_offspring) \times energy\_m$$

where:

`energy_milk` is a species-specific coefficient representing the net energy cost of producing one kilogram of milk (MJ/kg milk).

Species-specific values of `energy_milk` are:

- `CTL`, `BFL`: estimated as a function of milk fat content, $1.47 + 0.40 \times (milk\_fat\_fraction \times 100)$ (NRC, 1989),

- `CML`: 4.063 (Wardeh, 2004),
- `SHP`: 4.6 (AFRC, 1993),
- `GTS`: 3.0 (AFRC, 1998).

`milk_for_offspring` is the daily amount of milk required to rear offspring across the year (kg/day). It is calculated assuming that **5 kg of milk are required for each kilogram of live-weight gain up to weaning**:

$$milk\_for\_offspring = \frac{parturition\_rate \times 5 \times (weaning\_weight - birth\_weight)}{365}$$

For **SHP** and **GTS**, `milk_for_offspring` is multiplied by `litter_size` to account for multiple offspring per birth.

PGS (NRC, 1998):

Lactation energy accounts only for the milk consumed directly by offspring (`milk_for_offspring`), adjusted by the fraction of the reproductive cycle spent in lactation (`cadj`):

$$metabolic\_energy\_req\_lactation = litter\_size \times (1 - 0.5 \times death\_rate\_juvenile) \times \left(\frac{0.02059 \times (weaning\_weight - birth\_weight) \times 1000}{lactation\_duration} - \frac{0.3766}{0.67} \right) \times cadj$$

where:

- 0.02059 is the coefficient for lactation energy requirement (MJ/g live weight),
- 0.3766 is the coefficient for sow weight loss during lactation (MJ/head/day),
- 0.67 is the efficiency of conversion of dietary intake to milk energy (fraction),
- $cadj$ is the fraction of the reproductive cycle spent in lactation:

$$cadj = \frac{lactation\_duration}{non\_productive\_duration + pregnancy\_duration + lactation\_duration}$$

This function is part of the `run_metabolic_energy_req_module()`.

Value

Numeric. Energy required for lactation (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

References

AFRC (1998) *The Nutrition of Goats.* CAB International, Wallingford, UK.

AFRC (1993). *Energy and Protein Requirements of Ruminants. An Advisory Manual Prepared by the AFRC Technical Committee on Responses to Nutrients.* CAB International, Wallingford, UK.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.8-10.10.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.8-10.10.

NRC (1998). *Nutrient Requirements of Swine*, 10th Revised Edition. National Academies Press, Washington, DC.

NRC (1989) *Nutrient Requirements of Dairy Cattle*, 6th Ed. . Washington, D.C. U.S.A: National Academy Press.

Wardeh, M. F. (2004). *The nutrient requirements of the dromedary camel*. Journal of Camel Science, 1(1):37-45. The Camel Applied Research and Development Network (CARDN), Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD).

See Also

run_metabolic_energy_req_module

`calc_metabolic_energy_req_maintenance`
Calculate metabolic energy requirements for maintenance

Description

Calculates the energy requirement for maintenance by cohort (MJ/head/day), defined as the energy required to maintain basal physiological functions at equilibrium, with no net gain or loss of body energy.

Usage

```
calc_metabolic_energy_req_maintenance(
  species_short,
  cohort_short,
  live_weight_cohort_average,
  lactating_females_fraction = NA_real_,
  offtake_rate = NA_real_,
  age_first_parturition = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`live_weight_cohort_average` Numeric. Average live weight over the cohort stage. Computed by accounting for the share of offtaken animals within the cohort, using their slaughter weight, and the potential final weight of animals that remain in the cohort (kg).

`lactating_females_fraction` Numeric. Proportion of adult females that are lactating during the assessment period (fraction). Required only for species = CML, CTL, BFL, SHP, and GTS.

`offtake_rate` Numeric. Annual proportion of animals removed from the herd for each sex-age cohort (fraction).

`age_first_parturition` Numeric. Age at first parturition for female breeding animals (days)

Details

This approach follows the IPCC Tier 2 partitioning method and applies:

$metabolic\_energy\_req\_maintenance = cmain \times average\_weight^{0.75}$

where $cmain$ is a category-specific coefficient (MJ/day/kg$^{0.75}$) that reflects basal metabolic requirements and varies by species, physiological status, and sex.

For selected cohorts, $cmain$ is computed as a weighted average to account for:

- `CTL`, `BFL`: lactating vs. non-lactating females
- `CTL`, `BFL`, `SHP`: intact vs. castrated males - Offtaken animals assumed castrated
- `SHP`: animals below vs. above one year of age

Specific coefficients by species and cohort:

CTL and BFL (NRC, 1996; AFRC, 1993):

- `FA`: $cmain = 0.386 \times lactating\_females\_fraction + 0.322 \times (1 - lactating\_females\_fraction)$
- `FS`, `FJ`, `MJ`: $cmain = 0.322$
- `MA`, `MS`: $cmain = 0.322 \times offtake\_rate + 0.370 \times (1 - offtake\_rate)$

CML (Wardeh, 2004):

- All cohorts: $cmain = 0.435$

GTS (AFRC, 1993):

- All cohorts: $cmain = 0.315$

SHP (AFRC, 1993):

- FA: $cmain = 0.217$
- FJ: $cmain = 0.236$
- FS: $cmain = 0.236 \times (365/age\_first\_parturition) + 0.217 \times ((age\_first\_parturition - 365)/age\_first\_parturition)$
- MA: $cmain = 0.217 \times offtake\_rate + (0.217 \times 1.15) \times (1 - offtake\_rate)$
- MJ: $cmain = 0.236 \times offtake\_rate + (0.236 \times 1.15) \times (1 - offtake\_rate)$
- MS: $cmain = (0.217 \times offtake\_rate + (0.217 \times 1.15) \times (1 - offtake\_rate)) \times ((age\_first\_parturition - 365)/age\_first\_parturition) + (0.236 \times offtake\_rate + (0.236 \times 1.15) \times (1 - offtake\_rate)) \times (365/age\_first\_parturition)$

PGS (NRC, 1998):

- All cohorts: $cmain = 0.4435$

This function is part of the run_metabolic_energy_req_module().

Value

Numeric. Energy required for maintenance, defined as the amount of energy needed to keep the animal at equilibrium such that body energy is neither gained nor lost. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

References

NRC (1998). *Nutrient Requirements of Swine*, 10th Revised Edition. National Academies Press, Washington, DC.

NRC (1996). *Nutrient Requirements of Beef Cattle*, 7th Revised Edition. National Academies Press, Washington, DC.

AFRC (1993). *Energy and Protein Requirements of Ruminants. An Advisory Manual Prepared by the AFRC Technical Committee on Responses to Nutrients.* CAB International, Wallingford, UK.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.3; Table 10.4.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.3; Table 10.4.

Wardeh, M. F. (2004). *The nutrient requirements of the dromedary camel*. Journal of Camel Science, 1(1):37-45. The Camel Applied Research and Development Network (CARDN), Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD).

See Also

run_metabolic_energy_req_module, calc_avg_weights

`calc_metabolic_energy_req_pregnancy` *Calculate metabolic energy requirements for pregnancy*

Description

Calculates the energy requirement for pregnancy by cohort (MJ/head/day) for pregnant females, defined as the additional energy needed to support gestation.

Usage

```
calc_metabolic_energy_req_pregnancy(
  species_short,
  cohort_short,
  metabolic_energy_req_maintenance = NA_real_,
  parturition_rate = NA_real_,
  litter_size = NA_real_,
  pregnancy_duration = NA_real_,
  non_productive_duration = NA_real_,
  lactation_duration = NA_real_,
  cohort_duration_days = NA_real_,
  offtake_rate = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`metabolic_energy_req_maintenance` Numeric. Energy required for maintenance, defined as the amount of energy needed to keep the animal at equilibrium such that body energy is neither gained nor lost. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

`parturition_rate`
: Numeric. Average annual number of parturitions per female animal (# parturitions/adult female/year). A herd-level reproductive performance indicator calculated as the total number of parturitions (deliveries) occurring during a year divided by the number of adult females potentially able to give birth during that year.

`litter_size`
: Numeric. Average number of offspring born per parturition (# offspring/parturition). This value can be calculated as the total number of offspring born divided by the total number of parturitions during the year.

`pregnancy_duration`
: Numeric. Duration of pregnancy period (days).

`non_productive_duration`
: Numeric. Period during which the animal is not performing any productive physiological function such as pregnancy or lactation (days). Required only for PGS.

`lactation_duration`
: Numeric. Duration of the lactation period, defined as the number of days during which the animal is lactating (days). Required only for PGS.

`cohort_duration_days`
: Numeric. Amount of time that each animal spends in a specific cohort (days).

`offtake_rate`
: Numeric. Annual proportion of animals removed from the herd for each sex-age cohort (fraction).

Details

This component follows the IPCC Tier 2 partitioning framework and is applied only to **female cohorts** (`FA` and `FS`).

Pregnancy energy (`metabolic_energy_req_pregnancy`) represents the additional energy required to support gestation. Requirements are computed as a fraction of maintenance energy and are adjusted to reflect reproductive activity within the cohort:

- For `FA`, requirements are scaled by the annual parturition rate (`parturition_rate`) and (when applicable) by the fraction of the reproductive cycle spent in gestation (`pregnancy_duration/(pregnancy_duration+`
- For `FS`, only a fraction of animals is assumed to reach reproductive age within the cohort; requirements are therefore scaled by the proportion remaining in the cohort ($1 - offtake\_rate$) and by the share of the cohort duration spent pregnant (`pregnancy_duration/cohort_duration_days`).

General form

$$metabolic\_energy\_req\_pregnancy = metabolic\_energy\_req\_maintenance \times c_{preg} \times S$$

where

- c_{preg} is a species-specific pregnancy coefficient,
- S is a scaling term that depends on cohort (`FA` vs `FS`).
- $metabolic\_energy\_req\_maintenance$ can be calculated using `calc_metabolic_energy_req_maintenance()`

Specific coefficients by species and cohort:

- **CTL and BFL** (IPCC, 2006, 2019): Pregnancy energy is approximated as 10% of maintenance energy.
  - FA:

    $$metabolic\_energy\_req\_pregnancy = 0.10 \times metabolic\_energy\_req\_maintenance \times parturition\_rate \times \frac{pregnancy\_duration}{365}$$

  - FS:

    $$metabolic\_energy\_req\_pregnancy = 0.10 \times metabolic\_energy\_req\_maintenance \times \frac{pregnancy\_duration}{cohort\_duration\_days} \times (1 - offtake\_rate)$$

- **CML** (Wardeh, 2004): Pregnancy energy is estimated as 12% of maintenance energy.
  - FA:

    $$metabolic\_energy\_req\_pregnancy = 0.12 \times metabolic\_energy\_req\_maintenance \times parturition\_rate$$

  - FS:

    $$metabolic\_energy\_req\_pregnancy = 0.12 \times metabolic\_energy\_req\_maintenance \times \frac{pregnancy\_duration}{cohort\_duration\_days}$$

- **SHP and GTS** (IPCC 2006; 2019): Pregnancy energy is calculated as a litter-size-dependent fraction of maintenance energy (c_{preg}).
  - FA:

    $$metabolic\_energy\_req\_pregnancy = metabolic\_energy\_req\_maintenance \times c_{preg} \times parturition\_rate \times \frac{pregnancy\_duration}{365}$$

    where c_{preg} is:

    $$c_{preg} = \begin{cases} 0.077 \times (2 - litter\_size) + 0.126 \times (litter\_size - 1), & 1 \leq litter\_size \leq 2 \\ 0.150, & litter\_size > 2 \end{cases}$$

  - FS: A single-birth coefficient is used ($c_{preg} = 0.077$) and scaled by the proportion of reproductive individuals in the cohort:

    $$metabolic\_energy\_req\_pregnancy = 0.12 \times metabolic\_energy\_req\_maintenance \times \frac{pregnancy\_duration}{cohort\_duration\_days} \times (1 - offtake\_rate)$$

- **PGS** (NRC, 1998): Pregnancy energy is expressed using a gestation coefficient c_{gest} (MJ/piglet), with default $c_{gest} = 0.14985$.
  - FA:

    $$metabolic\_energy\_req\_pregnancy = c_{gest} \times litter\_size \times \frac{pregnancy\_duration}{non\_productive\_duration + pregnancy\_duration + lactation\_duratio}$$

- FS:

$$metabolic\_energy\_req\_pregnancy = c_{gest} \times litter\_size \times \frac{pregnancy\_duration}{cohort\_duration\_days} \times (1 - offtake\_rate)$$

This function is part of the run_metabolic_energy_req_module().

Value

Numeric. Energy required for pregnancy for pregnant females (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

References

NRC (1998). *Nutrient Requirements of Swine*, 10th Revised Edition. National Academies Press, Washington, DC.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.13; Table 10.7.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.13; Table 10.7.

Wardeh, M. F. (2004). *The nutrient requirements of the dromedary camel*. Journal of Camel Science, 1(1):37-45. The Camel Applied Research and Development Network (CARDN), Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD).

See Also

run_metabolic_energy_req_module, calc_metabolic_energy_req_maintenance

---

calc_metabolic_energy_req_work

Calculate metabolic energy requirements for work

Description

Calculates the energy requirement for work (MJ/head/day), defined as the additional energy required to support draught power and work-related physical activity.

Usage

```
calc_metabolic_energy_req_work(
  species_short,
  cohort_short,
  metabolic_energy_req_maintenance = NA_real_,
  draught_work_hours_female = NA_real_,
```

```
  draught_work_hours_male = NA_real_,
  draught_fraction_female = NA_real_,
  draught_fraction_male = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`metabolic_energy_req_maintenance`
: Numeric. Energy required for maintenance, defined as the amount of energy needed to keep the animal at equilibrium such that body energy is neither gained nor lost. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

`draught_work_hours_female`
: Numeric. Average daily working time per adult female (hours/head/day). Required only for species = CML, CTL and BFL.

`draught_work_hours_male`
: Numeric. Average daily working time per adult male (hours/head/day). Required only for species = CML, CTL and BFL.

`draught_fraction_female`
: Numeric. Fraction of adult females involved in draught work (fraction). Required only for species = CML, CTL and BFL.

`draught_fraction_male`
: Numeric. Fraction of adult males involved in draught work (fraction). Required only for species = CML, CTL and BFL.

Details

This approach follows the IPCC Tier 2 partitioning method and applies species-specific coefficients for draught work.

This energy component is calculated only for adult cohorts (`FA` and `MA`) of draught-capable species (`CTL`, `BFL`, and `CML`). It is scaled by the fraction of adult animals involved in draught work (`draught_fraction_female`,

draught_fraction_male) and their average daily working time (draught_work_hours_female, draught_work_hours_male).

Species-specific approach:

CTL and BFL - (Bamualim & Kartiarso, 1985; IPCC, 2006; IPCC 2019). Draught work energy is expressed as a proportion of net energy for maintenance:

$metabolic\_energy\_req\_work = 0.1 \times metabolic\_energy\_req\_maintenance \times work\_hours \times draught\_fraction$

where:

- $metabolic\_energy\_req\_maintenance$ is net energy required for maintenance (MJ/head/day) and can be calculated using calc_metabolic_energy_req_maintenance(),
- 0.1 represents a 10% increase in maintenance energy per hour of work,
- $work\_hours$ is the mean number of hours worked per animal per day - draught_work_hours_female (for FA) and draught_work_hours_male (for MA) and,
- $draught\_fraction$ is the fraction of adult animals performing draught work - draught_fraction_female (for FA) and draught_fraction_male (for MA)

CML - (Wilson, 1989) Draught work energy is calculated using a fixed metabolizable energy cost per hour of work:

$$metabolic\_energy\_req\_work = 4 \times work\_hours \times draught\_fraction$$

where:

- 4 is the metabolizable energy requirement for draught work (MJ/hour),
- $work\_hours$ is the mean number of hours worked per animal per day - draught_work_hours_female (for FA) and draught_work_hours_male (for MA) and,
- $draught\_fraction$ is the fraction of adult animals performing draught work - draught_fraction_female (for FA) and draught_fraction_male (for MA)

This function is part of the run_metabolic_energy_req_module().

Value

Numeric. Energy required for work, used to estimate the energy required for draught power for CTL, BFL and CML (MJ/head/day). Assumed to be 0 for other species. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

References

Bamualim A., Kartiarso (1985). *Nutrition of draught animals with special reference to Indonesia*. In: Draught Animal Power for Production. Australian Centre for International agricultural Research (ACIAR), Proceedings Series No. 10, ed. JW Copland. Canberra, A.C.T., Australia: ACIAR.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.11.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.11.

Wilson (1989). *The nutritional requirements of camel*. In: Tisserand J.-L. (ed.). Séminaire sur la digestion, la nutrition et l'alimentation du dromadaire. Zaragoza : CIHEAM. (1989). p. 171-179 (Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 2)

See Also

`run_metabolic_energy_req_module`, `calc_metabolic_energy_req_maintenance`

`calc_milk_allocation_energy` *Calculate milk energy requirements (for biophysical allocation)*

Description

Calculates the energy required for milk production over the assessment period (MJ/cohort/assessment period), based on total fat- and protein-corrected milk (FPCM) produced by the cohort.

Usage

```
calc_milk_allocation_energy(
  milk_production_fpcm_cohort,
  milk_protein_fraction_standard,
  milk_fat_fraction_standard,
  milk_lactose_fraction_standard
)
```

Arguments

`milk_production_fpcm_cohort`
: Numeric. Total fat-protein-corrected milk (FPCM) produced over the assessment period (kg/cohort/assessment period). Suggested standard fat, protein and lactose contents are 0.04, 0.033, and 0.048 respectively.

`milk_protein_fraction_standard`
: Numeric. Standard protein content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg protein/kg milk). Suggested value = 0.033.

`milk_fat_fraction_standard`
: Numeric. Standard fat content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg fat/kg milk). Suggested value = 0.04.

`milk_lactose_fraction_standard`
: Numeric. Standard lactose content of milk, used to calculate Fat-protein-corrected milk (FPCM) , (kg lactose/kg milk). Suggested value = 0.048.

Details

This function provides the milk-related energy term used in a biophysical allocation framework to apportion emissions between milk and other co-products in multifunctional livestock production systems.

The approach implements the IDF (2022) standard, adapted from Thoma and Nemecek (2020), and is consistent with FAO LEAP livestock LCA guidelines (FAO, 2016a, 2016b, 2016c) and with ISO 14044:2006 (Section 4.3.4.2, Step 2).

In accordance with ISO 14044:2006, known biophysical relationships may be used to assign shared inputs and outputs of a production system to individual products or sub-units. In livestock systems, this includes apportioning shared feed and energy use according to physiological energy requirements such as lactation, growth, and maintenance. If the resulting process remains multifunctional, these energy terms may subsequently be used to derive allocation factors among co-products.

The `milk_allocation_energy` is calculated as follows:

$$energy\_allocation\_milk = energy\_standard \times milk\_production\_fpcm\_cohort$$

where:

- `energy_standard` is the energy content of standard milk, calculated internally based on standard fat, protein, and lactose contents following IDF (2022) (MJ/kg milk).
- `milk_production_fpcm_cohort` is the total fat- and protein-corrected milk (FPCM) produced over the assessment period (kg/assessment period). It can be computed using `calc_milk_production` (see also `run_production_module`).

This function is part of the `run_allocation_module()`.

Value

Numeric. Energy required to produce total milk output by cohort (MJ/cohort/assessment period). Non-zero values are applicable only to milk-producing species and cohorts (species = CTL, BFL, CML, SHP, GTS; cohorts=FA). All other species–cohort combinations are assigned a value of 0.

References

ISO. (2006). *Environmental management — Life cycle assessment — Requirements and guidelines (ISO 14044:2006)*. International Organization for Standardization, Geneva.

IDF. (2022). *The IDF Global Carbon Footprint Standard for the Dairy Sector*. Bulletin of the IDF No. 520/2022. International Dairy Federation, Brussels.

Thoma, G., and Nemecek, T. (2020). Allocation between milk and meat in dairy LCA: Critical discussion of the IDF's standard methodology. In *Proceedings of the 12th International Conference on Life Cycle Assessment of Food (LCAFood 2020)* (pp. 83–89), 13–16 October, Berlin, Germany.

FAO. (2016a). *Environmental performance of large ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016b). *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016c). *Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

See Also

`run_allocation_module`, `calc_milk_production`, `run_production_module`

`calc_milk_production` *Calculate milk production*

Description

Calculates total milk production for the producing cohort (`FA`) of milk-producing species (`CML`, `CTL`, `BFL`, `SHP`, `GTS`) over the assessment period and returns multiple production metrics: total milk mass, milk protein, and fat-protein-corrected milk (FPCM) (kg/cohort/assessment period).

Usage

```
calc_milk_production(
  species_short,
  cohort_short,
  milk_yield_day,
  simulation_duration,
  cohort_stock_size,
  lactating_females_fraction,
  milk_protein_fraction,
  milk_fat_fraction,
  milk_lactose_fraction,
  milk_protein_fraction_standard,
  milk_fat_fraction_standard,
  milk_lactose_fraction_standard
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)

- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`milk_yield_day` Numeric. Average milk yield per milk-producing animal during the assessment duration (kg/head/day). This value is calculated as the total quantity of milk produced for human consumption by milk-producing animals during the assessment period, divided by the number of milk-producing animals, and the length of the assessment period (days). Required only for species = CML, CTL, BFL, SHP, and GTS.

`simulation_duration`
Numeric. Length of the assessment period (days).

`cohort_stock_size`
Numeric. Average population size in each of the 6 sex–age cohorts (# heads). (cohorts=FJ, FS, FA, MJ, MS, MA).

`lactating_females_fraction`
Numeric. Proportion of adult females that are lactating during the assessment period (fraction). Required only for species: CML, CTL, BFL, SHP, and GTS.

`milk_protein_fraction`
Numeric. Milk protein fraction (kg protein/kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

`milk_fat_fraction`
Numeric. Milk fat fraction (kg fat/kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

`milk_lactose_fraction`
Numeric. Milk lactose fraction (kg lactose/kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

`milk_protein_fraction_standard`
Numeric. Standard protein content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg protein/kg milk). Suggested value = 0.033.

`milk_fat_fraction_standard`
Numeric. Standard fat content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg fat/kg milk). Suggested value = 0.04.

`milk_lactose_fraction_standard`
Numeric. Standard lactose content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg lactose/kg milk). Suggested value = 0.048.

Details

Milk production outputs are computed as follows:

- `milk_production_mass_cohort` is computed as:
  $milk\_production = milk\_yield\_day \times simulation\_duration \times cohort\_stock\_size \times lactating\_females\_fraction$

- `milk_production_protein_cohort` is computed as:
  $milk\_protein\_production = milk\_production \times milk\_protein\_fraction$
- `milk_production_fpcm_cohort` is computed using the ratio of energy content of actual versus standard milk:
  $FPCM = milk\_production \times \frac{E_{milk}}{E_{standard}}$
  where milk energy content (Mcal/kg) is computed as (IDF, 2022):
  $E_{milk} = 0.0929 \times milk\_fat\_fraction + 0.0547 \times milk\_protein\_fraction + 0.0395 \times milk\_lactose\_fraction$
  $E_{standard} = 0.0929 \times milk\_fat\_fraction\_standard + 0.0547 \times milk\_protein\_fraction\_standard + 0.0395 \times milk\_lactose\_fraction\_standard$

Non-zero milk outputs are only expected for adult female cohorts of milk-producing species.

This function is part of the `run_production_module()`.

Value

A named list with:

milk_production_mass_cohort Numeric. Total milk production produced over the assessment period (kg/cohort/assessment period).

milk_production_protein_cohort Numeric. Total milk protein production produced over the assessment period (kg protein/cohort/assessment period).

milk_production_fpcm_cohort Numeric. Total fat-protein-corrected milk (FPCM) produced over the assessment period (kg/cohort/assessment period).

References

International Dairy Federation (IDF). 2022. *The IDF Global Carbon Footprint Standard for the Dairy Sector*. Bulletin of the IDF No. 520/2022. International Dairy Federation (ed.), Brussels, Belgium. Equation 10.

See Also

`run_production_module`

`calc_n2o_manure_direct`

Calculate direct Nitrous Oxide (N2O) emissions from manure management systems

---

Description

Calculates daily direct nitrous oxide (N2O) emissions from manure management using IPCC-based parameters and separates emissions from manure deposited on pasture, manure burned for fuel, and all other manure management systems.

Usage

```
calc_n2o_manure_direct(ratio_N2ON_to_N2O = 44/28, nitrogen_excretion, ...)
```

Arguments

`ratio_N2ON_to_N2O`

Numeric. Conversion factor from kg N2O–N to kg N2O, based on molecular weights. Defaults to 44/28.

`nitrogen_excretion`

Numeric. Daily nitrogen excretion (kg N/head/day).

`...`

A variable number of manure management system (MMS) arguments. Each MMS must be provided as a named numeric vector with exactly the following fields:

manure_management_system_fraction Numeric. Fraction of total manure excreted by animals in a given herd and cohort that is handled in a specific manure management system. Value ranges from 0 to 1. The sum of all fractions for each herd_id must equal 1.

n2o_ef3 Numeric. Emission factor for direct nitrous oxide (N2O) emissions for each manure management system, representing nitrous oxide emitted per unit of nitrogen from nitrification and denitrification processes occurring during manure storage and treatment (kg N2O–N per kg N). Default values may be selected from Table 10.21 and Table 11.1 (for manure deposited on pasture) in IPCC Guidelines (IPCC 2006, 2019).

Two MMS names are treated explicitly when present:

`mms_pasture` Manure deposited on pasture.

`mms_burned` Manure burned for fuel.

All remaining MMS arguments are grouped and treated as other manure management systems.

Details

This calculation follows the Tier 2 methodology for direct nitrous oxide (N2O) emissions from manure management as defined in the IPCC Guidelines (Equation 10.25).

In the IPCC formulation, annual direct emissions are:

$$N2O_{D(mm)} = \frac{44}{28} \sum_{S} (N \times AWMS_S \times EF3_S)$$

where:

$N2O_D(mm)$ Direct N2O emissions from Manure Management.

$44/28$ Conversion factor from N2O–N to N2O.

N Nitrogen excreted (kg N).

$AWMS_S$ Fraction of excreted nitrogen managed in manure management system S.

$EF3_S$ Direct emission factor for system S (kg N2O–N per kg N managed).

In this implementation, calculations are performed at daily, per-head resolution using `nitrogen_excretion` (kg N/head/day) - see also `calc_nitrogen_excretion`.

Daily emissions are computed as:

$$N2O = nitrogen\_excretion \times ratio\_N2ON\_to\_N2O \times \sum(manure\_management\_system\_fraction \times n2o\_ef3)$$

This function is part of the `run_emissions_manure_module()`.

Value

A named list with the following elements:

n2o_manure_pasture_direct Numeric. Direct nitrous oxide (N2O) emissions from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_direct Numeric. Direct nitrous oxide (N2O) emissions from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_direct Numeric. Direct nitrous oxide (N2O) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_direct Numeric. Direct nitrous oxide (N2O) emissions from manure management systems, excluding manure burned for fuel (kg N2O/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.25.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.25.

See Also

`run_emissions_manure_module`

Examples

```
calc_n2o_manure_direct(
  ratio_N2ON_to_N2O = 44 / 28,
  nitrogen_excretion = 0.9,
  mms_burned = c(
    manure_management_system_fraction = 0.020,
    n2o_ef3  = 0
  ),
  mms_drylot = c(
    manure_management_system_fraction = 0.264,
    n2o_ef3  = 0.02
  ),
  mms_pasture = c(
    manure_management_system_fraction = 0.310,
```

```
    n2o_ef3  = 0.02
  ),
  mms_solid = c(
    manure_management_system_fraction = 0.406,
    n2o_ef3  = 0.005
  )
)
```

`calc_n2o_manure_leaching` *Calculate indirect Nitrous Oxide (N2O) emissions from manure leaching and runoff*

Description

Calculates daily indirect nitrous oxide (N2O) emissions resulting from nitrogen leaching and runoff from manure management systems and separates emissions from manure deposited on pasture, manure burned for fuel, and all other manure management systems.

Usage

```
calc_n2o_manure_leaching(ratio_N2ON_to_N2O = 44/28, nitrogen_excretion, ...)
```

Arguments

`ratio_N2ON_to_N2O`
: Numeric. Conversion factor from kg N2O–N to kg N2O, based on molecular weights. Defaults to 44/28.

`nitrogen_excretion`
: Numeric. Daily nitrogen excretion (kg N/head/day).

`...`
: A variable number of manure management system (MMS) arguments. Each MMS must be provided as a named numeric vector with exactly the following fields:

  manure_management_system_fraction Numeric. Fraction of total manure excreted by animals in a given herd and cohort that is handled in a specific manure management system. Values ranges from 0 to 1. The sum of all fractions for each herd_id must equal 1.

  n2o_ef5 Numeric. Emission factor for indirect nitrous oxide (N2O) emissions resulting from nitrogen leaching and runoff, expressed as kilograms of N2O–N per kilogram of nitrogen leached or lost through runoff (kg N2O–N / kg N). Default values can be selected from Table 11.3 in IPCC Guidelines (IPCC 2006, 2019).

  nitrogen_fracleach Numeric. Fraction of manure nitrogen excreted by a given livestock category that is lost through leaching and runoff from a specific manure management system. This parameter is highly uncertain and is used

to estimate indirect N2O emissions from nitrogen that enters the surrounding environment of the storage facility. It is expressed as a dimensionless fraction (0–1). Default values are provided in Table 10.22 of IPCC Guidelines (IPCC 2006, 2019).

Two MMS names are treated explicitly when present:

`mms_pasture` Manure deposited on pasture.

`mms_burned` Manure burned for fuel.

All remaining MMS arguments are grouped and treated as other manure management systems.

Details

This calculation follows the Tier 2 methodology for indirect N2O emissions from manure management as defined in Equations 10.28 (IPCC, 2006), 10.27 (IPCC, 2019), and 10.29 (IPCC, 2006, 2019).

In the IPCC formulation, indirect emissions associated with nitrogen leaching and runoff are calculated as:

$$N2O_{L(mm)} = \frac{44}{28} \sum_{S} (N \times AWMS_S \times FracLeach_S \times EF5)$$

where:

$N2O_L(mm)$ Indirect N2O emissions due to leaching and runoff from Manure Management.

$44/28$ Conversion factor from N2O–N to N2O.

N Nitrogen excreted (kg N).

$AWMS_S$ Fraction of excreted nitrogen managed in manure management system S.

$FracLeach_S$ Fraction of nitrogen lost through leaching and runoff in manure management system S.

$EF5$ Emission factor for indirect N2O emissions from leaching and runoff (kg N2O–N per kg N leached or lost through runoff).

In this implementation, calculations are performed at daily, per-head resolution using `nitrogen_excretion` (kg N/head/day):

$$N_2O = nitrogen\_excretion \times ratio\_N2ON\_to\_N2O \times \sum_{S} (manure\_management\_system\_fraction \times nitrogen\_fracleach \times n2o\_ef5)$$

This function is part of the `run_emissions_manure_module()`.

Value

A named list with the following elements

n2o_manure_pasture_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure management systems, excluding losses from manure deposited on pasture and manure burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure management systems, excluding losses from manure burned for fuel (kg N2O/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equations 10.27; 10.29.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10: Emissions from Livestock and Manure Management. Equations 10.28; 10.29.

See Also

run_emissions_manure_module

Examples

```
calc_n2o_manure_leaching(
  ratio_N2ON_to_N2O = 44 / 28,
  nitrogen_excretion = 0.9,
  mms_burned = c(
    manure_management_system_fraction = 0.020,
    n2o_ef5 = 0.011,
    nitrogen_fracleach = 0
  ),
  mms_drylot = c(
    manure_management_system_fraction = 0.264,
    n2o_ef5 = 0.011,
    nitrogen_fracleach = 0.035
  ),
  mms_pasture = c(
    manure_management_system_fraction = 0.310,
    n2o_ef5 = 0.011,
    nitrogen_fracleach = 0.24
  ),
  mms_solid = c(
    manure_management_system_fraction = 0.406,
    n2o_ef5 = 0.011,
    nitrogen_fracleach = 0.02
  )
```

```
)
```

`calc_n2o_manure_total` *Calculate total Nitrous Oxide (N2O) emissions from manure*

Description

Aggregates direct and indirect nitrous oxide (N2O) emissions from manure, by manure management system group (deposited on pasture, burned for fuel, and all other systems). Indirect emissions include contributions from volatilization and from leaching and runoff.

Usage

```
calc_n2o_manure_total(
  n2o_manure_pasture_vol,
  n2o_manure_pasture_leach,
  n2o_manure_burned_vol,
  n2o_manure_burned_leach,
  n2o_manure_other_vol,
  n2o_manure_other_leach,
  n2o_manure_pasture_direct,
  n2o_manure_burned_direct,
  n2o_manure_other_direct
)
```

Arguments

`n2o_manure_pasture_vol`
: Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure deposited on pasture (kg N2O/head/day).

`n2o_manure_pasture_leach`
: Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure deposited on pasture (kg N2O/head/day).

`n2o_manure_burned_vol`
: Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure burned for fuel (kg N2O/head/day).

`n2o_manure_burned_leach`
: Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure burned for fuel (kg N2O/head/day).

`n2o_manure_other_vol`
: Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure management systems, excluding manure deposited on pasture and manure burned for fuel (kg N2O/head/day).

`n2o_manure_other_leach`
: Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure management systems, excluding losses from manure deposited on pasture and manure burned for fuel (kg N2O/head/day).

`n2o_manure_pasture_direct`
: Numeric. Direct nitrous oxide (N2O) emissions from manure deposited on pasture (kg N2O/head/day).

`n2o_manure_burned_direct`
: Numeric. Direct nitrous oxide (N2O) emissions from manure burned for fuel (kg N2O/head/day).

`n2o_manure_other_direct`
: Numeric. Direct nitrous oxide (N2O) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg N2O/head/day).

Details

The following aggregations are applied:

$$n2o\_manure\_pasture\_indirect = n2o\_vol\_manure\_pasture + n2o\_leach\_manure\_pasture$$

$$n2o\_manure\_burned\_indirect = n2o\_vol\_manure\_burned + n2o\_leach\_manure\_burned$$

$$n2o\_manure\_other\_indirect = n2o\_vol\_manure\_other + n2o\_leach\_manure\_other$$

$$n2o\_manure\_pasture\_total = n2o\_manure\_pasture\_indirect + n2o\_manure\_pasture\_direct$$

$$n2o\_manure\_burned\_total = n2o\_manure\_burned\_indirect + n2o\_manure\_burned\_direct$$

$$n2o\_manure\_other\_total = n2o\_manure\_other\_indirect + n2o\_manure\_other\_direct$$

Value

A named list with:

n2o_manure_pasture_indirect Numeric. Total indirect nitrous oxide (N2O) emissions from manure deposited on pasture. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_burned_indirect Numeric. Total indirect nitrous oxide (N2O) emissions originating from manure burned for fuel. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_other_indirect Numeric. Total indirect nitrous oxide (N2O) emissions originating from manure management systems, excluding manure deposited on pasture and manure burned for fuel. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_pasture_total Numeric. Total nitrous oxide (N2O) emissions from manure deposited on pasture. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

n2o_manure_burned_total Numeric. Total nitrous oxide (N2O) emissions from manure burned for fuel. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

n2o_manure_other_total Numeric. Total nitrous oxide (N2O) emissions from manure management systems, excluding manure deposited on pasture and manure burned for fuel. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

This function is part of the `run_emissions_manure_module()`.

See Also

`run_emissions_manure_module`

Examples

```
calc_n2o_manure_total(
  n2o_manure_pasture_vol = 0.0129,
  n2o_manure_pasture_leach = 0.0012,
  n2o_manure_burned_vol = 0,
  n2o_manure_burned_leach = 0,
  n2o_manure_other_vol = 0.052,
  n2o_manure_other_leach = 0.00027,
  n2o_manure_pasture_direct = 0.009,
  n2o_manure_burned_direct = 0,
  n2o_manure_other_direct = 0.01033
)
```

---

calc_n2o_manure_volatilization

Calculate indirect Nitrous Oxide (N2O) emissions from manure volatilization

---

Description

Calculates daily indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3–N and NOx–N) from manure management systems and separates emissions from manure deposited on pasture, manure burned for fuel, and all other manure management systems.

Usage

```
calc_n2o_manure_volatilization(
  ratio_N2ON_to_N2O = 44/28,
  nitrogen_excretion,
  ...
)
```

Arguments

`ratio_N2ON_to_N2O`
: Numeric. Conversion factor from kg N2O–N to kg N2O, based on molecular weights. Defaults to 44/28.

`nitrogen_excretion`
: Numeric. Daily nitrogen excretion (kg N/head/day).

`...`
: A variable number of manure management system (MMS) arguments. Each MMS must be provided as a named numeric vector with exactly the following fields:

  manure_management_system_fraction Numeric. Fraction of total manure excreted by animals in a given herd and cohort that is handled in a specific manure management system. Values ranges from 0 to 1. The sum of all fractions for each herd_id must equal 1.

  n2o_ef4 Numeric. Emission factor for indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3–N and NOx–N) onto soils and water surfaces (kg N2O–N per kg NH3–N + NOx–N). Default values can be selected from Table 11.3 in IPCC Guidelines (IPCC 2006, 2019).

  nitrogen_fracgas Numeric. Fraction of manure nitrogen excreted by a given livestock category that is lost through volatilisation as ammonia (NH3) and nitrogen oxides (NOx) within a specific manure management system. This parameter represents the share of excreted nitrogen that is mineralised and released to the atmosphere during manure collection, storage, and treatment. It is expressed as a dimensionless fraction (0–1). Default values are provided in Table 10.22 of IPCC Guidelines (IPCC 2006, 2019).

  Two MMS names are treated explicitly when present:

  `mms_pasture` Manure deposited on pasture.

  `mms_burned` Manure burned for fuel.

  All remaining MMS arguments are grouped and treated as other manure management systems.

Details

This calculation follows the Tier 2 methodology for indirect N2O emissions from manure management as defined in the IPCC Guidelines in Equations 10.26 (IPCC, 2006, 2019), 10.27 (IPCC, 2006) and 10.28 (IPCC, 2019).

In the IPCC formulation, indirect emissions from atmospheric deposition of volatilised nitrogen are calculated as:

$$N2O_{G(mm)} = \frac{44}{28} \sum_{S} (N \times AWMS_S \times FracGas_S \times EF4)$$

where:

$N2O_G(mm)$ Indirect N2O emissions due to volatilization of N from Manure Management.

$44/28$ Conversion factor from N2O-N to N2O.

N Nitrogen excreted (kg N).

$AWMS_S$ Fraction of excreted nitrogen managed in manure management system S.

$FracGas_S$ Fraction of nitrogen volatilised as NH3–N and NOx–N in manure management system S.

$EF4$ Emission factor for indirect N2O emissions from atmospheric deposition (kg N2O-N per kg NH3–N + NOx–N).

In this implementation, calculations are performed at daily, per-head resolution using `nitrogen_excretion` (kg N/head/day):

$$N_2O = nitrogen\_excretion \times ratio\_N2ON\_to\_N2O \times \sum_S (manure\_management\_system\_fraction \times nitrogen\_fracgas \times n2o\_ef4)$$

This function is part of the `run_emissions_manure_module()`.

Value

A named list with the following elements:

n2o_manure_pasture_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure management systems, excluding manure deposited on pasture and manure burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure management systems, excluding losses from manure burned for fuel (kg N2O/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.26; 10.28.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.26; 10.27.

See Also

`run_emissions_manure_module`

Examples

```
calc_n2o_manure_volatilization(
  ratio_N2ON_to_N2O = 44 / 28,
  nitrogen_excretion = 0.9,
  mms_burned = c(
    manure_management_system_fraction = 0.020,
    n2o_ef4 = 0.14,
    nitrogen_fracgas = 0
  ),
  mms_drylot = c(
    manure_management_system_fraction = 0.264,
    n2o_ef4 = 0.14,
    nitrogen_fracgas = 0.3
  ),
  mms_pasture = c(
    manure_management_system_fraction = 0.310,
    n2o_ef4 = 0.14,
    nitrogen_fracgas = 0.21
  ),
  mms_solid = c(
    manure_management_system_fraction = 0.406,
    n2o_ef4 = 0.14,
    nitrogen_fracgas = 0.45
  )
)
```

---

calc_n2o_ration_crop_residues

Calculate a ration component's contribution to nitrous oxide (N2O) emissions from crop residues decomposition

---

Description

Calculates the contribution of an individual feed component to nitrous oxide (N2O) emissions from crop residues decomposition in feed production, using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_n2o_ration_crop_residues(feed_ration_fraction, n2o_feed_crop_residues)
```

Arguments

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

n2o_feed_crop_residues
: Numeric. Nitrous oxide (N2O) emission factor of a feed component, representing N2O emissions from crop residues decomposition in feed production, expressed per kg of dry matter intake (g N2O/kg DM).

Details

The contribution is computed as:

$$diet\_n2o\_feed\_crop\_residues = feed\_ration\_fraction \times n2o\_feed\_crop\_residues$$

This function is part of the run_emissions_ration_module().

Value

Numeric. Contribution of an individual feed component to the diet-level average nitrous oxide (N2O) emission factor from crop residues decomposition in feed production (g N2O/kg DM).

See Also

run_emissions_ration_module

---

calc_n2o_ration_fertilizer

Calculate a ration component's contribution to nitrous oxide (N2O) emissions from fertilizer use

---

Description

Calculates the contribution of an individual feed component to nitrous oxide (N2O) emissions from synthetic fertilizer in feed production, using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_n2o_ration_fertilizer(feed_ration_fraction, n2o_feed_fertilizer)
```

Arguments

feed_ration_fraction
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

n2o_feed_fertilizer
: Numeric. Nitrous oxide (N2O) emission factor of a feed component, representing N2O emissions from fertilizer use in feed production, expressed per kg of dry matter intake (g N2O/kg DM).

Details

The contribution is computed as:

$$diet\_n2o\_feed\_fertilizer = feed\_ration\_fraction \times n2o\_feed\_fertilizer$$

This function is part of the `run_emissions_ration_module()`.

Value

Numeric. Contribution of an individual feed component to the diet-level average nitrous oxide (N2O) emission factor from fertilizer use in feed production (g N2O/kg DM).

See Also

`run_emissions_ration_module`

`calc_n2o_ration_manure`

Calculate a ration component's contribution to nitrous oxide (N2O) emissions from manure application and deposition

---

Description

Calculates the contribution of an individual feed component to nitrous oxide (N2O) emissions from manure application to or deposition on soil in feed production, using feed-specific emission factors weighted by the component's share in the ration.

Usage

```
calc_n2o_ration_manure(feed_ration_fraction, n2o_feed_manure_applied)
```

Arguments

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`n2o_feed_manure_applied`
: Numeric. Nitrous oxide (N2O) emission factor of a feed component, representing N2O emissions from manure applied to or deposited on soil in feed production, expressed per kg of dry matter intake (g N2O/kg DM).

Details

The contribution is computed as:

$$diet\_n2o\_feed\_manure\_applied = feed\_ration\_fraction \times n2o\_feed\_manure\_applied$$

This function is part of the `run_emissions_ration_module()`.

Value

Numeric. Contribution of an individual feed component to the diet-level average nitrous oxide (N2O) emission factor from manure applied to or deposited on soil in feed production (g N2O/kg DM).

See Also

run_emissions_ration_module

`calc_nitrogen_excretion` *Calculate daily nitrogen excretion*

Description

Calculates daily nitrogen excretion per animal (kg N/head/day) as the difference between nitrogen intake and nitrogen retention.

Usage

```
calc_nitrogen_excretion(species_short, nitrogen_intake, nitrogen_retention)
```

Arguments

`species_short`	Character. Code identifying the livestock species. Supported values include: • `PGS`: pigs • `CML`: camels • `CTL`: cattle • `BFL`: buffalo • `SHP`: sheep • `GTS`: goats
`nitrogen_intake`	Numeric. Daily nitrogen intake (kg N/head/day).
`nitrogen_retention`	Numeric. Daily nitrogen retention in animal body tissues and products (e.g., growth, pregnancy, milk...) (kg N/head/day).

Details

Nitrogen excretion represents the fraction of consumed nitrogen that is not retained in animal tissues or products and is therefore excreted in urine and dung.

Nitrogen excretion is calculated as:

$$nitrogen\_excretion = nitrogen\_intake - nitrogen\_retention$$

where all quantities are expressed in kg N/head/day.

This quantity forms the basis for subsequent calculations of nitrous oxide (N2O) emissions from manure management under the IPCC Tier 2 methodology.

Value

Numeric. Daily nitrogen excretion (kg N/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.31A.

This function is part of the `run_nitrogen_balance_module()`.

See Also

`run_nitrogen_balance_module`, `calc_nitrogen_retention`

`calc_nitrogen_intake` *Calculate daily nitrogen intake*

Description

Calculates the daily nitrogen intake per head (kg N/head/day) as the product of feed dry matter intake (DMI) and diet nitrogen content.

Usage

```
calc_nitrogen_intake(ration_intake, ration_nitrogen)
```

Arguments

`ration_intake`	Numeric. Average daily dry matter intake of feed (kg DM/head/day).
`ration_nitrogen`	Numeric. Average nitrogen content of diet (kg N/kg DM).

Details

This approach follows the IPCC Tier 2 approach and estimates `ration_intake` as follows:

$$nitrogen\_intake = dry\_matter\_intake \times diet\_nitrogen$$

This function is part of the `run_nitrogen_balance_module()`.

Value

Numeric. Daily nitrogen intake (kg N/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.32.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.32.

See Also

run_nitrogen_balance_module, calc_ration_intake, run_metabolic_energy_req_module, calc_ration_nitrogen_content, run_ration_quality_module

---

`calc_nitrogen_retention` *Calculate daily nitrogen retention*

Description

Calculates daily nitrogen retention per animal by species and cohort (kg N/head/day). Nitrogen retention represents the portion of consumed nitrogen that is incorporated into animal products or body tissues.

Usage

```
calc_nitrogen_retention(
  species_short,
  cohort_short,
  milk_protein_fraction = NA_real_,
  milk_yield_day = NA_real_,
  daily_weight_gain = NA_real_,
  fibre_yield_year = NA_real_,
  litter_size = NA_real_,
  parturition_rate = NA_real_,
  live_weight_at_weaning = NA_real_,
  live_weight_at_birth = NA_real_,
  pregnancy_duration = NA_real_,
  cohort_duration_days = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)

- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`milk_protein_fraction`
: Numeric. Milk protein fraction (kg protein / kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

`milk_yield_day`
: Numeric. Average milk yield per milk-producing animal during the assessment duration (kg/head/day). This value is calculated as the total quantity of milk produced for human consumption by milk-producing animals during the assessment period, divided by the number of milk-producing animals, and the length of the assessment period (days). Required only for species = CML, CTL, BFL, SHP, and GTS.

`daily_weight_gain`
: Numeric. Average live weight gain of the cohort over the cohort stage (kg/head/day).

`fibre_yield_year`
: Numeric. Annual production yield of fibre, such as wool, cashmere, mohair (kg/head/year). Required only for species = CML, SHP, and GTS.

`litter_size`
: Numeric. Average number of offspring born per parturition (# offsprings/parturition). This value can be calculated as the total number of offspring born divided by the total number of parturitions during the year.

`parturition_rate`
: Numeric. Average annual number of parturitions per female animal (# parturitions/adult female/year). A herd-level reproductive performance indicator calculated as the total number of parturitions (deliveries) occurring during a year divided by the number of adult females potentially able to give birth during that year.

`live_weight_at_weaning`
: Numeric. Live weight of the animal at weaning (kg).

`live_weight_at_birth`
: Numeric. Live weight of the animal at birth (kg).

`pregnancy_duration`
: Numeric. Duration of pregnancy period (days).

`cohort_duration_days`
: Numeric. Amount of time that each animal spends in a specific cohort (days).

Details

Species-specific nitrogen retention calculations are applied.

For CTL, BFL, SHP, GTS, and CML:

Nitrogen retained in products and tissues is computed consistent with the process described in the Technical paper from MPI (Ministry for Primary Industries (MPI), 2025), where nitrogen retention is calculated as the sum of:

- nitrogen secreted in milk,
- nitrogen retained in live weight gain (tissue),

- nitrogen retained in fibre (for fibre-producing species).

Coefficients for nitrogen content of deposited tissue, fibre, and milk are derived from Chapter 5 (Nitrogen Excretion) of the MPI Technical paper.

The following constants are used:

- **Tissue nitrogen content** (`tissue_n`)
  - `CTL` and `BFL`: **0.0326 kg N/kg live weight**
  - `SHP`, `GTS` and `CML`: **0.026 kg N/kg live weight**
- **Fibre nitrogen content** (`fibre_n`)
  - `SHP`, `GTS` and `CML`: **0.134 kg N/kg fibre**
- **Milk nitrogen content** (`milk_n`):
  - `CTL`, `BFL`, `SHP`, `GTS` and `CML`: derived from `milk_protein_fraction` using a protein-to-nitrogen conversion factor of **6.25 kg protein/kg nitrogen**

For PGS

Nitrogen retention is calculated following the IPCC (2019) Tier 2 equations for swine (Equations 10.33A and 10.33B).

Nitrogen retention includes nitrogen retained in:

- live weight gain (tissue),
- reproductive outputs (conceptus and weaned offspring).

In this implementation:

- Nitrogen content of live weight gain is assumed to be `0.025` **kg N/kg live weight**.
- Protein digestibility fraction is assumed to be `0.98` **(dimensionless)**.
- For breeding cohorts, the reproductive component is represented by annual nitrogen retention in conceptus and weaned offspring, expressed as a daily average by distributing the annual value uniformly over the year (365 days).
- A constant factor of `0.806` **(dimensionless)** is applied to piglets' live weight gain to correct for their higher nitrogen content per unit of live weight gain, following IPCC (2019).

This function is part of the `run_nitrogen_balance_module()`.

Value

Numeric. Daily nitrogen retention in animal body tissues and products (e.g., growth, pregnancy, milk...) (kg N/head/day)

References

Ministry for Primary Industries (MPI). (2025). *Detailed methodologies for agricultural greenhouse gas emission calculation: Methodology for calculation of New Zealand's agricultural greenhouse gas emissions* (Version 11). MPI Technical Paper, Wellington, New Zealand. Chapter 5.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.33A, 10.33B.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.33.

See Also

run_nitrogen_balance_module

---

calc_projected_population_size
Calculate one year of steady-state population dynamics

Description

Calculates one year of population dynamics under steady-state assumptions using demographic parameters and returns population size statistics and offtake results. The steady state is defined as a constant sex–age cohort structure over time, with population size potentially growing or declining at a constant rate.

Usage

```
calc_projected_population_size(
  herd_size_total,
  fecundity_female,
  fecundity_male,
  probability_death,
  probability_offtake,
  probability_growth,
  growth_rate_herd,
  herd_structure,
  cohort_share
)
```

Arguments

herd_size_total
: Numeric. Total population size at the start of the year, including all cohorts (# heads)

fecundity_female
: Numeric. Daily number of female offspring per adult female (# offspring/day)

fecundity_male
: Numeric. Daily number of male offspring per adult female (# offspring/day)

probability_death
: Named numeric vector of length 10. Probability of animal dying within the model time interval for 10 cohorts (fraction) (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult, FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling).

probability_offtake
: Named numeric vector of length 10. Probability that an animal will be removed from the herd within the model time interval for 10 cohorts (fraction). (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult,

FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling).

probability_growth
: Named numeric vector of length 10. Probability of growing into the next age class for 10 cohorts (fraction) (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult, FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling).

growth_rate_herd
: Numeric. Annualized growth rate at which the herd reaches steady state (fraction)

herd_structure
: Named numeric vector of length 8. Final steady-state share of each of 8 sex-age cohorts (FB, FJ, FS, FA, MB, MJ, MS, MA) (fraction). Shares should sum to 1.

cohort_share
: Named numeric vector of length 6. Final steady-state share of 6 grouped sex-age cohorts (FJ, FS, FA, MJ, MS, MA, where FJ = FB + FJ and MJ = MB + MJ) (fraction). Shares should sum to 1.

Value

A named list with:

cohort_stock_start Numeric vector of length 6. Population size in each of the 6 sex–age cohorts at the start of the year (# heads). (cohorts= FJ, FS, FA, MJ, MS, MA)

cohort_stock_end_projected Numeric vector of length 6. Population size in each of the 6 sex–age cohorts at the end of the year, projected using the steady-state growth rate (# heads). (cohorts= FJ, FS, FA, MJ, MS, MA)

cohort_stock_end_exact_simulated Numeric vector of length 10. Population size in each of 10 sex–age cohort at the end of the year, based on a demographic daily simulation over 365 days (# heads) (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult, FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling)

cohort_stock_average Numeric vector of length 6. Average population size in each of the 6 sex–age cohorts over the year (# heads). Estimated from cohort_stock_start and cohort_stock_end_projected (cohorts= FJ, FS, FA, MJ, MS, MA)

cohort_offtake_heads Numeric vector of length 10. Total number of animals removed from the herd over the year, by 10 sex–age cohorts (heads/year) (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult, FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling)

This function is part of the run_demographic_herd_module().

See Also

run_demographic_herd_module()

`calc_ration_ash` *Calculate diet ash contribution for a ration component*

Description

Calculates the contribution of a single feed component to diet ash content by weighting feed ash content by its ration composition share.

Usage

```
calc_ration_ash(feed_ration_fraction, feed_ash)
```

Arguments

`feed_ration_fraction`	Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.
`feed_ash`	Numeric. Average ash content by feed component, expressed as a fraction of the dry matter intake (g ash/100g DM).

Details

The ash contribution is defined as:

$$ration\_ash = feed\_ration\_fraction \times feed\_ash/100$$

Ash content is expressed as a percentage (g/100g DM); the result is a fraction.

This function is part of the `run_ration_quality_module()`.

Value

Numeric. Contribution of the feed component to total diet ash content (kg ash/kg DM).

See Also

`run_ration_quality_module`

`calc_ration_digestibility` *Calculate diet digestibility contribution for a ration component*

Description

Applies species-specific digestibility parameters to a ration composition share to compute the contribution of a single feed component to total diet digestibility.

Usage

```
calc_ration_digestibility(
  species_short,
  feed_ration_fraction,
  feed_digestibility_fraction_ruminant = NA_real_,
  feed_digestibility_fraction_pigs = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`feed_digestibility_fraction_ruminant`
: Numeric. Digestibility of a feed component for ruminants, expressed as the ratio of digestible energy to gross energy content (fraction).

`feed_digestibility_fraction_pigs`
: Numeric. Digestibility of a feed component for pigs, expressed as the ratio of digestible energy to gross energy content (fraction).

Details

The digestibility contribution uses the animal-specific digestibility ratio:

- Ruminants (`CTL`, `BFL`, `CML`, `SHP`, `GTS`): `feed_ration_fraction * feed_digestibility_fraction_ruminant`
- Pigs (`PGS`): `feed_ration_fraction * feed_digestibility_fraction_pigs`

This function is part of the `run_ration_quality_module()`.

Value

Numeric. Contribution of the feed component to total diet digestibility (fraction).

See Also

run_ration_quality_module

---

calc_ration_gross_energy *Calculate diet gross energy contribution for a ration component*

Description

Computes the contribution of a single feed component to diet gross energy content by weighting feed gross energy by its ration composition share.

Usage

```
calc_ration_gross_energy(feed_ration_fraction, feed_gross_energy)
```

Arguments

feed_ration_fraction	Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.
feed_gross_energy	Numeric. Gross energy content of a feed component, representing the total chemical energy released upon complete combustion of the feed (MJ/kg DM).

Details

The gross energy contribution is defined as:

$$diet\_gross\_energy = feed\_ration\_fraction \times feed\_gross\_energy$$

This function is part of the run_ration_quality_module().

Value

Numeric. Contribution of the feed component to total diet gross energy content (MJ/kg DM).

See Also

run_ration_quality_module

`calc_ration_intake` *Calculate daily ration intake in dry matter*

Description

Calculates daily feed intake as dry matter intake (DMI) per animal (kg DM/head/day) from the animal's daily energy requirement and the diet energy density.

Usage

```
calc_ration_intake(
  species_short,
  metabolic_energy_req_total,
  ration_gross_energy,
  ration_metabolizable_energy
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`metabolic_energy_req_total`
: Numeric. Total daily energy requirement (MJ/head/day). For CTL, BFL, SHP and GTS this is expressed as gross energy intake requirement (GE). For CML and PGS the function returns the summed daily metabolizable energy requirement.

`ration_gross_energy`
: Numeric. Average gross energy content of the diet (MJ/kg DM).

`ration_metabolizable_energy`
: Numeric. Average metabolizable energy content of the diet (MJ/kg DM).

Details

This function follows the IPCC Tier 2 framework. DMI is computed by dividing the appropriate daily energy requirement by the corresponding diet energy content (MJ/kg DM).

- **Energy expressed as gross energy intake requirement -** `CTL`**,** `BFL`**,** `SHP`**,** `GTS`:

$$ration\_intake = \frac{metabolic\_energy\_req\_total}{ration\_gross\_energy}$$

- **Energy expressed as metabolizable energy requirement -** `CML`**,** `PGS`:

$$ration\_intake = \frac{metabolic\_energy\_req\_total}{ration\_metabolizable\_energy}$$

This function is part of the `run_metabolic_energy_req_module()`.

Value

Numeric. Average daily dry matter intake of feed (kg DM/head/day).

References

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4 (AFOLU), Chapter 10: *Emissions from Livestock and Manure Management*.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4 (AFOLU), Chapter 10: *Emissions from Livestock and Manure Management*.

See Also

`run_metabolic_energy_req_module`, `calc_total_metabolic_energy_req` `calc_ration_gross_energy` `calc_ration_metabolizable_energy`

`calc_ration_metabolizable_energy` *Calculate diet metabolizable energy contribution for a ration component*

Description

Applies species-specific metabolizable energy parameters to a ration composition share to compute the contribution of a single feed component to total diet metabolizable energy content.

Usage

```
calc_ration_metabolizable_energy(
  species_short,
  feed_ration_fraction,
  feed_metabolizable_energy_ruminant = NA_real_,
  feed_metabolizable_energy_pigs = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`feed_metabolizable_energy_ruminant`
: Numeric. Metabolizable energy content of a feed component for ruminants, representing digestible energy minus energy losses in urine and gaseous products of digestion (MJ/kg DM).

`feed_metabolizable_energy_pigs`
: Numeric. Metabolizable energy content of a feed component for pigs, representing digestible energy minus energy losses in urine and gaseous products of digestion (MJ/kg DM).

Details

The metabolizable energy contribution uses the animal-specific parameter:

- Ruminants (`CTL`, `BFL`, `CML`, `SHP`, `GTS`): `feed_ration_fraction * feed_metabolizable_energy_ruminant`
- Pigs (`PGS`): `feed_ration_fraction * feed_metabolizable_energy_pigs`

This function is part of the `run_ration_quality_module()`.

Value

Numeric. Contribution of the feed component to total diet metabolizable energy content (MJ/kg DM).

See Also

`run_ration_quality_module`

`calc_ration_nitrogen_content` *Calculate diet nitrogen contribution for a ration component*

Description

Calculates the contribution of a single feed component to diet nitrogen content by weighting feed nitrogen content by its ration composition share.

Usage

```
calc_ration_nitrogen_content(feed_ration_fraction, feed_nitrogen_content)
```

Arguments

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`feed_nitrogen_content`
: Numeric. Nitrogen content of a feed component (kg N/kg DM).

Details

The nitrogen contribution is defined as:

$$diet\_nitrogen = feed\_ration\_fraction \times feed\_nitrogen\_content$$

Value

Numeric. Contribution of the feed component to total diet nitrogen content (kg N/kg DM).

`calc_ration_urinary_energy_fraction` *Calculate urinary energy fraction contribution for a ration component*

Description

Applies species-specific urinary energy fractions to a ration composition share to compute the contribution of a feed component to urinary energy losses.

Usage

```
calc_ration_urinary_energy_fraction(
  species_short,
  feed_ration_fraction,
  feed_urinary_energy_ruminant = NA_real_,
  feed_urinary_energy_pigs = NA_real_
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`feed_ration_fraction`
: Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`feed_urinary_energy_ruminant`
: Numeric. Fraction of feed's gross energy that is excreted in urine for ruminants (fraction).

`feed_urinary_energy_pigs`
: Numeric. Fraction of feed's gross energy that is excreted in urine for pigs (fraction).

Details

The urinary energy fraction contribution uses the animal-specific parameter:

- Ruminants (`CTL`, `BFL`, `CML`, `SHP`, `GTS`): `feed_ration_fraction * feed_urinary_energy_ruminant`
- Pigs (`PGS`): `feed_ration_fraction * feed_urinary_energy_pigs`

This function is part of the `run_ration_quality_module()`.

Value

Numeric. Contribution of the feed component to the fraction of total diet gross energy that is excreted in urine (fraction).

See Also

`run_ration_quality_module`

`calc_reg_growth` *Calculate the ratio of net energy available for growth in the diet (REG – Net Energy for Growth / Digestible Energy)*

Description

Calculates the ratio of net energy available for growth to digestible energy consumed (fraction), which represents the efficiency with which digestible energy in the diet is converted into net energy retained as body tissue.

Usage

```
calc_reg_growth(species_short, ration_digestibility_fraction = NA_real_)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`ration_digestibility_fraction`
Numeric. Average digestibility of the feed ration, expressed as ratio of digestible to gross energy content (fraction).

Details

This component follows the IPCC Tier 2 partitioning approach and returns REG for ruminants (`CTL`, `BFL`, `SHP`, `GTS`) as:

$$net\_energy\_growth\_digestible\_energy\_ratio = 1.164 - 0.005160 \times diet\_digestibility\_fraction \times 100 + 0.00001308 \times (d$$

For Other species REG is not applicable and the function returns `NA_real_`.

This function is part of the `run_metabolic_energy_req_module()`.

Value

Numeric. Ratio of net energy available for growth in the diet to digestible energy consumed (fraction).

References

Gibbs M.J., Johnson D.E. (1993) *Livestock Emissions*. In: International Methane Emissions. Washington, D.C., U.S.A: US Environmental Protection Agency, Climate Change Division.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.15.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.15.

See Also

`run_metabolic_energy_req_module`, `calc_ration_digestibility` `calc_total_metabolic_energy_req` `calc_ration_intake`

`calc_rem_maintenance` *Calculate ratio of net energy available for maintenance in the diet (REM - Net Energy for Maintenance / Digestible Energy)*

Description

Calculates the ratio of net energy available in the diet for maintenance to digestible energy.

Usage

```
calc_rem_maintenance(species_short, ration_digestibility_fraction = NA_real_)
```

Arguments

`species_short`	Character. Code identifying the livestock species. Supported values include: • `PGS`: pigs • `CML`: camels • `CTL`: cattle • `BFL`: buffalo • `SHP`: sheep • `GTS`: goats
`ration_digestibility_fraction`	Numeric. Average digestibility of the feed ration, expressed as ratio of digestible to gross energy content (fraction).

Details

This component follows the IPCC Tier 2 partitioning approach and it returns the value for ruminants (`CTL`, `BFL`, `SHP`, `GTS`) calculated as follows:

$$net\_energy\_maintenance\_digestible\_energy\_ratio = 1.123 - 0.004092 \times (diet\_digestibility\_fraction \times 100) + 0.0000$$

For the Other species REM is not applicable and the function returns `NA_real_`.

This function is part of the `run_metabolic_energy_req_module()`.

Value

Numeric. Ratio of net energy available for maintenance in the diet to digestible energy consumed (fraction).

References

Gibbs M.J., Johnson D.E. (1993) *Livestock Emissions*. In: International Methane Emissions. Washington, D.C., U.S.A: US Environmental Protection Agency, Climate Change Division.

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.14.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.14.

See Also

`run_metabolic_energy_req_module`, `calc_ration_digestibility` `calc_total_metabolic_energy_req` `calc_ration_intake`

`calc_steady_state_structure`

Calculate steady-state population structure

Description

Calculates population dynamics over time until a steady state is reached. The steady state is defined as a constant sex–age cohort structure over time, with population size potentially growing or declining at a constant rate. Tracks sex–age cohort structure and population growth based on survival, offtake, and fecundity parameters.

Usage

```
calc_steady_state_structure(
  initial_herd_structure,
  max_simulation_years,
  min_lambda_change,
  fecundity_female,
  fecundity_male,
  probability_death,
  probability_offtake,
  probability_growth
)
```

Arguments

`initial_herd_structure`
: Named numeric vector of length 6. Initial number of individuals in each of the 6 sex-age classes used to bootstrap the steady-state simulation (# heads). These values are used as starting points for the iterative simulation and do not affect the final steady-state results (only convergence speed). Must be named with: `FJ`, `FS`, `FA`, `MJ`, `MS`, `MA`.

`max_simulation_years`
: Numeric. Maximum number of years to simulate (years).

`min_lambda_change`
: Numeric. Convergence threshold for changes in cohort-specific growth rates of sex–age cohort proportions (lambda). Iterations of the herd simulation stop when the absolute change in lambda between successive iterations falls below this threshold.

`fecundity_female`
: Numeric. Daily number of female offspring per adult female (# offspring/day)

`fecundity_male`
: Numeric. Daily number of male offspring per adult female (# offspring/day)

`probability_death`
: Named numeric vector of length 10. Probability of animal dying within the model time interval for 10 cohorts (fraction) (cohorts= `FB`: Female Birth, `FJ`: Female Juvenile, `FS`: Female Sub-adult, `FA`: Female Adult, `FC`: Female Culling, `MB`: Male Birth, `MJ`: Male Juvenile, `MS`: Male Sub-adult, `MA`: Male Adult, `MC`: Male Culling).

`probability_offtake`
: Named numeric vector of length 10. Probability that an animal will be removed from the herd within the model time interval for 10 cohorts (fraction). (cohorts= `FB`: Female Birth, `FJ`: Female Juvenile, `FS`: Female Sub-adult, `FA`: Female Adult, `FC`: Female Culling, `MB`: Male Birth, `MJ`: Male Juvenile, `MS`: Male Sub-adult, `MA`: Male Adult, `MC`: Male Culling).

`probability_growth`
: Named numeric vector of length 10. Probability of growing into the next age class for 10 cohorts (fraction) (cohorts= `FB`: Female Birth, `FJ`: Female Juvenile, `FS`: Female Sub-adult, `FA`: Female Adult, `FC`: Female Culling, `MB`: Male Birth, `MJ`: Male Juvenile, `MS`: Male Sub-adult, `MA`: Male Adult, `MC`: Male Culling).

Value

A named list with:

days_to_steady_state Numeric. Number of days required for the herd population structure to converge to a steady state, defined as the point at which successive iterations produce negligible changes in cohort proportions (days)

herd_structure Named numeric vector of length 8. Final steady-state share of each of 8 sex-age cohorts (`FB`, `FJ`, `FS`, `FA`, `MB`, `MJ`, `MS`, `MA`) (fraction). Shares should sum to 1.

cohort_share Named numeric vector of length 6. Final steady-state share of 6 grouped sex-age cohorts (`FJ`, `FS`, `FA`, `MJ`, `MS`, `MA`, where `FJ = FB + FJ` and `MJ = MB + MJ`) (fraction). Shares should sum to 1.

growth_rate_herd Numeric. Annualized growth rate at which the herd reaches steady state (fraction)

This function is part of the `run_demographic_herd_module()`.

See Also

`run_demographic_herd_module()`

`calc_summary_offtake` *Summarise offtake and stock Variation for a steady-state year*

Description

Calculates annual offtake quantities and rates, as well as stock variation and their combined values across 6 sex-age classes based on steady-state population projections. The steady state is defined as a constant sex–age cohort structure over time, with population size potentially growing or declining at a constant rate.

Usage

```
calc_summary_offtake(
  cohort_stock_start,
  cohort_stock_end_projected,
  cohort_stock_average,
  cohort_offtake_heads,
  simulation_duration
)
```

Arguments

`cohort_stock_start`
: Numeric vector of length 6. Population size in each of the 6 sex–age cohorts at the start of the year (# heads). (cohorts= `FJ`, `FS`, `FA`, `MJ`, `MS`, `MA`)

`cohort_stock_end_projected`
: Numeric vector of length 6. Population size in each of the 6 sex–age cohorts at the end of the year, projected using the steady-state growth rate (# heads). (cohorts= `FJ`, `FS`, `FA`, `MJ`, `MS`, `MA`)

`cohort_stock_average`
: Numeric vector of length 6. Average population size in each of the 6 sex–age cohorts over the year (# heads). Estimated from cohort_stock_start and cohort_stock_end_projected (cohorts= `FJ`, `FS`, `FA`, `MJ`, `MS`, `MA`)

`cohort_offtake_heads`
: Numeric vector of length 10. Total number of animals removed from the herd over the year, by 10 sex–age cohorts (heads/year) (cohorts= `FB`: Female Birth, `FJ`: Female Juvenile, `FS`: Female Sub-adult, `FA`: Female Adult, `FC`: Female Culling, `MB`: Male Birth, `MJ`: Male Juvenile, `MS`: Male Sub-adult, `MA`: Male Adult, `MC`: Male Culling)

`simulation_duration`
: Numeric. Length of the assessment period (days)

Value

A named list with:

stock_variation_heads Numeric vector of length 6. Change in population size between the start and end of the year for each sex–age cohort (# heads) (cohorts= FJ, FS, FA, MJ, MS, MA).

offtake_heads Numeric vector of length 6. Total number of animals removed via offtake over the year, aggregated to 6 sex–age cohorts (heads/year) (cohorts= FJ, FS, FA, MJ, MS, MA)

offtake_heads_assessment Numeric vector of length 6. Total number of animals removed via offtake over the assessment period, aggregated to 6 sex–age cohorts (heads/assessment period) (cohorts= FJ, FS, FA, MJ, MS, MA)

offtake_rate_to_stock_start Numeric vector of length 6. Offtake rate relative to the starting population size in each sex–age cohort (fraction) (cohorts= FJ, FS, FA, MJ, MS, MA)

offtake_rate_to_stock_average Numeric vector of length 6. Offtake rate relative to the average population size in each sex–age cohort (fraction) (cohorts= FJ, FS, FA, MJ, MS, MA)

offtake_stock_variation_heads Numeric vector of length 6. Sum of offtake and stock variation for each sex–age cohort over the year (# heads) (cohorts= FJ, FS, FA, MJ, MS, MA)

offtake_stock_plus_variation_rate_to_stock_start Numeric vector of length 6. Offtake plus stock-variation rate relative to starting population size (fraction) (cohorts= FJ, FS, FA, MJ, MS, MA)

offtake_stock_plus_variation_rate_to_stock_average Numeric vector of length 6. Offtake plus stock-variation rate relative to average population size (fraction) (cohorts= FJ, FS, FA, MJ, MS, MA)

This function is part of the `run_demographic_herd_module()`.

See Also

`run_demographic_herd_module()`

`calc_total_metabolic_energy_req`
Calculate total metabolic energy requirements

Description

Calculates the total daily energy requirement (MJ/head/day) by summing relevant energy partitions (maintenance, activity, lactation, work, pregnancy, growth, fibre, egg deposition).

Usage

```
calc_total_metabolic_energy_req(
  species_short,
  metabolic_energy_req_maintenance,
  metabolic_energy_req_activity,
  metabolic_energy_req_lactation,
  metabolic_energy_req_work,
  metabolic_energy_req_pregnancy,
  net_energy_maintenance_digestible_energy_ratio,
  metabolic_energy_req_growth,
  metabolic_energy_req_fibre_production,
  metabolic_energy_req_egg_deposition,
  net_energy_growth_digestible_energy_ratio,
  ration_digestibility_fraction
)
```

Arguments

`species_short` Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

`metabolic_energy_req_maintenance`
: Numeric. Energy required for maintenance, defined as the amount of energy needed to keep the animal at equilibrium such that body energy is neither gained nor lost (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

`metabolic_energy_req_activity`
: Numeric. Energy required for activity, defined as the amount of energy needed to support animal movement and physical activity (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

`metabolic_energy_req_lactation`
: Numeric. Energy required for lactation (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

`metabolic_energy_req_work`
: Numeric. Energy required for work, used to estimate the energy required for draught power for CTL, BFL and CML (MJ/head/day). Assumed to be 0 for other species. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

`metabolic_energy_req_pregnancy`
: Numeric. Energy required for pregnancy for pregnant females (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

`net_energy_maintenance_digestible_energy_ratio`
: Ratio of net energy available for maintenance in the diet to digestible energy consumed (fraction).

`metabolic_energy_req_growth`
: Numeric. Energy required for growth (i.e., weight gain) (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

`metabolic_energy_req_fibre_production`
: Numeric. Energy required for the synthesis of fibre for SHP, GTS and CML. Assumed to be 0 for other species (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

`metabolic_energy_req_egg_deposition`
: Numeric. Net energy for egg production (MJ/head/day).

`net_energy_growth_digestible_energy_ratio`
: Numeric. Ratio of net energy available for growth in the diet to digestible energy consumed (fraction)

`ration_digestibility_fraction`
: Numeric. Average digestibility of the feed ration, expressed as ratio of digestible to gross energy content (fraction).

Details

This component follows the IPCC Tier 2 partitioning approach and the calculation is computed differently depending on whether species energy requirements are expressed as net or metabolizable energy.

Species-specific approach:

- **Energy requirements expressed as net energy** (`CTL`, `BFL`, `SHP`, `GTS`)
  - `CTL` **and** `BFL`:

$$metabolic\_energy\_req\_total = \frac{\left(\frac{metabolic\_energy\_req\_maintenance+metabolic\_energy\_req\_activity+metabolic\_energ}{REM}\right.}{a}$$

  - `SHP` **and** `GTS`:

$$metabolic\_energy\_req\_total = \frac{\left(\frac{metabolic\_energy\_req\_maintenance+metabolic\_energy\_req\_activity+metabolic\_energ}{REM}\right.}{}$$

- **Energy requirements expressed as metabolizable energy** (`CML`, `PGS`)
  For these species, the total daily requirement is computed as the **direct sum** of relevant energy components (MJ/head/day).
  - `CML`:

$$metabolic\_energy\_req\_total = metabolic\_energy\_req\_maintenance+metabolic\_energy\_req\_activity+m$$

  - `PGS`:

$$metabolic\_energy\_req\_total = metabolic\_energy\_req\_maintenance+metabolic\_energy\_req\_activity+m$$

This function is part of the `run_metabolic_energy_req_module()`.

Value

Numeric. Total daily energy requirement (MJ/head/day). For CTL, BFL, SHP and GTS this is expressed as gross energy intake requirement (GE). For CML and PGS the function returns the summed daily metabolizable energy requirement.

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.16.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management, Equation 10.16.

See Also

run_metabolic_energy_req_module, calc_metabolic_energy_req_maintenance calc_metabolic_energy_req_acti
calc_metabolic_energy_req_growth calc_metabolic_energy_req_lactation calc_metabolic_energy_req_work
calc_metabolic_energy_req_fibre calc_metabolic_energy_req_pregnancy calc_rem_maintenance
calc_reg_growth calc_ration_intake

---

calc_transition_probabilities

Calculate transition probabilities for sex-age classes

Description

Calculates hazard rates and daily transition probabilities (death, offtake, survival, and growth) across different sex-age cohorts. Converts annual inputs to daily hazards, then derives daily probabilities from those hazards.

Usage

```
calc_transition_probabilities(cohort_duration_days, offtake_rate, death_rate)
```

Arguments

cohort_duration_days	Numeric vector of length 6. Amount of time that each animal spends in a specific cohort (days).
offtake_rate	Numeric vector of length 6. Annual proportion of animals removed from the herd for each sex-age cohort (fraction).
death_rate	Numeric vector of length 6. Fraction of deaths in a herd over a year for each sex-age cohort (fraction)

Value

A named list with:

hazard_death Numeric vector of length 6. Instantaneous mortality hazard rate for the 6 sex–age cohorts. Represents the risk of death per unit time (day) (cohorts= FJ, FS, FA, MJ, MS, MA)

hazard_offtake Numeric vector of length 6. Instantaneous offtake hazard rate for the 6 sex-age cohorts. Represents the risk to leave the herd through planned removals per unit of time (day-1) (cohorts= FJ, FS, FA, MJ, MS, MA)

probability_death Named numeric vector of length 10. Probability of animal dying within the model time interval for 10 cohorts (fraction). (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult, FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling)

probability_offtake Named numeric vector of length 10. Probability that an animal will be removed from the herd within the model time interval for 10 cohorts (fraction). (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult, FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling)

probability_survival Named numeric vector of length 10. Probability that an animal remains alive in the herd within the model time interval for 10 cohorts (fraction). (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult, FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling)

probability_growth Named numeric vector of length 10. Probability of growing into the next age class for 10 cohorts (fraction) (cohorts= FB: Female Birth, FJ: Female Juvenile, FS: Female Sub-adult, FA: Female Adult, FC: Female Culling, MB: Male Birth, MJ: Male Juvenile, MS: Male Sub-adult, MA: Male Adult, MC: Male Culling)

This function is part of the run_demographic_herd_module().

See Also

run_demographic_herd_module()

---

calc_volatile_solids *Calculate Volatile Solids (VS)*

Description

Calculates daily volatile solids (VS) excretion in manure (kg VS/head/day). VS represent the organic fraction of manure dry matter, including both biodegradable and non-biodegradable organic material. VS is a key intermediate variable required for estimating methane (CH4) emissions from manure management systems under IPCC methodologies.

Usage

```
calc_volatile_solids(
  ration_intake,
  ration_digestibility_fraction,
  ration_urinary_energy_fraction,
  ration_ash
)
```

Arguments

`ration_intake`	Numeric. Average daily dry matter intake of feed (kg DM/head/day).
`ration_digestibility_fraction`	Numeric. Average digestibility of the feed ration, expressed as ratio of digestible to gross energy content (fraction).
`ration_urinary_energy_fraction`	Numeric. Fraction of feed's gross energy that is excreted in urine (fraction).
`ration_ash`	Numeric. Average ash content of feed, calculated as a fraction of the dry matter intake (kg ash/kg DM).

Details

The IPCC recommends estimating volatile solids (VS) excretion from feed intake and digestibility when country-specific average daily VS excretion rates are not available. The core relationship is provided in **IPCC Equation 10.24 (Volatile solids excretion rates)**, which estimates daily VS excretion as a function of:

- Gross energy intake (gross_energy_intake, MJ/day)
- Digestibility of the diet (ration_digestibility_fraction)
- Urinary energy expressed as a fraction of GE (ration_urinary_energy_fraction)
- Ash content of the diet (ration_ash, fraction of dry matter)
- A conversion factor representing the average gross energy content of dry matter (18.45 MJ/kg DM)

The general structure of Eq. 10.24 partitions gross energy intake into digestible energy, urinary losses, and ash, and converts the remaining organic matter into volatile solids using the energy density of dry matter.

Implementation note. This function applies an algebraically simplified formulation from Equation 10.24 of IPCC.

In this implementation, the function takes `ration_intake` directly as an input. It can be calculated upstream with `calc_ration_intake` as a function of energy requirements and the energy content of the diet.

$$dry\_matter\_intake = \frac{gross\_energy\_intake}{diet\_gross\_energy}$$

This reflects the use of ration-specific energy content upstream and avoids assuming a fixed gross energy density of 18.45 MJ/kg DM, as in the IPCC default approach.

The volatile solids excretion is then calculated as:

$$volatile\_solids = dry\_matter\_intake \times (1 - diet\_digestibility\_fraction + urinary\_energy\_fraction) \times (1 - diet\_ash)$$

The resulting calculations are algebraically equivalent to the IPCC approach and fully consistent with Equation 10.24.

This function is part of the `run_emissions_manure_module()`.

Value

Numeric. Total volatile solids (VS) excreted per animal per day, representing the organic material in livestock manure and consisting of both biodegradable and non-biodegradable fractions (kg VS/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.24.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Chapter 10: Emissions from Livestock and Manure Management. Equation 10.24.

See Also

`run_emissions_manure_module`

Examples

```
calc_volatile_solids <- calc_volatile_solids(
  ration_intake = 5,
  ration_digestibility_fraction = 0.6,
  ration_urinary_energy_fraction = 0.04,
  ration_ash = 0.08
)
```

---

calc_work_allocation_energy

Calculate work energy requirements (for biophysical allocation)

Description

Calculates the energy required for animal work over the assessment period (MJ/cohort/assessment period), based on the daily energy requirement for work, cohort size, and assessment duration.

Usage

```
calc_work_allocation_energy(
  species_short,
  cohort_stock_size,
  metabolic_energy_req_work,
  simulation_duration,
  ratio_me_to_ne = NA_real_
)
```

Arguments

species_short	Character. Code identifying the livestock species. Supported values include: • PGS: pigs • CML: camels • CTL: cattle • BFL: buffalo • SHP: sheep • GTS: goats
cohort_stock_size	Numeric. Population size in the cohort at the start of the assessment period (heads).
metabolic_energy_req_work	Numeric. Energy required for work, used to estimate the energy required for draught power for CTL, BFL and CML. (MJ/head/day) Assumed to be 0 for other species. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.
simulation_duration	Numeric. Length of the assessment period (days).
ratio_me_to_ne	Numeric. Ratio of metabolizable energy converted to net energy (fraction).

Details

This function provides the work-related energy term used in a biophysical allocation framework to apportion emissions between milk and other co-products in multifunctional livestock production systems.

The approach implements the IDF (2022) standard, adapted from Thoma and Nemecek (2020), and is consistent with FAO LEAP livestock LCA guidelines (FAO, 2016a, 2016b, 2016c) and with ISO 14044:2006 (Section 4.3.4.2, Step 2).

In accordance with ISO 14044:2006 (Section 4.3.4.2, Step 2), known processing or biophysical relationships may be used to assign shared inputs and outputs of a single production unit to individual products or sub-units. In livestock systems, this includes apportioning shared feed and energy use according to physiological energy requirements (e.g., net energy for lactation, growth, etc.). If the resulting process remains multifunctional, these energy terms may subsequently be used to derive allocation factors among co-products.

Total work-related energy is computed for species (CTL, BFL, CML) and cohorts (, FA, MA) assumed to be potentially involved in draught power generation.

The work_allocation_energy is calculated as follows:

$$energy\_allocation\_work = energy\_requirement\_work \times simulation\_duration \times cohort\_stock\_size$$

for cattle (CTL) and buffalo (BFL), and:

$$energy\_allocation\_work = \frac{energy\_requirement\_work \times simulation\_duration \times cohort\_stock\_size}{ratio\_me\_to\_ne}$$

for camels (CML).

where metabolic_energy_req_work can be computed using calc_metabolic_energy_req_work (see also run_metabolic_energy_req_module).

This function is part of the run_allocation_module().

Value

Numeric. Energy required to provide all draught power (traction/work) by cohort (MJ/cohort/assessment period). Non-zero values are expected only for draught or work-producing species (CTL, BFL CML).

References

ISO. (2006). *Environmental management — Life cycle assessment — Requirements and guidelines (ISO 14044:2006)*. International Organization for Standardization, Geneva.

IDF. (2022). *The IDF Global Carbon Footprint Standard for the Dairy Sector*. Bulletin of the IDF No. 520/2022. International Dairy Federation, Brussels.

Thoma, G., and Nemecek, T. (2020). Allocation between milk and meat in dairy LCA: Critical discussion of the IDF's standard methodology. In *Proceedings of the 12th International Conference on Life Cycle Assessment of Food (LCAFood 2020)* (pp. 83–89), 13–16 October, Berlin, Germany.

FAO. (2016a). *Environmental performance of large ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016b). *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016c). *Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

See Also

run_allocation_module, calc_metabolic_energy_req_work, run_metabolic_energy_req_module

`run_aggregation_module` *Run Aggregation Module Pipeline*

Description

This function generates final herd-level results by aggregating key cohort-level outputs, scaling variables over the assessment duration, allocating emissions to commodities, and converting methane (CH4) and nitrous oxide (N2O) emissions to CO2-equivalents (CO2eq) using selected 100-year Global Warming Potential (GWP-100) factors.

Usage

```
run_aggregation_module(
  cohort_level_data,
  allocation_herd_long,
  simulation_duration = 365,
  global_warming_potential_set = "AR6",
  show_indicator = TRUE
)
```

Arguments

`cohort_level_data`

data.table. Cohort-level input table with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Livestock species code. Supported values include:

- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats
- `PGS`: pigs
- `CML`: camels

cohort_short Character. Sex- and age-specific cohort code. Supported values include:

- `FA`: adult females
- `FS`: sub-adult females
- `FJ`: juvenile females
- `MA`: adult males
- `MS`: sub-adult males
- `MJ`: juvenile males

cohort_stock_size Numeric. Average population size in each of the 6 sex-age cohorts (# heads). (cohorts=FJ, FS, FA, MJ, MS, MA).

Feed variables **ration_intake** Numeric. Average daily dry matter intake of feed (kg DM/head/day).

Nitrogen balance variables **nitrogen_intake** Numeric. Daily nitrogen intake (kg N/head/day)

nitrogen_retention Numeric. Daily nitrogen retention in animal body tissues and products (e.g., growth, pregnancy, milk...) (kg N/head/day)

nitrogen_excretion Numeric. Daily nitrogen excretion (kg N/head/day)

Production variables **milk_production_mass_cohort** Numeric. Total milk production produced over the assessment period (kg/cohort/assessment period).

milk_production_protein_cohort Numeric. Total milk protein production produced over the assessment period (kg protein/cohort/assessment period).

milk_production_fpcm_cohort Numeric. Total fat-protein-corrected milk (FPCM) produced over the assessment period (kg/cohort/assessment period).

meat_production_live_weight_cohort Numeric . Total meat produced as live weight over the assessment period by cohort (kg/cohort/assessment period).

meat_production_carcass_weight_cohort Numeric. Total meat as carcass weight (excluding organs, and other by-products after dressing) produced over the assessment period by cohort (kg/cohort/assessment period).

meat_production_bone_free_meat_cohort Numeric. Total bone-free-meat (excluding bones, organs, and other by-products after dressing and bone removal) produced over the assessment period by cohort (kg/cohort/assessment period)

meat_production_protein_cohort Numeric. Total meat protein (excluding bones, organs, and other by-products after dressing and bone removal) produced over the assessment period by cohort (kg protein/cohort/assessment period).

fibre_production_cohort Numeric. Total fibre produced over the assessment period by cohort (kg/cohort/assessment period)

Emission variables **ch4_enteric** Numeric. Average daily enteric methane (CH4) emissions (kg CH4/head/day).

ch4_manure_pasture Numeric. Methane (CH4) emissions from manure deposited on pasture (kg CH4/head/day)

ch4_manure_burned Numeric. Methane (CH4) emissions from manure burned for fuel (kg CH4/head/day)

ch4_manure_other Numeric. Methane (CH4) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg CH4/head/day)

n2o_manure_pasture_direct Numeric. Direct nitrous oxide (N2O) emissions from manure deposited on pasture (kg N2O/head/day)

n2o_manure_burned_direct Numeric. Direct nitrous oxide (N2O) emissions from manure burned for fuel (kg N2O/head/day)

n2o_manure_other_direct Numeric. Direct nitrous oxide (N2O) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg N2O/head/day)

n2o_manure_burned_indirect Numeric. Total indirect nitrous oxide (N2O) emissions from manure deposited on pasture. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_pasture_indirect Numeric. Total indirect nitrous oxide (N2O) emissions originating from manure burned for fuel. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_other_indirect Numeric. Total indirect nitrous oxide (N2O) emissions originating from manure management systems, excluding manure deposited on pasture and burned for fuel. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

co2_ration_fertilizer Numeric. Diet-level average carbon dioxide (CO2) emission factor from fertilizer manufacture in feed production (g CO2/kg DM).

co2_ration_pesticides Numeric. Diet-level average carbon dioxide (CO2) emission factor from pesticide manufacture in feed production (g CO2/kg DM).

co2_ration_crop_activities Numeric. Diet-level average carbon dioxide (CO2) emission factor from on-field agricultural activities in feed production (g CO2/kg DM).

co2_ration_luc_nopeat Numeric. Diet-level average carbon dioxide (CO2) emission factor from land-use change (excluding peatland drainage) in feed production (g CO2/kg DM).

co2_ration_luc_peat Numeric. Diet-level average carbon dioxide (CO2) emission factor from peatland drainage in feed production (g CO2/kg DM).

n2o_ration_fertilizer Numeric. Diet-level average nitrous oxide (N2O) emission factor from fertilizer use in feed production (g N2O/kg DM).

n2o_ration_manure_applied Numeric. Diet-level average nitrous oxide (N2O) emission factor from manure applied to or deposited on soil in feed production (g N2O/kg DM).

n2o_ration_crop_residues Numeric. Diet-level average nitrous oxide (N2O) emission factor from crop residues decomposition in feed production (g N2O/kg DM).

ch4_ration_rice Numeric. Diet-level average methane (CH4) emission factor from rice cultivation in feed production (g CH4/kg DM).

`allocation_herd_long`

data.table. Herd-level allocation table in long format, typically generated by `run_allocation_module()`, with the following data requirements:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include PGS, CML, CTL, BFL, SHP, GTS

variable_name Character. Names of emission variables to which allocation should be applied (e.g., "ch4_enteric", "ch4_manure_pasture", "ch4_manure_burned", "ch4_manure_other", "n2o_manure_pasture_direct", "n2o_manure_burned_direct", "n2o_manure_other_direct", "n2o_manure_burned_indirect", "n2o_manure_pasture_indirect", "n2o_manure_other_indirect", "co2_ration_fertilizer", "co2_ration_pesticides", "co2_ration_crop_activities", "co2_ration_luc_nopeat", "co2_ration_luc_peat", "n2o_ration_fertilizer", "n2o_ration_manure_applied", "n2o_ration_crop_residues", "ch4_ration_rice")

commodity_name Character. List of commodity categories to which emissions may be allocated. List = c("None", "Milk", "Meat", "Fibre", "Work", "Eggs")

commodity_type Character. Commodity (commodity_name) grouping, either `"Edible"` or `"Non-Edible"`.

allocation_share Numeric. Allocation share assigned to the commodity for the corresponding emission source (fraction).

`simulation_duration`

Numeric. Length of the assessment period (days).

`global_warming_potential_set`

Character. Settings for the 100-year Global Warming Potential (GWP-100) conversion factors used to express CH4 and N2O emissions as CO2eq. Must be one of:

- `"AR6"`: IPCC Sixth Assessment Report (IPCC, 2021) - CH4 = 27, N2O = 273
- `"AR5_excluding_carbon_feedback"`: IPCC Fifth Assessment Report (excluding climate-carbon feedbacks) (IPCC, 2013) - CH4 = 28, N2O = 265
- `"AR5_including_carbon_feedback"`: IPCC Fifth Assessment Report (including climate-carbon feedbacks) (IPCC, 2013) - CH4 = 34, N2O = 298
- `"AR4"`: IPCC Fourth Assessment Report (IPCC, 2007) - CH4 = 25, N2O = 298

`show_indicator` Logical. Whether to display progress indicators during the pipeline run. Defaults to `TRUE`.

Details

This function represents the final step of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` and performs the following calculation sequence:

1. Cohort-level variables are reshaped from wide to long format.
2. Variables are classified into `"Feed"`, `"NitrogenBalance"`, `"Production"`, and `"Emissions"`.
3. Cohort totals are calculated using `calc_cohort_totals()`. Production variables are retained as provided, whereas emissions, feed, and nitrogen balance variables are scaled using cohort stock size and simulation duration.
4. Cohort totals are aggregated to herd level within each `herd_id` x `species_short` x `variable_type` x `variable_name` group.

5. Herd-level emissions are merged with commodity allocation shares from `allocation_herd_long`.
6. Emissions are allocated to commodities using `calc_allocated_emissions()`.
7. Gas type is identified from the emission variable name as `"CH4"`, `"N2O"`, or `"CO2"`.
8. Allocated CH4, N2O, and CO2 emissions are converted to CO2-equivalents (CO2eq) using `calc_co2eq()` and the selected GWP-100 option.
9. Final output tables are produced summarizing herd-level results for emissions, feed, production, and nitrogen balance variables.

Value

A named list with the following elements:

results_emissions A `data.table` containing herd-level emissions scaled to the assessment duration and allocated to commodities. Includes gas type, allocation shares, commodity metadata, GWP factors, and emissions expressed both as allocated gas mass (kg gas) and as CO2-equivalents (kg CO2eq).

results_feed A `data.table` containing herd-level feed variables, aggregated at herd level and scaled to the assessment duration.

results_production A `data.table` containing herd-level production variables aggregated from cohort-level values over the assessment duration.

results_nitrogen A `data.table` containing herd-level nitrogen balance variables aggregated from cohort-level values and scaled to the assessment duration.

See Also

`run_gleam()`, `calc_cohort_totals()`, `calc_cohort_to_herd_aggregation()`, `calc_allocated_emissions()`, `calc_co2eq()`, `run_allocation_module()`

Examples

```
# Load cohort-level aggregation input
aggregation_chrt_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/aggregation_input_chrt_data.csv",
  package = "gleam"
))

# Load allocation shares (herd-level, long format)
allocation_long <- data.table::fread(system.file(
  "extdata/run_modules_examples/aggregation_allocation_input_data.csv",
  package = "gleam"
))

# Run aggregation
results <- run_aggregation_module(
  cohort_level_data = aggregation_chrt_dt,
  allocation_herd_long = allocation_long,
  simulation_duration = 365,
  global_warming_potential_set = "AR6"
)
```

`run_allocation_module` *Run Allocation Module Pipeline*

Description

Calculates biophysical allocation shares for livestock commodities by computing cohort-level energy requirements for meat, milk, fibre, work, and eggs, aggregating these terms to herd level, and assigning allocation shares to emission sources.

Usage

```
run_allocation_module(
  cohort_level_data,
  herd_level_data,
  simulation_duration = 365,
  show_indicator = TRUE
)
```

Arguments

`cohort_level_data`

Cohort-level input table with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

milk_production_fpcm_cohort Numeric. Total fat-protein-corrected milk (FPCM) produced over the assessment period (kg/cohort/assessment period). Suggested standard fat, protein and lactose contents are 0.04, 0.033, and 0.048 respectively.

live_weight_cohort_at_slaughter Numeric. Live weight at slaughter for animals removed from the cohort (kg).

meat_production_live_weight_cohort Numeric. Total meat produced as live weight over the assessment period by cohort (kg/cohort/assessment period).

metabolic_energy_req_fibre_production Numeric. Energy required for the synthesis of fibre for SHP, GTS and CML. Assumed to be 0 for other species. (MJ/head/day). Expressed as net energy for SHP and GTS and as metabolizable energy for CML.

cohort_stock_size Numeric. Average population size in each of the 6 sex–age cohorts (# heads). (cohorts=FJ, FS, FA, MJ, MS, MA).

metabolic_energy_req_work Numeric. Energy required for work, used to estimate the energy required for draught power for CTL, BFL and CML. (MJ/head/day) Assumed to be 0 for other species. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML.

`herd_level_data`

data.table. Herd-level input table (one row per `herd_id`) with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

live_weight_at_birth Numeric. Live weight of the animal at birth (kg).

milk_protein_fraction_standard Numeric. Standard protein content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg protein/kg milk). Suggested value = 0.033.

milk_fat_fraction_standard Numeric. Standard fat content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg fat/kg milk). Suggested value = 0.04.

milk_lactose_fraction_standard Numeric. Standard lactose content of milk, used to calculate Fat-protein-corrected milk (FPCM) , (kg lactose/kg milk). Suggested value = 0.048.

ratio_me_to_ne Numeric. Ratio of metabolizable energy converted to net energy (fraction). Used for species_short = CML.

`simulation_duration`

Numeric. Length of the assessment period (days).

show_indicator Logical. Whether to display progress indicators during simulation. Defaults to TRUE.

Details

This function implements the allocation pipeline used to derive biophysical allocation shares for livestock commodities in multifunctional production systems.

The approach follows the IDF standard for the dairy sector, adapted for livestock systems in which emissions are apportioned among multiple products according to their physiological energy requirements. In accordance with ISO 14044:2006, known biophysical relationships may be used to assign shared inputs and outputs of a production system to individual products or sub-units.

This function represents the intermediate allocation module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` and performs the following calculation sequence:

1. Calculation of cohort-level energy allocation terms for meat, milk, fibre, work, and eggs using `calc_meat_allocation_energy`, `calc_milk_allocation_energy`, `calc_fibre_allocation_energy`, `calc_work_allocation_energy`, and `calc_eggs_allocation_energy`.
2. Aggregation of cohort-level energy terms to herd level using `calc_cohort_to_herd_aggregation`.
3. Calculation of herd-level allocation shares for commodities using `calc_allocation_shares`.
4. Reshaping of allocation shares to long format and assignment of shares to emission sources using `assign_allocation_shares`.

Commodity-specific allocation shares represent the fraction of total herd-level energy requirements attributable to each commodity. These shares are then used to assign emissions to meat, milk, fibre, work, eggs, or the residual category `"None"`.

Emissions from manure burned for fuel and manure deposited on pasture are not allocated to livestock commodities. These flows are assigned fully to `"None"` in accordance with the rules implemented in `assign_allocation_shares`.

Value

A named list of two `data.table` objects:

cohort_allocation_inputs A `data.table` with the original cohort-level input columns plus the following new variables:

- **milk_allocation_energy** Numeric. Energy required to produce total milk output by cohort (MJ/cohort/assessment period).
- **meat_allocation_energy** Numeric. Energy required by a given sex–age cohort for total meat output by cohort during the assessment period, equal to the energy needed to produce all live-weight gain to reach the target slaughter weight (MJ/cohort/assessment period).
- **fibre_allocation_energy** Numeric. Energy required to produce all fibre output by cohort (MJ/cohort/assessment period).
- **work_allocation_energy** Numeric. Energy required to provide all draught power (traction/work) by cohort (MJ/cohort/assessment period).
- **egg_allocation_energy** Numeric. Energy required for egg production over the assessment period (MJ/cohort/assessment period). Currently set to 0.

allocation_long A herd-level `data.table` in long format with one row per herd, commodity, and emission source combination, containing the following columns:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

variable_name Character. Names of emission variables to which allocation should be applied (e.g.,"ch4_enteric", "ch4_manure_pasture", "ch4_manure_burned","ch4_manure_other", "n2o_manure_pasture_direct", "n2o_manure_burned_direct","n2o_manure_other_direct", "n2o_manure_burned_indirect","n2o_manure_pasture_indirect", "n2o_manure_other_indirect", "co2_ration_fertilizer", "co2_ration_pesticides", "co2_ration_crop_activities", "co2_ration_luc_nopeat", "co2_ration_luc_peat", "n2o_ration_fertilizer", "n2o_ration_manure_applied", "n2o_ration_crop_residues", "ch4_ration_rice")

commodity_name Character. List of commodity categories to which emissions may be allocated. List=c("None","Milk","Meat","Fibre","Work","Eggs")

commodity_type Character. Commodity (commodity_name) grouping, either `"Edible"` or `"Non-Edible"`.

allocation_share Numeric. Allocation share assigned to the commodity for the corresponding emission source (fraction).

References

ISO. (2006). *Environmental management — Life cycle assessment — Requirements and guidelines (ISO 14044:2006)*. International Organization for Standardization, Geneva.

IDF. (2022). *The IDF Global Carbon Footprint Standard for the Dairy Sector*. Bulletin of the IDF No. 520/2022. International Dairy Federation, Brussels.

Thoma, G., and Nemecek, T. (2020). Allocation between milk and meat in dairy LCA: Critical discussion of the IDF's standard methodology. In *Proceedings of the 12th International Conference on Life Cycle Assessment of Food (LCAFood 2020)* (pp. 83–89), 13–16 October, Berlin, Germany.

FAO. (2016a). *Environmental performance of large ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016b). *Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

FAO. (2016c). *Greenhouse gas emissions and fossil energy use from poultry supply chains: Guidelines for assessment*. Livestock Environmental Assessment and Performance (LEAP) Partnership. FAO, Rome, Italy.

See Also

run_gleam, calc_milk_production, calc_meat_production, run_production_module, calc_meat_allocation_energ
calc_milk_allocation_energy, calc_fibre_allocation_energy, calc_work_allocation_energy,
calc_eggs_allocation_energy, calc_cohort_to_herd_aggregation, calc_allocation_shares,
assign_allocation_shares

Examples

```
# Load allocation inputs (cohort and herd-level)
allocation_chrt_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/allocation_input_chrt_data.csv",
  package = "gleam"
))
allocation_hrd_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/allocation_input_hrd_data.csv",
  package = "gleam"
))
results <- run_allocation_module(
cohort_level_data = allocation_chrt_dt,
herd_level_data = allocation_hrd_dt
)
head(results$allocation_long)
```

---

run_demographic_herd_module

Run Demographic Herd Module Pipeline

Description

This function takes herd- and cohort-level demographic inputs and estimates a steady-state sex–age herd structure compatible with downstream calculations in the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline run_gleam(). In addition to cohort population sizes, it derives population growth rates, and offtake numbers. The steady state is defined as a constant sex–age cohort structure over time, with population size potentially growing or declining at a constant rate.

Usage

```
run_demographic_herd_module(
  cohort_level_data,
  herd_level_data,
  initial_herd_structure = c(FJ = 100, FS = 50, FA = 30, MJ = 100, MS = 50, MA = 30),
  max_simulation_years = 100,
  min_lambda_change = 1e-09,
  show_indicator = TRUE,
  simulation_duration = 365
)
```

Arguments

`cohort_level_data`

A `data.table` with the one row per herd and cohort, and the following mandatory columns:

`herd_id` Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

`cohort_short` Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

`cohort_duration_days` Numeric vector of length 6. Amount of time that each animal spends in a specific cohort (days).

`offtake_rate` Numeric vector of length 6. Annual proportion of animals removed from the herd for each sex-age cohort (fraction).

`death_rate` Numeric vector of length 6. Fraction of deaths in a herd over a year for each sex-age cohort (fraction).

`herd_level_data`

A `data.table` with one row per herd, and the following mandatory columns:

`herd_id` Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

`parturition_rate` Numeric. Average annual number of parturitions per female animal (# parturitions/adult female/year). A herd-level reproductive performance indicator calculated as the total number of parturitions (deliveries) occurring during a year divided by the number of adult females potentially able to give birth during that year.

`litter_size` Numeric. Average number of offspring born per parturition (# offspring/parturition). This value can be calculated as the total number of offspring born divided by the total number of parturitions during the year.

`birth_fraction_female` Numeric. Female birth fraction, defined as the probability that a newborn offspring is female (fraction). Can be calculated as the number of female offspring born divided by the total number of offspring born.

`herd_size_total` Numeric. Total population size at the start of the year, including all cohorts (# heads).

`initial_herd_structure`

Named numeric vector of length 6. Initial number of individuals in each of the 6 sex-age cohorts used to bootstrap the steady-state simulation (# heads).These values are used as starting points for the iterative simulation and do not affect the final steady-state results (only convergence speed). Default is `c(FJ = 100, FS = 50, FA = 30, MJ = 100, MS = 50, MA = 30)`.

`max_simulation_years`
: Numeric. Maximum number of years to simulate (years). Defaults to `100`.

`min_lambda_change`
: Numeric. Convergence threshold for changes in cohort-specific growth rates of sex–age cohort proportions (lambda). Iterations of the herd simulation stop when the absolute change in lambda between successive iterations falls below this threshold. Defaults to `1e-9`.

`show_indicator`
: Logical. Whether to display progress indicators during simulation. Defaults to `TRUE`.

`simulation_duration`
: Numeric. Length of the assessment period (days).

Details

The function operates under a **steady-state assumption**: demographic parameters are constant over time, so the population converges to a stable cohort composition and a constant annual growth rate. Once this regime is reached, the model computes cohort population sizes (start/end/average), cohort shares, and offtake totals.

A key feature of this implementation is that it applies demography at a **daily** resolution. Annual mortality and offtake inputs are converted into daily hazards and daily transition probabilities under competing risks (death vs. offtake vs. survival).

Conceptually, this corresponds to the steady-state demographic approach implemented in Dynmod *STEADY1* (Lesnoff, 2013), adapted here to a daily time-step formulation within an R workflow and fully integrated into the GLEAM computational pipeline.

Model structure:

The population is divided by sex (female/male) and age class (juvenile/subadult/adult), represented by six cohorts:

- `FJ`, `FS`, `FA` (female juvenile, subadult, adult)
- `MJ`, `MS`, `MA` (male juvenile, subadult, adult)

Only adult females (`FA`) contribute to reproduction. Births are distributed between females and males using `birth_fraction_female`. Reproduction is assumed to be distributed over time (no birth pulse). Daily fecundity rates are computed in `calc_fecundity_rates`.

Dynamics and parameters:

Herd dynamics result from:

- births (driven by `parturition_rate` and `litter_size`)
- natural deaths (driven by `death_rate`)
- removals by offtake (driven by `offtake_rate`)
- cohort aging / growth transitions (driven by `cohort_duration_days`)

As in Dynmod, `offtake_rate` is interpreted as a *net removal rate* for the cohort (e.g. slaughter), while `death_rate` represents natural mortality excluding offtake.

Competing risks and conversion to daily probabilities:

Mortality and offtake are treated as **competing risks** within each cohort: at any time an animal can survive, die, or be offtaken.Annual inputs are converted to daily hazards and then daily transition probabilities in `calc_transition_probabilities`.

Internally, the model:

1. Converts annual mortality (`death_rate`) into a daily mortality hazard.
2. Solves for the daily offtake hazard such that the implied offtake probability matches `offtake_rate` under competing risks.
3. Computes daily probabilities of death, offtake, and survival from the hazards.

Steady state:

Under constant parameters, the cohort structure converges to a stable composition and a stable population growth rate. This function seeks that steady state by iterating the demographic system (see `calc_steady_state_structure`) starting from `initial_herd_structure` until changes in cohort-specific growth rates of sex–age cohort proportions (λ) fall below `min_lambda_change`, or until `max_simulation_years` is reached.

Projection of population size:

The steady-state solution obtained here provides:

- cohort shares used to scale herd-level population sizes,
- a stable annual herd growth rate,
- internally consistent death, offtake, and survival probabilities.

These outputs are subsequently used to project one year of population dynamics (`calc_projected_population_size`) and to summarise annual offtake and stock variation (`calc_summary_offtake`).

Value

A named list with two elements:

`cohort_level_results` A `data.table` with one row per herd and cohort containing all original `cohort_level_data` columns plus the following simulation results:

- `cohort_stock_size` - Numeric vector of length 6. Average population size in each of the 6 sex–age cohorts (# heads) (cohorts = (`FJ`, `FS`, `FA`, `MJ`, `MS`, `MA`)). This corresponds to `cohort_stock_start` returned by `calc_projected_population_size`, as it reflects the size of the population by cohort while preserving the total population size (`herd_size_total`) provided in the inputs.
- `offtake_heads` - Numeric vector of length 6. Total number of animals removed via offtake over the year, aggregated to 6 sex–age cohorts (heads/year) (cohorts = `FJ`, `FS`, `FA`, `MJ`, `MS`, `MA`).
- `offtake_heads_assessment` - Numeric vector of length 6. Total number of animals removed via offtake over the assessment period, aggregated to 6 sex–age cohorts (heads/assessment period) (cohorts = `FJ`, `FS`, `FA`, `MJ`, `MS`, `MA`).

`herd_level_results` A `data.table` with one row per herd containing all original `herd_level_data` columns plus the following herd-level simulation results:

- `growth_rate_herd` - Numeric. Annualized growth rate at which the herd size reaches steady state (fraction).

References

Lesnoff, M. (2013). *DYNMOD: A spreadsheet interface for demographic projections of tropical livestock populations, User's manual*. CIRAD, Montpellier, France.

See Also

calc_fecundity_rates, calc_transition_probabilities, calc_steady_state_structure, calc_projected_population_size, calc_summary_offtake

Examples

```
# Load herd simulation inputs (cohort- and herd-level)
herd_simulation_chrt_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/herd_simulation_input_chrt_data.csv",
  package = "gleam"
))
herd_simulation_hrd_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/herd_simulation_input_hrd_data.csv",
  package = "gleam"
))

# Run herd simulation
results <- run_demographic_herd_module(
  cohort_level_data = herd_simulation_chrt_dt,
  herd_level_data = herd_simulation_hrd_dt,
  simulation_duration = 200
)

# Access results
print(results$cohort_level_results)
print(results$herd_level_results)
```

---

run_emissions_enteric_module

Run Enteric Methane (CH4) Emissions Module Pipeline

Description

Calculates daily enteric methane emissions by cohort (kg CH4/head/day) using a Tier 2 IPCC approach, by applying species-, cohort- and diet-specific methane conversion factors (ym).

Usage

```
run_emissions_enteric_module(cohort_level_data, show_indicator = TRUE)
```

Arguments

`cohort_level_data`
: data.table. Cohort-level input table with the following data requirement:

  herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

ration_digestibility_fraction Numeric. Average digestibility of the feed ration, expressed as ratio of digestible (or metabolizable, for poultry) to gross energy content (fraction).

ration_gross_energy Numeric. Average gross energy content of the diet (MJ/kg DM).

ration_intake Numeric. Average daily dry matter intake of feed (kg DM/head/day).

ch4_mitigation_factor Numeric. Optional. Multiplicative mitigation factor applied to baseline enteric methane (CH4) emissions (dimensionless). If not provided, a default value of `1` (no mitigation) is used. Values lower than 1 represent proportional reductions (e.g., `0.90` = 10% reduction). This factor can represent mitigation measures with a direct effect on enteric methane emissions, such as the use of feed additives or methane inhibitors.

`show_indicator` Logical. Whether to display progress indicators during calculations. Defaults to `TRUE`.

Details

This function represents the intermediate module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` to estimate enteric methane emissions and performs the following calculation sequence:

1. If `ch4_mitigation_factor` is not provided in the input data, it is set to `1` (no mitigation).
2. The methane conversion factor (ym) is computed using `calc_conversion_factor_ym`.
3. Daily enteric methane emissions are computed using `calc_ch4_enteric`.

Value

A `data.table` with the original input columns plus the following new variables:

ch4_mitigation_factor Added by the function if not provided as input.

ch4_conversion_factor_ym Numeric. Methane (CH4) conversion factor (ym), representing the percentage of gross energy of the feed ration that is converted to CH4 (percentage).

ch4_enteric Numeric. Average daily enteric methane (CH4) emissions (kg CH4/head/day).

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.21.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Chapter 10: Emissions from Livestock and Manure Management, Equation 10.21.

See Also

run_gleam, calc_conversion_factor_ym, calc_ch4_enteric

Examples

```
# Load example input (6 herd_ids, cohort-level; only required columns)
input_path <- system.file(
  "extdata/run_modules_examples/emissions_enteric_input_chrt_data.csv",
  package = "gleam"
)
emissions_enteric_input_chrt_data <- data.table::fread(input_path)
results <- run_emissions_enteric_module(
cohort_level_data = emissions_enteric_input_chrt_data
)
```

---

run_emissions_manure_module

Run Emissions from Manure Module Pipeline

Description

Calculates methane (CH4) and nitrous oxide (N2O) emissions at cohort-level from manure management systems (MMS).

Usage

```
run_emissions_manure_module(
  cohort_level_data,
  manure_management_system_fraction,
  manure_management_system_factors,
  show_indicator = TRUE
)
```

Arguments

`cohort_level_data`

data.table. Cohort-level input table with the following minimum data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

ration_intake Numeric. Average daily dry matter intake of feed (kg DM/head/day).

ration_digestibility_fraction Numeric. Average digestibility of the feed ration, expressed as ratio of digestible to gross energy content (fraction).

ration_urinary_energy_fraction Numeric. Fraction of feed's gross energy that is excreted in urine (fraction).

ration_ash Numeric. Average ash content of feed, calculated as a fraction of the dry matter intake (kg ash/kg DM).

nitrogen_excretion Numeric. Daily nitrogen excretion (kg N/head/day).

`manure_management_system_fraction`

data.table. Cohort-level MMS fractions with:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

manure_management_system Character. Name identifying the manure management system. The identifiers mms_pasture and mms_burned are reserved for manure deposited on pasture and manure burned for fuel, respectively. No specific naming convention is required for other manure management systems, which are grouped and handled as "other" systems.

manure_management_system_fraction Numeric. Fraction of total manure excreted by animals in a given herd and cohort that is handled in a specific manure management system. Values ranges from 0 to 1. The sum of all fractions for each herd_id must equal 1.

`manure_management_system_factors`

data.table. Herd-level MMS factors with:

manure_management_system Character. Name identifying the manure management system. The identifiers mms_pasture and mms_burned are reserved for manure deposited on pasture and manure burned for fuel, respectively. No specific naming convention is required for other manure management systems, which are grouped and handled as "other" systems.

ratio_m3CH4_to_kgCH4 Numeric. Conversion factor used to convert methane (CH4) from volumetric unit (m3) to a mass unit (kg). This value represents the density of methane. It defaults to 0.67 kg/m3

methane_conversion_factor_mcf Numeric. Methane (CH4) conversion factor represents the portion or degree of the maximum methane producing capacity (Bo) that is effectively achieved within a specific manure management system. It represents the extent to which the theoretical methane yield is realized based on management practices and environmental conditions, specifically the temperature of the system, the retention time of the organic material, and the degree of anaerobic conditions present. The value theoretically ranges from 0 to 100 percent. Default values can be selected from Table 10.17 of IPCC guidelines (IPCC 2006, 2019).

ch4_max_producing_capacity_bo Numeric. Maximum methane (CH4) producing capacity (B0) for all systems (m3 CH4/kg VS). The value is region- and species-specific, and represents the theoretical maximum methane yield per unit of volatile solids. Default can be selected from Table 10.16 (IPCC, 2019) or from Tables 10A-4 to 10A-9 (IPCC, 2006).

n2o_ef3 Numeric. Emission factor for direct nitrous oxide (N2O) emissions for each manure management system, representing nitrous oxide emitted per unit of nitrogen from nitrification and denitrification processes occurring during manure storage and treatment (kg N2O–N per kg N). Default values can be selected from Table 10.21 and Table 11.1 (for manure deposited on pasture) in IPCC Guidelines (IPCC 2006, 2019).

n2o_ef4 Numeric. Emission factor for indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3–N and NOx–N) onto soils and water surfaces (kg N2O–N / (kg NH3–N + NOx–N)). Default values can be selected from Table 11.3 in IPCC Guidelines (IPCC 2006, 2019).

nitrogen_fracgas Numeric. Fraction of manure nitrogen excreted by a given livestock category that is lost through volatilisation as ammonia (NH3) and nitrogen oxides (NOx) within a specific manure management system. This parameter represents the share of excreted nitrogen that is mineralised and released to the atmosphere during manure collection, storage, and treatment. It is expressed as a dimensionless fraction (0–1). Default values are provided in Table 10.22 of IPCC Guidelines (IPCC 2006, 2019).

n2o_ef5 Numeric. Emission factor for indirect nitrous oxide (N2O) emissions resulting from nitrogen leaching and runoff, expressed as kilograms of N2O–N per kilogram of nitrogen leached or lost through runoff (kg N2O–N/kg N). Default values can be selected from Table 11.3 in IPCC Guidelines (IPCC 2006, 2019).

nitrogen_fracleach Numeric. Fraction of manure nitrogen excreted by a given livestock category that is lost through leaching and runoff from a specific manure management system. This parameter is highly uncertain and is used to estimate indirect N2O emissions from nitrogen that enters the surrounding environment of the storage facility. It is expressed as a dimensionless fraction (0–1). Default values are provided in Table 10.22 of IPCC Guidelines (IPCC 2006, 2019).

`show_indicator` Logical. Whether to display progress indicators during the calculation. Defaults to TRUE.

Details

This function represents the intermediate module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` to estimate emissions from manure management systems (MMS) and orchestrates a cohort-level implementation of the IPCC manure management methodology.

The following calculation sequence is applied:

1. VS excretion is computed from nutritional parameters of the feed ration (digestibility, urinary energy, and ash) using a simplified formulation of Equation 10.24 (IPCC 2006, 2019) - `calc_volatile_solids`
2. Methane (CH4) emissions from manure management are computed from VS and MMS-specific factors (MCF and B0) and reported by MMS group (pasture, burned, and other), consistently with Equation 10.23 (IPCC, 2006, 2019) - `calc_ch4_manure`
3. Direct nitrous oxide (N2O) emissions from manure management are computed from nitrogen excretion and MMS-specific EF3 values, and reported by MMS group, consistently with Equation 10.25 (IPCC, 2006, 2019) - `calc_n2o_manure_direct`
4. Indirect N2O emissions are computed as the sum of:
   - volatilisation-driven N2O using MMS-specific nitrogen losses (FracGas) and EF4, consistently with Equations 10.26 (IPCC, 2006, 2019), 10.27 (IPCC, 2006), and 10.28 (IPCC, 2019) - `calc_n2o_manure_volatilization`
   - leaching/runoff-driven N2O using MMS-specific nitrogen losses (FracLeach) and EF5, consistently with Equations 10.28 (IPCC, 2006), 10.27 (IPCC, 2019), and 10.29 (IPCC, 2006, 2019) - `calc_n2o_manure_leaching`
5. Total N2O emissions are aggregated by MMS group (pasture, burned, other) - `calc_n2o_manure_total`

The approach corresponds to a Tier 2 implementation as:

- VS is derived from ration-level inputs rather than using fixed daily excretion defaults, and
- emissions are allocated across MMS categories using herd/cohort MMS fractions and MMS-specific parameters.

Value

cohort_level_data data.table. Input cohort table with added manure emissions columns:

volatile_solids Numeric. Total volatile solids (VS) excreted per animal per day, representing the organic material in livestock manure and consisting of both biodegradable and non-biodegradable fractions (kg VS/head/day).

ch4_manure_pasture Numeric. Methane (CH4) emissions from manure deposited on pasture (kg CH4/head/day).

ch4_manure_burned Numeric. Methane (CH4) emissions from manure burned for fuel (kg CH4/head/day).

ch4_manure_other Numeric. Methane (CH4) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg CH4/head/day).

ch4_manure_all_noburn Numeric. Methane (CH4) emissions from manure management systems, excluding manure burned for fuel (kg CH4/head/day).

n2o_manure_pasture_direct Numeric. Direct nitrous oxide (N2O) emissions from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_direct Numeric. Direct nitrous oxide (N2O) emissions from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_direct Numeric. Direct nitrous oxide (N2O) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_direct Numeric. Direct nitrous oxide (N2O) emissions from manure management systems, excluding emissions from manure burned for fuel (kg N2O/head/day).

n2o_manure_pasture_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure management systems, excluding manure deposited on pasture and manure burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure management systems, excluding losses from manure burned for fuel (kg N2O/head/day).

n2o_manure_pasture_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure management systems, excluding losses from manure deposited on pasture and manure burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure management systems, excluding losses from manure burned for fuel (kg N2O/head/day).

n2o_manure_pasture_indirect Numeric. Total indirect nitrous oxide (N2O) emissions from manure deposited on pasture. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_burned_indirect Numeric. Total indirect nitrous oxide (N2O) emissions originating from manure burned for fuel. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_other_indirect Numeric. Total indirect nitrous oxide (N2O) emissions originating from manure management systems, excluding manure deposited on pasture and burned for fuel. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen.

n2o_manure_pasture_total Numeric. Total nitrous oxide emissions from manure deposited on pasture. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

n2o_manure_burned_total Numeric. Total nitrous oxide emissions (N2O) from manure burned for fuel. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

n2o_manure_other_total Numeric. Total nitrous oxide (N2O) emissions from manure management systems, excluding manure deposited on pasture and manure burned for fuel. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

Manure management system (MMS) reference

A complete list of MMS names, definitions, and associated emission factors can be accessed in the GLEAM Data Explorer.

References

IPCC. (2019). *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10: Emissions from Livestock and Manure Management. Equations 10.23, 10.24, 10.25, 10.26, 10.27, 10.28, and 10.29.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Volume 4, Chapter 10: Emissions from Livestock and Manure Management. Equations 10.23, 10.24, 10.25, 10.26, 10.27, 10.28, and 10.29.

See Also

run_gleam, calc_volatile_solids, calc_ch4_manure, calc_n2o_manure_direct, calc_n2o_manure_volatilizatior
calc_n2o_manure_leaching, calc_n2o_manure_total

Examples

```
# Load emissions manure inputs (cohort-level and system lookups)
emissions_manure_input_chrt_data <- data.table::fread(system.file(
  "extdata/run_modules_examples/emissions_manure_input_chrt_data.csv",
  package = "gleam"
))
manure_management_system_factors <- data.table::fread(system.file(
  "extdata/run_modules_examples/manure_management_system_factors.csv",
  package = "gleam"
))
manure_management_system_fraction <- data.table::fread(system.file(
  "extdata/run_modules_examples/manure_management_system_fraction.csv",
  package = "gleam"
))
```

```
results <- run_emissions_manure_module(
  cohort_level_data = emissions_manure_input_chrt_data,
  manure_management_system_fraction = manure_management_system_fraction,
  manure_management_system_factors = manure_management_system_factors
)
```

`run_emissions_ration_module` *Run Emissions from Feed Production Module Pipeline*

Description

Computes cohort-level average greenhouse gas (GHG) emission factors from feed production by weighting emission factors of individual feed components by diet composition. Returns diet-level average GHG emission factors by gas and emission source for each cohort.

Usage

```
run_emissions_ration_module(
  rations_share,
  feed_emissions,
  show_indicator = TRUE
)
```

Arguments

`rations_share` data.table. Cohort-level feed ration composition shares with the following minimum data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)

- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

feed_id Character. Unique identifier for the feed component, used to join feed ration data with feed parameter tables.

feed_name Character. Feed component name (optional, for readability and reporting). If provided, it should uniquely identify the same feed component as `feed_id`.

feed_ration_fraction Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`feed_emissions` data.table. Emission factors of individual feed components with the following data requirement:

feed_id Character. Unique identifier for the feed component, used to join feed ration data with feed parameter tables.

feed_name Character. Feed component name (optional, for readability and reporting). If provided, it should uniquely identify the same feed component as `feed_id`.

co2_feed_fertilizer Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from fertilizer manufacture in feed production, expressed per kilogram of dry matter intake (g CO2/kg DM).

co2_feed_pesticides Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from pesticide manufacture in feed production, expressed per kilogram of dry matter intake (g CO2/kg DM).

co2_feed_crop_activities Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from on-field agricultural activities in feed production, expressed per kilogram of dry matter intake (kg CO2/kg DM).

co2_feed_luc_nopeat Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from land-use change in feed production (excluding peatland drainage), expressed per kilogram of dry matter intake (g CO2/kg DM).

co2_feed_luc_peat Numeric. Carbon dioxide (CO2) emission factor of a feed component, representing CO2 emissions from peatland drainage in feed production, expressed per kilogram of dry matter intake (g CO2/kg DM).

n2o_feed_fertilizer Numeric. Nitrous oxide (N2O) emission factor of a feed component, representing N2O emissions from fertilizer use in feed production, expressed per kg of dry matter intake (g N2O/kg DM).

n2o_feed_manure_applied Numeric. Nitrous oxide (N2O) emission factor of a feed component, representing N2O emissions from manure applied to or deposited on soil in feed production, expressed per kg of dry matter intake (g N2O/kg DM).

n2o_feed_crop_residues Numeric. Nitrous oxide (N2O) emission factor of a feed component, representing N2O emissions from crop residues decomposition in feed production, expressed per kg of dry matter intake (g N2O/kg DM).

ch4_feed_rice Numeric. Methane (CH4) emission factor of a feed component, representing CH4 emissions from rice cultivation in feed production, expressed per kg of dry matter intake (g CH4/kg DM).

`show_indicator` Logical. Whether to display progress indicators during calculations. Defaults to `TRUE`.

Details

This function represents the intermediate module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` to estimate emissions from feed production used in the animal's ration. The function joins `rations_share` with `feed_emissions` by `feed_id`, uses `species_short` directly, and computes ration-weighted emission factors by cohort.

The following calculation sequence is applied:

1. **Merge ration shares with emission factors** at the feed-component level using `merge` on `feed_id` (left join: `all.x = TRUE`).
2. **Compute feed-component contributions** (row-wise) for each emission source by multiplying the ration share of each feed component (`feed_ration_fraction`) by the corresponding feed emission factor. Each contribution is computed using the specific helper below (called with `by = .I`):
   - CO2 fertilizer: `calc_co2_ration_fertilizer`
   - CO2 pesticides: `calc_co2_ration_pesticides`
   - CO2 crop operations: `calc_co2_ration_crop_activities`
   - CO2 land-use change (no peat): `calc_co2_ration_luc_nopeat`
   - CO2 land-use change (peat): `calc_co2_ration_luc_peat`
   - N2O fertilizer: `calc_n2o_ration_fertilizer`
   - N2O manure applied: `calc_n2o_ration_manure`
   - N2O crop residues: `calc_n2o_ration_crop_residues`
   - CH4 rice cultivation: `calc_ch4_ration_rice`
3. **Aggregate to cohort-level diet emission factors** by summing feed-component contributions across all feeds within each group (`herd_id, species_short, cohort_short`).

For each emission source, cohort-level dietary emission factors are computed as:

$$\text{diet\_ef} = \sum_{i=1}^{n} (\text{feed\_ration\_fraction}_i \times \text{feed\_ef}_i)$$

Value

data.table. Cohort-level emission factors summarized by `herd_id`, `species_short`, and `cohort_short` with the following columns:

co2_ration_fertilizer Numeric. Diet-level average carbon dioxide (CO2) emission factor from fertilizer manufacture in feed production (g CO2/kg DM).

co2_ration_pesticides Numeric. Diet-level average carbon dioxide (CO2) emission factor from pesticide manufacture in feed production (g CO2/kg DM).

co2_ration_crop_activities Numeric. Diet-level average carbon dioxide (CO2) emission factor from on-field agricultural activities in feed production (g CO2/kg DM).

co2_ration_luc_nopeat Numeric. Diet-level average carbon dioxide (CO2) emission factor from land-use change (excluding peatland drainage) in feed production (g CO2/kg DM).

co2_ration_luc_peat Numeric. Diet-level average carbon dioxide (CO2) emission factor from peatland drainage in feed production (g CO2/kg DM).

n2o_ration_fertilizer Numeric. Diet-level average nitrous oxide (N2O) emission factor from fertilizer use in feed production (g N2O/kg DM).

n2o_ration_manure_applied Numeric. Diet-level average nitrous oxide (N2O) emission factor from manure applied to or deposited on soil in feed production (g N2O/kg DM).

n2o_ration_crop_residues Numeric. Diet-level average nitrous oxide (N2O) emission factor from crop residues decomposition in feed production (g N2O/kg DM).

ch4_ration_rice Numeric. Diet-level average methane (CH4) emission factor from rice cultivation in feed production (g CH4/kg DM).

See Also

run_gleam, calc_co2_ration_fertilizer, calc_co2_ration_pesticides, calc_co2_ration_crop_activities, calc_co2_ration_luc_nopeat, calc_co2_ration_luc_peat, calc_n2o_ration_fertilizer, calc_n2o_ration_manure, calc_n2o_ration_crop_residues, calc_ch4_ration_rice

Examples

```
# Load cleaned example input from the package and compute the calculation of feed emission factors

# Load table with ration shares
rations_share <- data.table::fread(system.file(
  "extdata/run_modules_examples/feed_rations_share_chrt.csv",
  package = "gleam"
))

# Load table with feed emission factors
feed_emissions <- data.table::fread(system.file(
  "extdata/run_modules_examples/feed_emission_factors.csv",
  package = "gleam"
))

# Run the code
result <- run_emissions_ration_module(
  rations_share = rations_share,
  feed_emissions = feed_emissions
)
```

`run_gleam` *Run the full Global Livestock Environmental Assessment Model (GLEAM) Pipeline*

Description

Runs the full GLEAM pipeline from master herd and cohort inputs through all modules: herd (optional), weights, ration quality, energy requirements, manure emissions, enteric fermentation, nitrogren balance, feed emissions, allocation, and aggregation.

Common identifiers: Several input tables share the following identifier columns. Their supported values are listed once here and referenced throughout.

`species_short` — Character. Species code:

- `CTL`: Cattle
- `BFL`: Buffalo
- `SHP`: Sheep
- `GTS`: Goats
- `PGS`: Pigs
- `CML`: Camels

`cohort_short` — Character. Sex- and age-specific cohort code:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

Usage

```
run_gleam(
  has_herd_structure = FALSE,
  cohort_level_data,
  herd_level_data,
  feed_rations,
  feed_params,
  feed_emissions,
  manure_management_system_fraction,
  manure_management_system_factors,
  simulation_duration = 365,
  global_warming_potential_set = "AR6",
  show_indicator = TRUE
)
```

Arguments

`has_herd_structure`

Logical. If `TRUE`, `cohort_level_data` is treated as an existing herd structure and the demographic herd simulation step is skipped. If `FALSE`, herd structure is first generated from `cohort_level_data` and `herd_level_data` using `run_demographic_herd_module`.

`cohort_level_data`

data.table. Cohort-level master input table. Required columns:

herd_id Character. Unique herd identifier, repeated for each cohort within the same herd.

species_short Character. Species code (see Common identifiers).

cohort_short Character. Cohort code (see Common identifiers).

cohort_duration_days Numeric. Time each animal spends in the cohort (days).

offtake_rate Numeric. Annual proportion of animals removed from the herd per cohort (fraction).

low_activity_fraction Numeric. Proportion of the assessment period with low-intensity movement, e.g. stall-feeding or near-field grazing (fraction).

high_activity_fraction Numeric. Proportion of the assessment period with sustained locomotion, e.g. herding or long-distance grazing over uneven terrain (fraction).

Additional columns when `has_herd_structure = FALSE`:

death_rate Numeric. Annual fraction of deaths per cohort (fraction).

Additional columns when `has_herd_structure = TRUE`:

cohort_stock_size Numeric. Average population size in each cohort (heads).

offtake_heads_assessment Numeric. Total animals removed via offtake over the assessment period per cohort (heads/assessment period).

Optional column (both cases):

ch4_mitigation_factor Numeric. Multiplicative factor applied to baseline enteric CH4 emissions (dimensionless). Defaults to 1 (no mitigation). Values < 1 represent proportional reductions (e.g. `0.90` = 10 percent reduction). Can represent feed additives or methane inhibitors.

`herd_level_data`

data.table. Herd-level master input table (one row per `herd_id`). Required columns:

herd_id Character. Unique herd identifier.

species_short Character. Species code (see Common identifiers).

live_weight_female_adult Numeric. Adult female live weight (kg).

live_weight_male_adult Numeric. Adult male live weight (kg).

live_weight_at_birth Numeric. Live weight at birth (kg).

live_weight_at_weaning Numeric. Live weight at weaning (kg).

live_weight_female_at_slaughter Numeric. Female sub-adult slaughter weight (kg).

live_weight_male_at_slaughter Numeric. Male sub-adult slaughter weight (kg).

age_first_parturition Numeric. Age at first parturition (days).

lactating_females_fraction Numeric. Proportion of adult females lactating during the assessment period (fraction). Required for CTL, BFL, CML, SHP, GTS.

milk_yield_day Numeric. Average daily milk yield per milk-producing animal (kg/head/day), calculated as total milk produced for human consumption divided by the number of milk-producing animals and the assessment period length. Required for CTL, BFL, CML, SHP, GTS.

milk_fat_fraction Numeric. Milk fat content (kg fat/kg milk). Required for CTL, BFL, CML, SHP, GTS.

milk_protein_fraction Numeric. Milk protein content (kg protein/kg milk). Required for CTL, BFL, CML, SHP, GTS.

milk_lactose_fraction Numeric. Milk lactose content (kg lactose/kg milk). Required for CTL, BFL, CML, SHP, GTS.

milk_protein_fraction_standard Numeric. Standard milk protein content for FPCM calculation (kg protein/kg milk). Suggested: 0.033.

milk_fat_fraction_standard Numeric. Standard milk fat content for FPCM calculation (kg fat/kg milk). Suggested: 0.04.

milk_lactose_fraction_standard Numeric. Standard milk lactose content for FPCM calculation (kg lactose/kg milk). Suggested: 0.048.

non_productive_duration Numeric. Period without productive function (pregnancy/lactation) (days). Required for PGS.

pregnancy_duration Numeric. Pregnancy duration (days).

death_rate_juvenile Numeric. Annual death fraction for juvenile cohorts (FJ, MJ) (fraction).

lactation_duration Numeric. Lactation period length (days). Required for PGS.

parturition_rate Numeric. Average annual parturitions per adult female (parturitions/adult female/year).

litter_size Numeric. Average offspring born per parturition (offspring/parturition).

draught_work_hours_female Numeric. Average daily working time per adult female (hours/head/day). Required for CTL, BFL, CML.

draught_work_hours_male Numeric. Average daily working time per adult male (hours/head/day). Required for CTL, BFL, CML.

draught_fraction_female Numeric. Fraction of adult females doing draught work (fraction). Required for CTL, BFL, CML.

draught_fraction_male Numeric. Fraction of adult males doing draught work (fraction). Required for CTL, BFL, CML.

fibre_yield_year Numeric. Annual fibre production (wool, cashmere, mohair) (kg/head/year). Required for CML, SHP, GTS.

carcass_dressing_fraction Numeric. Carcass weight to live weight ratio (fraction).

bone_free_meat_fraction Numeric. Bone-free meat to carcass weight ratio (fraction).

meat_protein_fraction Numeric. Protein content of bone-free meat (kg protein/kg bone-free meat).

ratio_me_to_ne Numeric. Metabolizable-to-net energy ratio (fraction). Used for CML. Suggested: 0.43.

Additional columns when `has_herd_structure = FALSE`:

birth_fraction_female Numeric. Probability that a newborn is female (fraction).

herd_size_total Numeric. Total population at start of year, all cohorts (heads).

`feed_rations` data.table. Cohort-level feed ration shares, also used by `run_ration_quality_module` and `run_emissions_ration_module`. Required columns:

herd_id Character. Unique herd identifier.

species_short Character. Species code (see Common identifiers).

cohort_short Character. Cohort code (see Common identifiers).

feed_id Character. Unique feed component identifier, used as join key with feed parameter tables.

feed_name Character. Optional. Human-readable feed name; should match `feed_id` uniquely if provided.

feed_ration_fraction Numeric. Proportion of this feed component in the total ration as a fraction of diet dry matter intake (fraction). Must sum to 1 within each herd_id $\times$ cohort combination.

`feed_params` data.table. Feed nutritional parameters. Required columns:

feed_id Character. Unique feed component identifier.

feed_gross_energy Numeric. Gross energy: total chemical energy upon complete combustion (MJ/kg DM).

feed_digestible_energy_ruminant Numeric. Digestible energy for ruminants: energy absorbed after faecal losses (MJ/kg DM).

feed_digestible_energy_pigs Numeric. Digestible energy for pigs (MJ/kg DM).

feed_metabolizable_energy_ruminant Numeric. Metabolizable energy for ruminants: digestible energy minus urinary and gaseous losses (MJ/kg DM).

feed_metabolizable_energy_pigs Numeric. Metabolizable energy for pigs (MJ/kg DM).

feed_metabolizable_energy_chicken Numeric. Metabolizable energy for chickens: digestible energy minus uric acid and gaseous losses (MJ/kg DM).

feed_nitrogen_content Numeric. Nitrogen content (kg N/kg DM).

feed_urinary_energy_ruminant Numeric. Fraction of gross energy excreted in urine for ruminants (fraction).

feed_urinary_energy_pigs Numeric. Fraction of gross energy excreted in urine for pigs (fraction).

feed_ash Numeric. Ash content as a fraction of dry matter (g ash/100 g DM).

category Character. Optional. Feed category; should be used consistently with `feed_id`.

feed_name Character. Optional. Human-readable feed name; should match `feed_id` uniquely if provided.

`feed_emissions` data.table. Emission factors per feed component. All emission factors are expressed per kg of feed dry matter intake. Required columns:

feed_id Character. Unique feed component identifier.

feed_name Character. Optional. Human-readable feed name.

co2_feed_fertilizer Numeric. CO2 from fertilizer manufacture (g CO2/kg DM).

co2_feed_pesticides Numeric. CO2 from pesticide manufacture (g CO2/kg DM).

co2_feed_crop_activities Numeric. CO2 from on-field agricultural activities (g CO2/kg DM).

co2_feed_luc_nopeat Numeric. CO2 from land-use change, excluding peatland drainage (g CO2/kg DM).

co2_feed_luc_peat Numeric. CO2 from peatland drainage (g CO2/kg DM).

n2o_feed_fertilizer Numeric. N2O from fertilizer use (g N2O/kg DM).

n2o_feed_manure_applied Numeric. N2O from manure applied to or deposited on soil (g N2O/kg DM).

n2o_feed_crop_residues Numeric. N2O from crop residue decomposition (g N2O/kg DM).

ch4_feed_rice Numeric. CH4 from rice cultivation (g CH4/kg DM).

`manure_management_system_fraction`

data.table. Cohort-level manure management system fractions passed to `run_emissions_manure_module`. Required columns:

herd_id Character. Unique herd identifier.

cohort_short Character. Cohort code (see Common identifiers).

manure_management_system Character. Manure management system name. `mms_pasture` and `mms_burned` are reserved for manure deposited on pasture and burned for fuel, respectively. All other systems are grouped as "other".

manure_management_system_fraction Numeric. Fraction of total manure handled by this system for each herd × cohort combination (0–1). Must sum to 1 per herd_id.

`manure_management_system_factors`

data.table. Emission factors and parameters per manure management system, passed to `run_emissions_manure_module`. Required columns:

manure_management_system Character. System name (see `manure_management_system_fraction`).

ratio_m3CH4_to_kgCH4 Numeric. CH4 density conversion factor (kg/m3). Default: 0.67.

methane_conversion_factor_mcf Numeric. Fraction of maximum CH4-producing capacity (Bo) realised under given management and environmental conditions (0–1). See IPCC Table 10.17 (2006, 2019).

ch4_max_producing_capacity_bo Numeric. Maximum CH4-producing capacity per unit volatile solids (m3 CH4/kg VS). Region- and species-specific. See IPCC Table 10.16 (2019) or Tables 10A-4 to 10A-9 (2006).

n2o_ef3 Numeric. Direct N2O emission factor per manure management system (kg N2O-N/kg N). See IPCC Table 10.21 and Table 11.1 (2006, 2019).

n2o_ef4 Numeric. Indirect N2O emission factor from atmospheric deposition of volatilised N (kg N2O-N/(kg NH3-N + NOx-N)). See IPCC Table 11.3 (2006, 2019).

nitrogen_fracgas Numeric. Fraction of excreted N volatilised as NH3 and NOx during collection, storage, and treatment (0–1). See IPCC Table 10.22 (2006, 2019).

n2o_ef5 Numeric. Indirect N2O emission factor from leaching and runoff (kg N2O-N/kg N). See IPCC Table 11.3 (2006, 2019).

nitrogen_fracleach Numeric. Fraction of excreted N lost through leaching and runoff (0–1). See IPCC Table 10.22 (2006, 2019).

`simulation_duration`
: Numeric. Assessment period length (days). Used by the demographic herd simulation (when `has_herd_structure = FALSE`) and by the production and aggregation steps. Default: `365`.

`global_warming_potential_set`
: Character. GWP-100 conversion factors for expressing CH4 and N2O as CO2-eq. One of:

- `"AR6"`: IPCC 6th Assessment (2021) — CH4 = 27, N2O = 273.
- `"AR5_excluding_carbon_feedback"`: IPCC 5th Assessment, excl. climate-carbon feedbacks (2013) — CH4 = 28, N2O = 265.
- `"AR5_including_carbon_feedback"`: IPCC 5th Assessment, incl. climate-carbon feedbacks (2013) — CH4 = 34, N2O = 298.
- `"AR4"`: IPCC 4th Assessment (2007) — CH4 = 25, N2O = 298.

`show_indicator`
: Logical. Whether to display progress indicators during calculations. Defaults to `TRUE`.

Details

The GLEAM package implements the core computational engine of the Global Livestock Environmental Assessment Model (GLEAM), developed by the Food and Agriculture Organization of the United Nations (FAO). It provides a modular workflow for quantifying greenhouse gas emissions from livestock systems using a Life Cycle Assessment (LCA) approach based on the IPCC Tier 2 methodology.

The pipeline covers seven species (CTL, BFL, CML, SHP, GTS, PGS). Within each herd, animals are organised into six sex-age cohorts (FJ, FS, FA, MJ, MS, MA). These identifiers are used consistently across all modules.

The assessment period is specified in days via `simulation_duration` (typically 365). Intermediate per-head-per-day variables are carried through the cohort workflow and scaled to cohort and herd totals in the final aggregation step.

Pipeline sequence:

1. If `has_herd_structure = FALSE`, generate herd structure with `run_demographic_herd_module`; otherwise use supplied tables directly.
2. Compute cohort weights (`run_weights_module`).
3. Summarise ration quality (`run_ration_quality_module`) and merge into the cohort table.
4. Compute energy requirements and dry matter intake (`run_metabolic_energy_req_module`).
5. Compute enteric CH4 (`run_emissions_enteric_module`).
6. Compute nitrogen balance (`run_nitrogen_balance_module`).

7. Compute manure emissions (run_emissions_manure_module).
8. Summarise feed production emissions (run_emissions_ration_module) and merge into the cohort table.
9. Compute production outputs (run_production_module).
10. Compute allocation (run_allocation_module).
11. Aggregate to herd-level results and CO2-eq (run_aggregation_module).

All inputs containing herd_id must refer to the same herd set. Validation blocks variables that are expected to be produced internally.

Value

A named list with four elements:

cohort_level_results A cohort-level data.table containing the original input columns plus all variables generated across the pipeline. Calculated variables are grouped below by module.

Demographic herd simulation: Computed when has_herd_structure = FALSE:

cohort_stock_size Numeric. Average population size in each of the 6 sex-age cohorts (# heads). (cohorts = FJ, FS, FA, MJ, MS, MA).

offtake_heads Numeric. Total number of animals removed via offtake over the year, aggregated to 6 sex-age cohorts (heads/year) (cohorts = FJ, FS, FA, MJ, MS, MA).

offtake_heads_assessment Numeric. Total number of animals removed via offtake over the assessment period, aggregated to 6 sex-age cohorts (heads/assessment period) (cohorts = FJ, FS, FA, MJ, MS, MA).

Weight variables:

live_weight_mature_stage Numeric. Mature (adult) live weight that the animal can attain under given biological and management conditions (kg).

live_weight_cohort_initial Numeric. Live weight at the beginning of the cohort stage (kg).

live_weight_cohort_potential_final Numeric. Potential final live weight attainable at the end of the cohort stage in the absence of offtake (kg). (For juveniles: equals weaning weight; For subadults: equals adult live weight; For adults: equals adult live weight)

live_weight_cohort_at_slaughter Numeric. Live weight at slaughter for animals removed from the cohort (kg).

live_weight_cohort_average Numeric. Average live weight over the cohort stage. Computed by accounting for the share of offtaken animals within the cohort, using their slaughter weight, and the potential final weight of animals that remain in the cohort (kg).

live_weight_cohort_final Numeric. Live weight at the end of the cohort stage, accounting for both surviving and offtaken animals. Computed as a weighted average of the potential final weight of surviving animals and the slaughter weight of offtaken animals, based on the offtake rate (kg).

daily_weight_gain Numeric. Average live weight gain of the cohort over the cohort stage (kg/head/day).

Ration quality variables:

ration_gross_energy Numeric. Average gross energy content of the diet (MJ/kg DM).

ration_metabolizable_energy Numeric. Average metabolizable energy content of the diet (MJ/kg DM).

ration_nitrogen Numeric. Average nitrogen content of diet (kg N/kg DM).

ration_digestibility_fraction Numeric. Average digestibility of the feed ration, expressed as ratio of digestible (or metabolizable, for poultry) to gross energy content (fraction).

ration_urinary_energy_fraction Numeric. Fraction of feed's gross energy that is excreted in urine (fraction).

ration_ash Numeric. Average ash content of feed, calculated as a fraction of the dry matter intake (kg ash/kg DM).

Energy requirement variables: Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS unless stated otherwise.

metabolic_energy_req_maintenance Numeric. Energy required for maintenance, defined as the amount of energy needed to keep the animal at equilibrium such that body energy is neither gained nor lost (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_activity Numeric. Energy required for activity, defined as the amount of energy needed to support animal movement and physical activity (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_growth Numeric. Energy required for growth (i.e., weight gain) (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_lactation Numeric. Energy required for lactation (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_work Numeric. Energy required for work, used to estimate the energy required for draught power for CTL, BFL and CML (MJ/head/day). Assumed to be 0 for other species. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_fibre_production Numeric. Energy required for the synthesis of fibre for SHP, GTS and CML. Assumed to be 0 for other species. (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

metabolic_energy_req_pregnancy Numeric. Energy required for pregnancy for pregnant females (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

net_energy_maintenance_digestible_energy_ratio Numeric. Ratio of net energy available for maintenance in the diet to digestible energy consumed (fraction).

net_energy_growth_digestible_energy_ratio Numeric. Ratio of net energy available for growth in the diet to digestible energy consumed (fraction).

metabolic_energy_req_total Numeric. Total daily energy requirement (MJ/head/day). For CTL, BFL, SHP and GTS this is expressed as gross energy intake requirement (GE). For CML and PGS the function returns the summed daily metabolizable energy requirement.

ration_intake Numeric. Average daily dry matter intake of feed (kg DM/head/day).

Enteric emission variables:

ch4_mitigation_factor Numeric. Multiplicative mitigation factor applied to baseline enteric methane (CH4) emissions (dimensionless). If not provided, a default value of 1 (no mitigation) is used.

ch4_conversion_factor_ym Numeric. Methane (CH4) conversion factor (ym), representing the percentage of gross energy of the feed ration that is converted to CH4 (percentage).

ch4_enteric Numeric. Average daily enteric methane (CH4) emissions (kg CH4/head/day).

Nitrogen balance variables:

nitrogen_intake Numeric. Daily nitrogen intake (kg N/head/day).

nitrogen_retention Numeric. Daily nitrogen retention in animal body tissues and products (e.g., growth, pregnancy, milk...) (kg N/head/day).

nitrogen_excretion Numeric. Daily nitrogen excretion (kg N/head/day).

Manure emission variables:

volatile_solids Numeric. Total volatile solids (VS) excreted per animal per day, representing the organic material in livestock manure and consisting of both biodegradable and non-biodegradable fractions (kg VS/head/day).

ch4_manure_pasture Numeric. Methane (CH4) emissions from manure deposited on pasture (kg CH4/head/day).

ch4_manure_burned Numeric. Methane (CH4) emissions from manure burned for fuel (kg CH4/head/day).

ch4_manure_other Numeric. Methane (CH4) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg CH4/head/day).

ch4_manure_all_noburn Numeric. Methane (CH4) emissions from manure management systems, excluding manure burned for fuel (kg CH4/head/day).

n2o_manure_pasture_direct Numeric. Direct nitrous oxide (N2O) emissions from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_direct Numeric. Direct nitrous oxide (N2O) emissions from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_direct Numeric. Direct nitrous oxide (N2O) emissions from manure management systems, excluding emissions from manure deposited on pasture and burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_direct Numeric. Direct nitrous oxide (N2O) emissions from manure management systems, excluding emissions from manure burned for fuel (kg N2O/head/day).

n2o_manure_pasture_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure management systems, excluding manure deposited on pasture and manure burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_vol Numeric. Indirect nitrous oxide (N2O) emissions resulting from atmospheric deposition of volatilised nitrogen (NH3 and NOx) from manure management systems, excluding losses from manure burned for fuel (kg N2O/head/day).

n2o_manure_pasture_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure deposited on pasture (kg N2O/head/day).

n2o_manure_burned_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure burned for fuel (kg N2O/head/day).

n2o_manure_other_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure management systems, excluding losses from manure deposited on pasture and manure burned for fuel (kg N2O/head/day).

n2o_manure_all_noburn_leach Numeric. Indirect nitrous oxide (N2O) emissions resulting from leaching and runoff of manure nitrogen from manure management systems, excluding losses from manure burned for fuel (kg N2O/head/day).

n2o_manure_pasture_indirect Numeric. Total indirect nitrous oxide (N2O) emissions from manure deposited on pasture. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_burned_indirect Numeric. Total indirect nitrous oxide (N2O) emissions originating from manure burned for fuel. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_other_indirect Numeric. Total indirect nitrous oxide (N2O) emissions originating from manure management systems, excluding manure deposited on pasture and burned for fuel. Includes emissions from atmospheric deposition of volatilised nitrogen (NH3 and NOx) and from leaching and runoff of manure nitrogen (kg N2O/head/day).

n2o_manure_pasture_total Numeric. Total nitrous oxide emissions from manure deposited on pasture. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

n2o_manure_burned_total Numeric. Total nitrous oxide emissions (N2O) from manure burned for fuel. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

n2o_manure_other_total Numeric. Total nitrous oxide (N2O) emissions from manure management systems, excluding manure deposited on pasture and manure burned for fuel. Includes direct emissions and indirect emissions from volatilisation, leaching, and runoff (kg N2O/head/day).

Feed production emission variables:

co2_ration_fertilizer Numeric. Diet-level average carbon dioxide (CO2) emission factor from fertilizer manufacture in feed production (g CO2/kg DM).

co2_ration_pesticides Numeric. Diet-level average carbon dioxide (CO2) emission factor from pesticide manufacture in feed production (g CO2/kg DM).

co2_ration_crop_activities Numeric. Diet-level average carbon dioxide (CO2) emission factor from on-field agricultural activities in feed production (g CO2/kg DM).

co2_ration_luc_nopeat Numeric. Diet-level average carbon dioxide (CO2) emission factor from land-use change (excluding peatland drainage) in feed production (g CO2/kg DM).

co2_ration_luc_peat Numeric. Diet-level average carbon dioxide (CO2) emission factor from peatland drainage in feed production (g CO2/kg DM).

n2o_ration_fertilizer Numeric. Diet-level average nitrous oxide (N2O) emission factor from fertilizer use in feed production (g N2O/kg DM).

n2o_ration_manure_applied Numeric. Diet-level average nitrous oxide (N2O) emission factor from manure applied to or deposited on soil in feed production (g N2O/kg DM).

n2o_ration_crop_residues Numeric. Diet-level average nitrous oxide (N2O) emission factor from crop residues decomposition in feed production (g N2O/kg DM).

ch4_ration_rice Numeric. Diet-level average methane (CH4) emission factor from rice cultivation in feed production (g CH4/kg DM).

Production variables:

milk_production_mass_cohort Numeric. Total milk production produced over the assessment period (kg/cohort/assessment period).

milk_production_protein_cohort Numeric. Total milk protein production produced over the assessment period (kg protein/cohort/assessment period).

milk_production_fpcm_cohort Numeric. Total fat-protein-corrected milk (FPCM) produced over the assessment period (kg/cohort/assessment period).

fibre_production_cohort Numeric. Total fibre produced over the assessment period by cohort (kg/cohort/assessment period).

meat_production_live_weight_cohort Numeric. Total meat produced as live weight over the assessment period by cohort (kg/cohort/assessment period).

meat_production_carcass_weight_cohort Numeric. Total meat as carcass weight (excluding organs, and other by-products after dressing) produced over the assessment period by cohort (kg/cohort/assessment period).

meat_production_bone_free_meat_cohort Numeric. Total bone-free-meat (excluding bones, organs, and other by-products after dressing and bone removal) produced over the assessment period by cohort (kg/cohort/assessment period).

meat_production_protein_cohort Numeric. Total meat protein (excluding bones, organs, and other by-products after dressing and bone removal) produced over the assessment period by cohort (kg protein/cohort/assessment period).

Allocation variables:

milk_allocation_energy Numeric. Energy required to produce total milk output by cohort (MJ/cohort/assessment period). Non-zero values are applicable only to milk-producing species and cohorts (species = CTL, BFL, CML, SHP, GTS; cohorts = FA). All other species-cohort combinations are assigned a value of 0.

meat_allocation_energy Numeric. Energy required by a given sex-age cohort for total meat output by cohort during the assessment period, equal to the energy needed to produce all live-weight gain to reach the target slaughter weight (MJ/cohort/assessment period).

fibre_allocation_energy Numeric. Energy required to produce all fibre output by cohort (MJ/cohort/assessment period).

work_allocation_energy Numeric. Energy required to provide all draught power (traction/work) by cohort (MJ/cohort/assessment period).

egg_allocation_energy Numeric. Energy required for egg production over the assessment period (MJ/cohort/assessment period). Currently set to 0.

herd_level_results A herd-level `data.table`. When `has_herd_structure = FALSE`, the output from `run_demographic_herd_module`, including:

growth_rate_herd Numeric. Annualized growth rate at which the herd reaches steady state (fraction).

When `has_herd_structure = TRUE`, the supplied `herd_level_data` is returned unchanged.

allocation_long A herd-level `data.table` in long format with one row per herd × commodity × emission source:

herd_id Character. Herd identifier.

species_short Character. Species code.

variable_name Character. Emission variable name (e.g. `"ch4_enteric"`, `"n2o_manure_pasture_direct"`).

commodity_name Character. Commodity category: one of `"None"`, `"Milk"`, `"Meat"`, `"Fibre"`, `"Work"`, `"Eggs"`.

commodity_type Character. `"Edible"` or `"Non-Edible"`.

allocation_share Numeric. Allocation share for this commodity-emission combination (fraction).

aggregation_results A named list from `run_aggregation_module` with elements `results_emissions`, `results_feed`, `results_production`, and `results_nitrogen`. These tables summarise herd-level emissions, feed intake, production, and nitrogen balance, all scaled to the assessment duration.

See Also

`run_demographic_herd_module`, `run_weights_module`, `run_ration_quality_module`, `run_metabolic_energy_req_mo`
`run_emissions_enteric_module`, `run_nitrogen_balance_module`, `run_emissions_manure_module`,
`run_emissions_ration_module`, `run_production_module`, `run_allocation_module`, `run_aggregation_module`

Examples

```
# Example 1: You do NOT have herd structure — use cohort input for herd simulation.
# Pipeline runs herd simulation first, then the rest of the pipeline.

path_run_gleam_examples <- system.file("extdata/run_gleam_examples", package = "gleam")

master_chrt_lvl_no_structure_dt <- data.table::fread(file.path(
  path_run_gleam_examples, "master_chrt_lvl_no_structure_data.csv"
))
master_hrd_lvl_dt <- data.table::fread(
file.path(path_run_gleam_examples, "master_hrd_lvl_data.csv")
)
feed_rations_chrt_dt <- data.table::fread(
file.path(path_run_gleam_examples, "feed_rations_share_chrt.csv")
)
feed_params_dt <- data.table::fread(system.file(
  "extdata/run_gleam_examples/feed_quality.csv",
  package = "gleam"
))
feed_emissions_dt <- data.table::fread(system.file(
  "extdata/run_gleam_examples/feed_emission_factors.csv",
  package = "gleam"
))
```

```
manure_management_system_fraction_dt <- data.table::fread(
  file.path(path_run_gleam_examples, "manure_management_system_fraction.csv")
)
manure_management_system_factors_dt <- data.table::fread(
  file.path(path_run_gleam_examples, "manure_management_system_factors.csv")
)

results <- run_gleam(
  has_herd_structure = FALSE,
  cohort_level_data = master_chrt_lvl_no_structure_dt,
  herd_level_data = master_hrd_lvl_dt,
  feed_rations = feed_rations_chrt_dt,
  feed_params = feed_params_dt,
  feed_emissions = feed_emissions_dt,
  manure_management_system_fraction = manure_management_system_fraction_dt,
  manure_management_system_factors = manure_management_system_factors_dt,
  simulation_duration = 365
)
print(results$cohort_level_results)
print(results$allocation_long)


# Example 2: You already HAVE herd structure — use cohort table and skip herd simulation.
# Pipeline skips herd simulation and uses this as the starting cohort table.

path_run_gleam_examples <- system.file("extdata/run_gleam_examples", package = "gleam")

master_chrt_lvl_structure_dt <- data.table::fread(file.path(
  path_run_gleam_examples, "master_chrt_lvl_structure_data.csv"
))
master_hrd_lvl_dt <- data.table::fread(
file.path(path_run_gleam_examples, "master_hrd_lvl_data.csv")
)
feed_rations_chrt_dt <- data.table::fread(
file.path(path_run_gleam_examples, "feed_rations_share_chrt.csv")
)
feed_params_dt <- data.table::fread(system.file(
  "extdata/run_gleam_examples/feed_quality.csv",
  package = "gleam"
))
feed_emissions_dt <- data.table::fread(system.file(
  "extdata/run_gleam_examples/feed_emission_factors.csv",
  package = "gleam"
))

manure_management_system_fraction_dt <- data.table::fread(
  file.path(path_run_gleam_examples, "manure_management_system_fraction.csv")
)
manure_management_system_factors_dt <- data.table::fread(
  file.path(path_run_gleam_examples, "manure_management_system_factors.csv")
)

results <- run_gleam(
```

```
  has_herd_structure = TRUE,
  cohort_level_data = master_chrt_lvl_structure_dt,
  herd_level_data = master_hrd_lvl_dt,
  feed_rations = feed_rations_chrt_dt,
  feed_params = feed_params_dt,
  feed_emissions = feed_emissions_dt,
  manure_management_system_fraction = manure_management_system_fraction_dt,
  manure_management_system_factors = manure_management_system_factors_dt,
  simulation_duration = 365,
  global_warming_potential_set = "AR6"
)
print(results$cohort_level_results)
print(results$allocation_long)
```

`run_metabolic_energy_req_module` *Run Metabolic Energy Requirements and Dry Matter Intake Module Pipeline*

Description

Calculates cohort-level daily energy requirements (MJ/head/day) and ration dry matter intake (kg DM/head/day) by applying the IPCC Tier 2 energy partitioning functions.

Usage

```
run_metabolic_energy_req_module(
  cohort_level_data,
  herd_level_data,
  show_indicator = TRUE
)
```

Arguments

`cohort_level_data`

data.table. Cohort-level input table with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

live_weight_cohort_average Numeric. Average live weight over the cohort stage. Computed by accounting for the share of offtaken animals within the cohort, using their slaughter weight, and the potential final weight of animals that remain in the cohort (kg).

offtake_rate Numeric. Annual proportion of animals removed from the herd for each sex-age cohort (fraction).

low_activity_fraction Numeric. Proportion of the assessment period during which the animal performs low-intensity movement typical of stall-feeding or near-field grazing, characterized by minimal walking distances and flat terrain (fraction).

high_activity_fraction Numeric. Proportion of the assessment period during which the animal engages in sustained locomotion associated with herding or long-distance grazing, typically involving extended walking distances and/or uneven or hilly terrain (fraction).

live_weight_cohort_initial Numeric. Live weight at the beginning of the cohort stage (kg).

live_weight_cohort_final Numeric. Live weight at the end of the cohort stage, accounting for both surviving and offtaken animals. Computed as a weighted average of the potential final weight of surviving animals and the slaughter weight of offtaken animals, based on the offtake rate (kg).

live_weight_mature_stage Numeric. Mature (adult) live weight that the animal can attain under given biological and management conditions (kg).

daily_weight_gain Numeric. Average live weight gain of the cohort over the cohort stage (kg/head/day).

cohort_duration_days Numeric. Amount of time that each animal spends in a specific cohort (days).

ration_digestibility_fraction Numeric. Average digestibility of the feed ration, expressed as ratio of digestible to gross energy content (fraction).

ration_gross_energy Numeric. Average gross energy content of the diet (MJ/kg DM).

ration_metabolizable_energy Numeric. Average metabolizable energy content of the diet (MJ/kg DM).

`herd_level_data`

data.table. Herd-level input table (one row per `herd_id`) with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

age_first_parturition Numeric. Age at first parturition for female breeding animals (days).

lactating_females_fraction Numeric. Proportion of adult females that are lactating during the assessment period (fraction). Required only for species = CML, CTL, BFL, SHP, and GTS.

milk_yield_day Numeric. Average milk yield per milk-producing animal during the assessment duration (kg/head/day). This value is calculated as the total quantity of milk produced for human consumption by milk-producing animals during the assessment period, divided by the number of milk-producing animals, and the length of the assessment period (days). Required only for species = CML, CTL, BFL, SHP, and GTS.

milk_fat_fraction Numeric. Milk fat fraction (kg fat / kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

non_productive_duration Numeric. Period during which the animal is not performing any productive physiological function such as pregnancy or lactation (days). Required only for PGS.

pregnancy_duration Numeric. Duration of pregnancy period (days).

litter_size Numeric. Average number of offspring born per parturition (# offsprings/parturition). This value can be calculated as the total number of offspring born divided by the total number of parturitions during the year.

death_rate_juvenile Numeric. Fraction of deaths in a herd over a year for juvenile cohorts (i.e. FJ and MJ), (fraction).

live_weight_at_birth Numeric. Live weight of the animal at birth (kg).

live_weight_at_weaning Numeric. Live weight of the animal at weaning (kg).

lactation_duration Numeric. Duration of the lactation period, defined as the number of days during which the animal is lactating (days). Required only for PGS.

parturition_rate Numeric. Average annual number of parturitions per female animal (# parturitions/adult female/year). A herd-level reproductive performance indicator calculated as the total number of parturitions (deliveries) occurring during a year divided by the number of adult females potentially able to give birth during that year.

draught_work_hours_female Numeric. Average daily working time per adult female (hours/head/day). Required only for species = CML, CTL, and BFL.

draught_work_hours_male Numeric. Average daily working time per adult male (hours/head/day). Required only for species = CML, CTL, and BFL.

draught_fraction_female Numeric. Fraction of adult females involved in draught work (fraction). Required only for species = CML, CTL, and BFL.

draught_fraction_male Numeric. Fraction of adult males involved in draught work (fraction). Required only for species = CML, CTL, and BFL.

fibre_yield_year Numeric. Annual production yield of fibre, such as wool, cashmere, mohair (kg/head/year). Required only for species = CML, SHP, and GTS.

`show_indicator` Logical. Whether to display progress indicators during simulation. Defaults to `TRUE`.

Details

This function joins `cohort_level_data` with `herd_level_data` by `herd_id`, uses `species_short` directly for all species-specific energy calculations, and computes IPCC Tier 2 energy partition components and derived feed intake metrics by cohort.

Energy requirements are expressed as:

- **Net energy** for CTL, BFL, SHP, GTS.
- **Metabolizable energy** for CML and PGS.

This function represents the intermediate module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` to estimate animals' metabolic energy requirements and dry matter intake and performs the following calculation sequence:

1. Maintenance energy is computed using `calc_metabolic_energy_req_maintenance`.
2. Activity energy is computed using `calc_metabolic_energy_req_activity`.
3. Growth energy is computed using `calc_metabolic_energy_req_growth`.
4. Lactation energy is computed using `calc_metabolic_energy_req_lactation`.
5. Work energy is computed using `calc_metabolic_energy_req_work`.
6. Fibre production energy is computed using `calc_metabolic_energy_req_fibre`.
7. Pregnancy energy is computed using `calc_metabolic_energy_req_pregnancy`.
8. Diet net energy ratios are computed using `calc_rem_maintenance` and `calc_reg_growth` (ruminants only).
9. Total daily energy requirement is computed using `calc_total_metabolic_energy_req`.
10. Daily dry matter intake is computed using `calc_ration_intake`.

Value

A `data.table` with the original cohort-level input columns plus the following new variables:

metabolic_energy_req_maintenance Numeric. Energy required for maintenance, defined as the amount of energy needed to keep the animal at equilibrium such that body energy is neither gained nor lost. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

metabolic_energy_req_activity Numeric. Energy required for activity, defined as the amount of energy needed to support animal movement and physical activity (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_growth Numeric. Energy required for growth (i.e., weight gain) (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_lactation Numeric. Energy required for lactation (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_work Numeric. Energy required for work, used to estimate the energy required for draught power for CTL, BFL and CML (MJ/head/day). Assumed to be 0 for other species. Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

metabolic_energy_req_fibre_production Numeric. Energy required for the synthesis of fibre for SHP, GTS and CML. Assumed to be 0 for other species. (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS (MJ/head/day).

metabolic_energy_req_pregnancy Numeric. Energy required for pregnancy for pregnant females (MJ/head/day). Expressed as net energy for CTL, BFL, SHP, GTS and as metabolizable energy for CML and PGS.

net_energy_maintenance_digestible_energy_ratio Numeric. Ratio of net energy available for maintenance in the diet to digestible energy consumed (fraction).

net_energy_growth_digestible_energy_ratio Numeric. Ratio of net energy available for growth in the diet to digestible energy consumed (fraction).

metabolic_energy_req_total Numeric. Total daily energy requirement (MJ/head/day). For CTL, BFL, SHP and GTS this is expressed as gross energy intake requirement (GE). For CML and PGS the function returns the summed daily metabolizable energy requirement.

ration_intake Numeric. Average daily dry matter intake of feed (kg DM/head/day).

See Also

run_gleam, calc_metabolic_energy_req_maintenance, calc_metabolic_energy_req_activity, calc_metabolic_energy_req_growth, calc_metabolic_energy_req_lactation, calc_metabolic_energy_req_work, calc_metabolic_energy_req_fibre, calc_metabolic_energy_req_pregnancy, calc_rem_maintenance, calc_reg_growth, calc_total_metabolic_energy_req, calc_ration_intake

Examples

```
# Load metabolic energy requirements inputs (cohort and herd-level)
metabolic_energy_req_chrt_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/metabolic_energy_req_input_chrt_data.csv",
  package = "gleam"
))
metabolic_energy_req_hrd_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/metabolic_energy_req_input_hrd_data.csv",
  package = "gleam"
))

# Run metabolic energy requirement and rations calculations
results <- run_metabolic_energy_req_module(
  cohort_level_data = metabolic_energy_req_chrt_dt,
  herd_level_data = metabolic_energy_req_hrd_dt
)
```

---

run_nitrogen_balance_module

Run Nitrogen Balance Module Pipeline

Description

Calculates cohort-level daily nitrogen intake, retention, and excretion (kg N/head/day) by applying IPCC Tier 2 approach.

Usage

```
run_nitrogen_balance_module(
  cohort_level_data,
  herd_level_data,
  show_indicator = TRUE
)
```

Arguments

`cohort_level_data`

data.table. Cohort-level input table with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

ration_intake Numeric. Average daily dry matter intake of feed (kg DM/head/day).

ration_nitrogen Numeric. Average nitrogen content of diet (kg N/kg DM).

daily_weight_gain Numeric. Average live weight gain of the cohort over the cohort stage (kg/head/day).

cohort_duration_days Numeric. Amount of time that each animal spends in a specific cohort (days).

`herd_level_data`

data.table. Herd-level input table (one row per `herd_id`) with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

milk_protein_fraction Numeric. Milk protein fraction (kg protein / kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

milk_yield_day Numeric. Average milk yield per milk-producing animal during the assessment duration (kg/head/day). This value is calculated as the total quantity of milk produced for human consumption by milk-producing animals during the assessment period, divided by the number of milk-producing animals, and the length of the assessment period (days). Required only for species = CML, CTL, BFL, SHP, and GTS.

fibre_yield_year Numeric. Annual production yield of fibre, such as wool, cashmere, mohair (kg/head/year). Required only for species = CML, SHP, and GTS.

litter_size Numeric. Average number of offspring born per parturition (# offsprings/parturition). This value can be calculated as the total number of offspring born divided by the total number of parturitions during the year.

parturition_rate Numeric. Average annual number of parturitions per female animal (# parturitions/adult female/year). A herd-level reproductive performance indicator calculated as the total number of parturitions (deliveries) occurring during a year divided by the number of adult females potentially able to give birth during that year.

live_weight_at_weaning Numeric. Live weight of the animal at weaning (kg).

live_weight_at_birth Numeric. Live weight of the animal at birth (kg).

pregnancy_duration Numeric. Duration of pregnancy period (days).

`show_indicator` Logical. Whether to display progress indicators during simulation. Defaults to `TRUE`.

Details

This function represents the intermediate module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` to compute the nitrogen balance. The function joins `cohort_level_data` with `herd_level_data` by `herd_id`, uses `species_short` directly for all species-specific nitrogen balance calculations, and computes cohort-level nitrogen balance components following the IPCC Tier 2 structure.

The following calculation sequence is applied:

1. Daily nitrogen intake is computed using `calc_nitrogen_intake` from `ration_intake` and `ration_nitrogen`.
2. Daily nitrogen retention is computed using `calc_nitrogen_retention` from cohort-level and herd-level species parameters.
3. Daily nitrogen excretion is computed using `calc_nitrogen_excretion` as intake minus retention (species-specific validation applied).

Value

A `data.table` with the original cohort-level input columns plus the following new variables:

nitrogen_intake Numeric. Daily nitrogen intake (kg N/head/day).

nitrogen_retention Numeric. Daily nitrogen retention in animal body tissues and products (e.g., growth, pregnancy, milk...) (kg N/head/day)

nitrogen_excretion Numeric. Daily nitrogen excretion (kg N/head/day).

See Also

run_gleam, calc_nitrogen_intake, calc_nitrogen_retention, calc_nitrogen_excretion

Examples

```
# Load nitrogen balance inputs (cohort and herd-level)
nitrogen_balance_chrt_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/nitrogen_balance_input_chrt_data.csv",
  package = "gleam"
))
nitrogen_balance_hrd_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/nitrogen_balance_input_hrd_data.csv",
  package = "gleam"
))

# Run nitrogen balance calculations
results <- run_nitrogen_balance_module(
  cohort_level_data = nitrogen_balance_chrt_dt,
  herd_level_data = nitrogen_balance_hrd_dt
)
```

---

run_production_module *Run Production Module Pipeline*

Description

Calculates cohort-level production outputs over the assessment period by combining cohort-level herd structure inputs with herd-level production parameters. The function returns milk, fibre, and meat outputs for each cohort.

Usage

```
run_production_module(
  cohort_level_data,
  herd_level_data,
  simulation_duration = 365,
  show_indicator = TRUE
)
```

Arguments

`cohort_level_data`

data.table. Cohort-level input table (one row per herd-cohort) with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

cohort_stock_size Numeric. Average population size in each of the 6 sex–age cohorts (# heads). (cohorts=FJ, FS, FA, MJ, MS, MA).

offtake_heads_assessment Numeric. Total number of animals removed via offtake over the assessment period, aggregated to 6 sex–age cohorts (heads/assessment period) (cohorts = FJ, FS, FA, MJ, MS, MA).

live_weight_cohort_at_slaughter Numeric. Live weight at slaughter for animals removed from the cohort (kg).

`herd_level_data`

data.table. Herd-level input table (one row per `herd_id`) with the following data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

milk_yield_day Numeric. Average milk yield per milk-producing animal during the assessment duration (kg/head/day). This value is calculated as the total quantity of milk produced for human consumption by milk-producing animals during the assessment period, divided by the number of milk-producing animals, and the length of the assessment period (days). Required only for species = CML, CTL, BFL, SHP, and GTS.

lactating_females_fraction Numeric. Proportion of adult females that are lactating during the assessment period (fraction). Required only for species: CML, CTL, BFL, SHP, and GTS.

milk_protein_fraction Numeric. Milk protein fraction (kg protein/kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

milk_fat_fraction Numeric. Milk fat fraction (kg fat/kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

milk_lactose_fraction Numeric. Milk lactose fraction (kg lactose/kg milk). Required only for species = CML, CTL, BFL, SHP, and GTS.

milk_protein_fraction_standard Numeric. Standard protein content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg protein/kg milk). Suggested value = 0.033.

milk_fat_fraction_standard Numeric. Standard fat content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg fat/kg milk). Suggested value = 0.04.

milk_lactose_fraction_standard Numeric. Standard lactose content of milk, used to calculate Fat-protein-corrected milk (FPCM), (kg lactose/kg milk). Suggested value = 0.048.

fibre_yield_year Numeric. Annual production yield of fibre, such as wool, cashmere, mohair (kg/head/year). Required only for species = CML, SHP, and GTS.

carcass_dressing_fraction Numeric. Ratio of a slaughtered animal's carcass weight to its live weight (fraction).

bone_free_meat_fraction Numeric. Ratio of bone-free-meat to carcass weight (fraction).

meat_protein_fraction Numeric. Protein content of bone-free-meat (kg protein/kg bone-free-meat).

`simulation_duration`
Numeric. Length of the assessment period (days).

`show_indicator` Logical. Whether to display progress indicators during simulation. Defaults to `TRUE`.

Details

This function represents the intermediate module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` to estimate meat, milk and fibre production outputs from livestock and performs the following calculation sequence:

1. Milk outputs are computed using `calc_milk_production`
2. Fibre outputs are computed using `calc_fibre_production`
3. Meat outputs are computed using `calc_meat_production`

For species/cohorts where milk or fibre production is not applicable, outputs are returned as zero.

Value

A `data.table` with the original cohort-level input columns plus the following new variables:

milk_production_mass_cohort Numeric. Total milk production produced over the assessment period (kg/cohort/assessment period).

milk_production_protein_cohort Numeric. Total milk protein production produced over the assessment period (kg protein/cohort/assessment period).

milk_production_fpcm_cohort Numeric. Total fat-protein-corrected milk (FPCM) produced over the assessment period (kg/cohort/assessment period).

fibre_production_cohort Numeric. Total fibre produced over the assessment period by cohort (kg /cohort/assessment period).

meat_production_live_weight_cohort Numeric . Total meat produced as live weight over the assessment period by cohort (kg/cohort/assessment period).

meat_production_carcass_weight_cohort Numeric. Total meat as carcass weight (excluding organs, and other by-products after dressing) produced over the assessment period by cohort (kg/cohort/assessment period).

meat_production_bone_free_meat_cohort Numeric. Total bone-free-meat (excluding bones, organs, and other by-products after dressing and bone removal) produced over the assessment period by cohort (kg/cohort/assessment period).

meat_production_protein_cohort Numeric. Total meat protein (excluding bones, organs, and other by-products after dressing and bone removal) produced over the assessment period by cohort (kg protein/cohort/assessment period).

See Also

run_gleam, calc_milk_production, calc_fibre_production, calc_meat_production

Examples

```
# Load production inputs (cohort and herd-level)
production_chrt_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/production_input_chrt_data.csv",
  package = "gleam"
))
production_hrd_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/production_input_hrd_data.csv",
  package = "gleam"
))

# Run production calculations
results <- run_production_module(
  cohort_level_data = production_chrt_dt,
  herd_level_data = production_hrd_dt,
  simulation_duration = 365
)
```

---

run_ration_quality_module

Run Ration Quality Module Pipeline

Description

Calculates cohort-level diet nutritional metrics (gross and metabolizable energy content, digestibility, nitrogen content, urinary energy losses, and ash content) from cohort-level feed ration composition shares and feed component nutrient parameters.

Usage

```
run_ration_quality_module(rations_share, feed_params, show_indicator = TRUE)
```

Arguments

`rations_share` data.table. Cohort-level feed ration composition shares with the following minimum data requirement:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

species_short Character. Code identifying the livestock species. Supported values include:

- `PGS`: pigs
- `CML`: camels
- `CTL`: cattle
- `BFL`: buffalo
- `SHP`: sheep
- `GTS`: goats

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

feed_id Character. Unique identifier for the feed component, used to join feed ration data with feed parameter tables.

feed_name Character. Feed component name (optional, for readability and reporting). If provided, it should uniquely identify the same feed component as `feed_id`.

feed_ration_fraction Numeric. Proportion of a specific feed component in the total ration, expressed as its fraction of diet dry matter intake (fraction). Within each herd_id and cohort, proportions should sum to 1.

`feed_params` data.table. Feed nutritional parameters with the following minimum data requirement:

feed_id Character. Unique identifier for the feed component, used to join feed ration data with feed parameter tables.

feed_gross_energy Numeric. Gross energy content of a feed component, representing the total chemical energy released upon complete combustion of the feed (MJ/kg DM).

feed_digestible_energy_ruminant Numeric. Digestible energy content of a feed component for ruminants, representing the energy absorbed by the animal after fecal losses (MJ/kg DM).

feed_digestible_energy_pigs Numeric. Digestible energy content of a feed component for pigs, representing the energy absorbed by the animal after fecal losses (MJ/kg DM).

feed_metabolizable_energy_ruminant Numeric. Metabolizable energy content of a feed component for ruminants, representing digestible energy minus energy losses in urine and gaseous products of digestion (MJ/kg DM).

feed_metabolizable_energy_pigs Numeric. Metabolizable energy content of a feed component for pigs, representing digestible energy minus energy losses in urine and gaseous products of digestion (MJ/kg DM).

feed_nitrogen_content Numeric. Nitrogen content of a feed component (kg N/kg DM).

feed_urinary_energy_ruminant Numeric. Fraction of feed's gross energy that is excreted in urine for ruminants (fraction).

feed_urinary_energy_pigs Numeric. Fraction of feed's gross energy that is excreted in urine for pigs (fraction).

feed_ash Numeric. Average ash content by feed component, calculated as a fraction of the dry matter intake (g ash/100g DM).

category Character. Feed category (optional). If provided, it should be used consistently with `feed_id`, for a coherent result.

feed_name Character. Feed component name (optional, for readability and reporting). If provided, it should uniquely identify the same feed component as `feed_id`.

`show_indicator` Logical. Whether to display progress indicators during calculations. Defaults to `TRUE`.

Details

This function represents the intermediate module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` to estimate the nutritional quality of the feed ration. This function joins `rations_share` with `feed_params` by `feed_id`, uses `species_short` directly, and computes ration-weighted nutritional metrics by cohort.

The following calculation sequence is applied:

1. Species-specific digestibility ratios are computed from energy parameters and `feed_gross_energy` using `calc_feed_digestibility_fraction`.
2. Contributions of each feed component are computed as ration-weighted values:
   - gross energy using `calc_ration_gross_energy`
   - nitrogen using `calc_ration_nitrogen_content`
   - digestibility using `calc_ration_digestibility`
   - metabolizable energy using `calc_ration_metabolizable_energy`
   - urinary energy fraction using `calc_ration_urinary_energy_fraction`
   - ash using `calc_ration_ash`
3. Cohort-level nutritional metrics are obtained for the whole feed ration by summing contributions across feed components within each `herd_id`, `species_short`, and `cohort_short`.

Value

data.table. Cohort-level nutritional metrics summarized by `herd_id`, `species_short`, and `cohort_short` with the following columns:

ration_gross_energy Numeric. Average gross energy content of the diet (MJ/kg DM).

ration_metabolizable_energy Numeric. Average metabolizable energy content of the diet (MJ/kg DM).

ration_nitrogen Numeric. Average nitrogen content of diet (kg N/kg DM).

ration_digestibility_fraction Numeric. Average digestibility of the feed ration, expressed as ratio of digestible to gross energy content (fraction).

ration_urinary_energy_fraction Numeric. Fraction of feed's gross energy that is excreted in urine (fraction).

ration_ash Numeric. Average ash content of feed, calculated as a fraction of the dry matter intake (kg ash/kg DM).

See Also

run_gleam, calc_feed_digestibility_fraction, calc_ration_gross_energy, calc_ration_nitrogen_content, calc_ration_digestibility, calc_ration_metabolizable_energy, calc_ration_urinary_energy_fraction, calc_ration_ash

Examples

```
# Load feed rations inputs (cohort-level shares and feed parameters)
feed_rations_chrt_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/feed_rations_share_chrt.csv",
  package = "gleam"
))
feed_params_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/feed_quality.csv",
  package = "gleam"
))

result <- run_ration_quality_module(
  rations_share = feed_rations_chrt_dt,
  feed_params = feed_params_dt
)
```

---

run_weights_module *Run Weights Module Pipeline*

Description

Calculates cohort-level live weight metrics by combining cohort-level inputs with herd-level biological parameters. The function appends cohort weights (initial, potential final, slaughter), then derives average and final live weights accounting for offtake, and finally computes average daily live weight gain over each cohort stage.

Usage

```
run_weights_module(cohort_level_data, herd_level_data, show_indicator = TRUE)
```

Arguments

`cohort_level_data`

A `data.table` in long format with one row per herd × cohort. Must include:

herd_id Character. Unique identifier for the herd, repeated for each cohort belonging to the same herd.

cohort_short Character. Sex- and age-specific cohort code describing the production stage of the animals. Supported values include:

- `FA`: adult females (from age at first parturition)
- `FS`: sub-adult females (from weaning to age at first parturition)
- `FJ`: juvenile females (from birth to weaning)
- `MA`: adult males (from age at first breeding)
- `MS`: sub-adult males (from weaning to age at first breeding)
- `MJ`: juvenile males (from birth to weaning)

cohort_duration_days Numeric. Amount of time that each animal spends in a specific cohort (days).

offtake_rate Numeric. Annual proportion of animals removed from the herd for each sex-age cohort (fraction).

`herd_level_data`

A `data.table` with one row per herd. Must include:

- `live_weight_female_adult` Numeric. Live weight of adult females (kg)
- `live_weight_male_adult` Numeric. Live weight of adult males (kg)
- `live_weight_at_birth` Numeric. Live weight of the animal at birth (kg).
- `live_weight_at_weaning` Numeric. Live weight of the animal at weaning (kg)
- `live_weight_female_at_slaughter` Numeric. Slaughter weight of female sub-adult animals (kg)
- `live_weight_male_at_slaughter` Numeric. Slaughter weight of male sub-adult animals (kg)

`show_indicator` Logical. Whether to display progress indicators during calculations. Defaults to `TRUE`.

Details

This function represents the intermediate module of the Global Livestock Environmental Assessment Model (GLEAM) computational pipeline `run_gleam()` to estimate animals' live weight and is composed of the following steps:

1. **Cohort-stage weight assignment** using `calc_cohort_weights`. Herd-level biological parameters are matched to each cohort row by `herd_id` via `data.table` joins.
2. **Calculation of average and final live weights (accounting for offtake)** using `calc_avg_weights`.
3. **Calculation of average daily live weight gain** using `calc_daily_weight_gain`.

Value

A named list with two data.tables:

cohort_level_results The input cohort_level_data with these additional columns:

- **live_weight_mature_stage** Numeric. Mature (adult) live weight that the animal can attain under given biological and management conditions (kg).
- **live_weight_cohort_initial** Numeric. Live weight at the beginning of the cohort stage (kg).
- **live_weight_cohort_potential_final** Numeric. Potential final live weight attainable at the end of the cohort stage in the absence of offtake (kg). (For juveniles: equals weaning weight; For subadults: equals adult live weight; For adults: equals adult live weight)
- **live_weight_cohort_at_slaughter** Numeric. Live weight at slaughter for animals removed from the cohort (kg).
- **live_weight_cohort_average** Numeric. Average live weight over the cohort stage. Computed by accounting for the share of offtaken animals within the cohort, using their slaughter weight, and the potential final weight of animals that remain in the cohort (kg).
- **live_weight_cohort_final** Numeric. Live weight at the end of the cohort stage, accounting for both surviving and offtaken animals. Computed as a weighted average of the potential final weight of surviving animals and the slaughter weight of offtaken animals, based on the offtake rate (kg).
- **daily_weight_gain** Numeric. Average live weight gain of the cohort over the cohort stage (kg/head/day).

herd_level_results A copy of the input herd_level_data.

See Also

run_gleam, calc_cohort_weights, calc_avg_weights, calc_daily_weight_gain,

Examples

```
# Load weights inputs (cohort- and herd-level)
weights_chrt_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/weights_input_chrt_data.csv",
  package = "gleam"
))
weights_hrd_dt <- data.table::fread(system.file(
  "extdata/run_modules_examples/weights_input_hrd_data.csv",
  package = "gleam"
))

# Run weight calculations
results <- run_weights_module(
  cohort_level_data = weights_chrt_dt,
  herd_level_data = weights_hrd_dt
)

# Access results
print(results$cohort_level_results)
print(results$herd_level_results)
```

Index