# No milk without meat: Dynamic implications of the biological link between milk and bovine meat production on nutrition guidelines

## Supplementary material – technical documentation

This supplement describes the model structure and provides full documentation of the model. The simulation model is implemented in Stella Architect (© isee systems), version 2.1.5. The files needed to run the model and replicate the analyses are appended to this supplement and can be viewed and run with the isee Player, https://www.iseesystems.com/soft-wares/player/iseeplayer.aspx.

# 1 Model structure

Our model is a simplified version of the meat supply and demand policy model by [BLINDED FOR REVIEW], designed to specifically capture the biological link between milk and bovine meat production. It is based on the system dynamics simulation methodology (Sterman, 2000), using differential equation modeling and continuous time simulation.

Our model uses the same herd structure as the comprehensive model. Yet, different from it, our model is initialized to equilibrium, meaning that all model parameters and therefore also the behavior remain unchanged throughout the simulation horizon in the absence of shocks or stressors. This enables users to better analyze impacts on model behavior as changes in consumption patterns are not confounded by other processes. Effects on production are thus more clearly visible. To highlight production effects of consumption changes, we present simulation results of this study (in the manuscript, the accompanying STELLA model, and the freely accessible online simulator) as relative values where the reference or 2020 value of a variable is equal to 1. in the paper.

Similar to how (Willett et al. (2019)) calculated the planetary health diet, we also consider food demand an input parameter and food production and environmental impacts as outputs. For analytical clarity, we assume that milk and meat production react to recommended consumptions (converted into indicated production based on consideration of food waste and loss as well as consumption by animals in the case of milk) in a mechanistic way—i.e., without mitigation by economic mechanisms such as own- and cross-price elasticities.

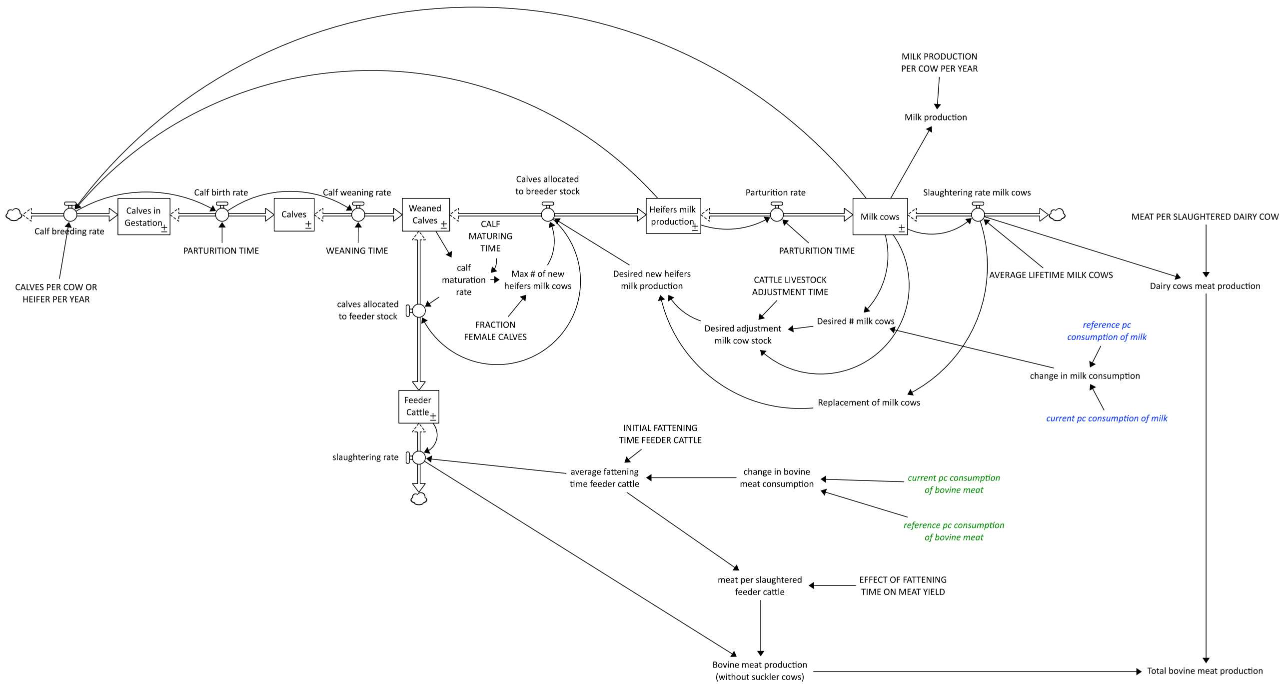


*Figure A-1: Structure of the model: Main herd structure with milk and bovine meat production*

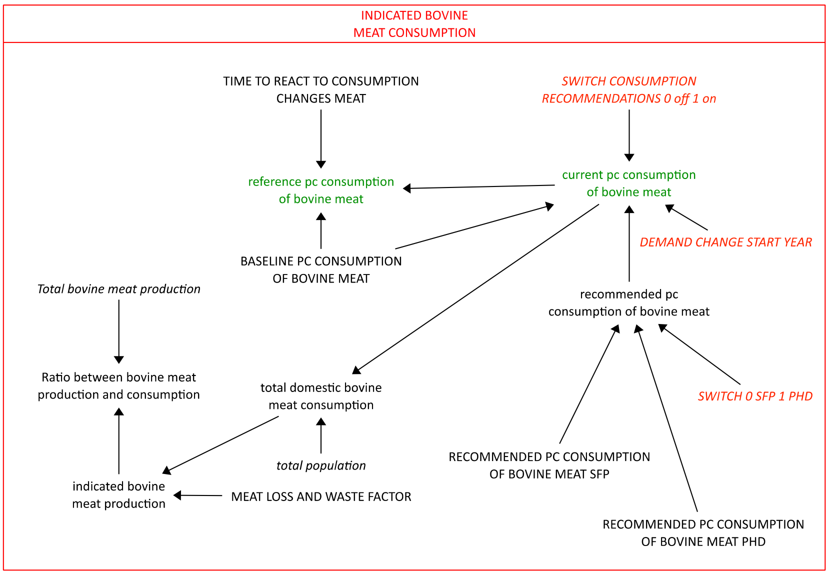


*Figure A-2: Structure of the model: Meat demand*

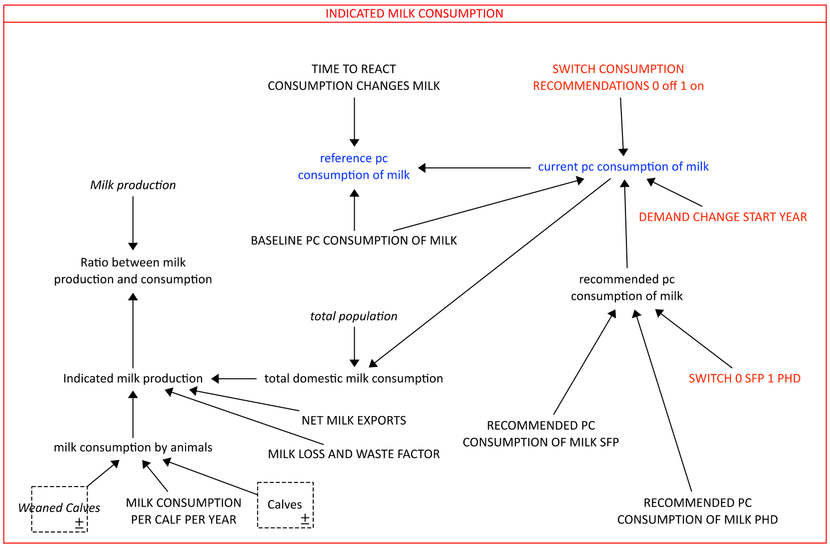


*Figure A-3: Structure of the model: Milk demand*

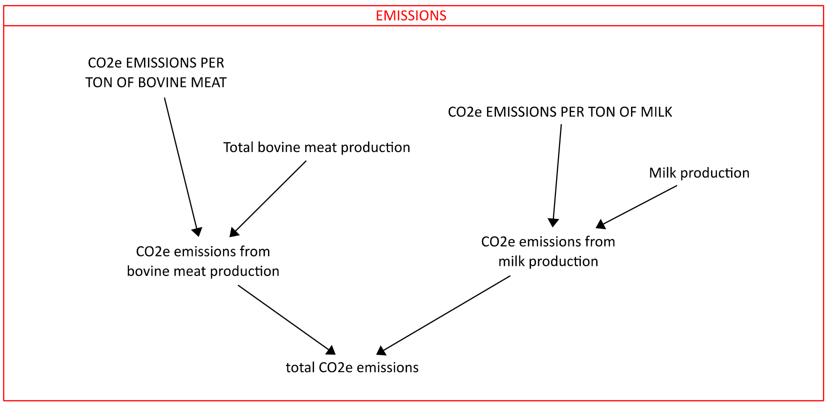

*Figure A-4: Structure of the model: Emissions*

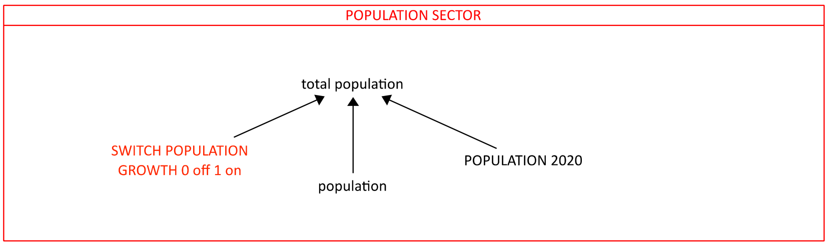


*Figure A-5: Structure of the model: Population*

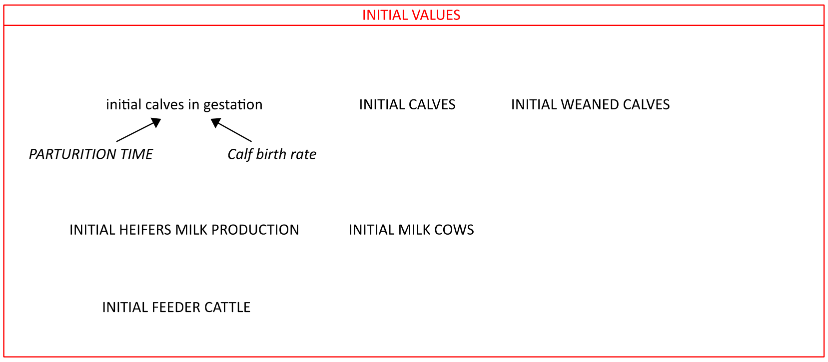


*Figure A-6: Structure of the model: Initial values*

## 2 Model equations

### Table A.1 List of Model Equations – Stocks

| Where to find | Variable Name | Equation | Units | Interpretation | Initial |
|---|---|---|---|---|---|
| Herd structure | **Calves** | Calves(t) = Calves(t - dt) + (Calf_birth_rate - Calf_weaning_rate) * dt | animal | This is a stock variable that calculates the number of calves at each point in time based on the initial value of calves plus the integrated difference between calf birth rate and calf weaning rate over time. | INITIAL_CALVES |
| Herd structure | **Calves in Gestation** | Calves_in_Gestation(t) = Calves_in_Gestation(t - dt) + (Calf_breeding_rate - Calf_birth_rate) * dt | animal | This is a stock variable that calculates the calves in gestation at each point in time based on the initial value of calves in gestation plus the integrated difference between calf breeding rate and calf birth rate over time. | INIT Calves_in_Gestation = initial_calves_in_gestation |
| Herd structure | **Feeder Cattle** | Feeder_Cattle(t) = Feeder_Cattle(t - dt) + (calves_allocated_to_feeder_stock - slaughtering_rate) * dt | animal | The stock of cattle who are fattened and later slaughtered. | INIT Feeder_Cattle = INITIAL_FEEDER_CATTLE |
| Herd structure | **Heifers milk production** | Heifers_milk_production(t) = Heifers_milk_production(t - dt) + (Calves_allocated_to_breeder_stock - Parturition_rate) * dt | animal | This is a stock variable that calculates the number of heifers at each point in time based on the initial value of heifers plus the integrated difference between the calves allocated to the breeder stock and the parturition rate over time. | INIT Heifers_milk_production = INITIAL_HEIFERS_MILK_PRODUCTION |
| Herd structure | **Milk cows** | Milk_cows(t) = Milk_cows(t - dt) + (Parturition_rate - Slaughtering_rate_milk_cows) * dt | animal | This is a stock variable that calculates the number of dairy cows at each point in time based on the initial value of milk cows plus the integrated difference between the parturition rate and the slaughtering rate over time. | INIT Milk_cows = INITIAL_MILK_COWS |

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| Herd structure | **Weaned calves** | Weaned_Calves(t) = Weaned_Calves(t - dt) + (Calf_weaning_rate - Calves_allocated_to_breeder_stock - calves_allocated_to_feeder_stock) * dt | animal | This is a stock variable that calculates the number of weaned calves at each point in time based on the initial value of weaned calves plus the integrated difference between calf weaning rate and calf maturation rate over time. | INIT Weaned_Calves = INITIAL_WEANED_CALVES |

## Table A.2 List of Model Equations - Flows

| Where to find | Variable Name | Equation | Units | Interpretation |
|---|---|---|---|---|
| Herd structure | **Calf birth rate** | Calf_birth_rate = DELAY3(Calf_breeding_rate, PARTURITION_TIME) | animal/Year | The number of calves born each year after a delay equal to the average parturition time. |
| Herd structure | **Calf weaning rate** | Calf_weaning_rate = DELAY3(Calf_birth_rate, WEANING_TIME) | animal/Year | The number of calves weaned each year after a delay equal to the average weaning time. |
| Herd structure | **Calf breeding rate** | Calf_breeding_rate = (Milk_cows+Heifers_milk_production)*Calves_per_cow_or_heifer_per_year | animal/Year | The number of calves that are born each year depends on the size of the stocks of cows and heifers and on the number of calves that each cow and heifer produce per year. |
| Herd structure | **Calf birth rate** | Calf_birth_rate = DELAY3(Calf_breeding_rate, PARTURITION_TIME) | animal/Year | The number of calves born each year after a delay equal to the average parturition time. |
| Herd structure | **Calves allocated to feeder stock** | calves_allocated_to_feeder_stock = calf_maturation_rate-Calves_allocated_to_breeder_stock | animal/Year | The number of matured calves each year that are allocated to the feeder stock. the number is calculated from the total number of weaned calves. |
| Herd structure | **Slaughtering rate** | slaughtering_rate = Feeder_Cattle/average_fattening_time_feeder_cattle | animal/Year | This is the outflow to the stock of feeder cattle. Feeder cattle are slaughtered when they reach the average fattening time. The average fattening time is not constant but depends on the profitability of meat. In this simplified model, we equate profitability with demand (desired meat consumption). |
| Herd structure | **Calves allocated to breeder stock** | Calves_allocated_to_breeder_stock = MIN(Desired_new_heifers_milk_production, Max_#_of_new_heifers_milk_cows) | animal/Year | The desired number of calves that are allocated to the breeding stock can be higher than the maximum possible number of new breeder calves given the existing herd structure. Under such extreme conditions, the minimum function makes sure that not more calves are allocated to the breeding stock than are physically available (the “maximum number of new heifers milk cows”). |
| Herd structure | **Parturition rate** | Parturition_rate = Heifers_milk_production/PARTURITION_TIME | animal/Year | This flow describes the process of heifers becoming dairy cows after having their first calf. |
| Herd structure | **Slaughtering rate milk cows** | Slaughtering_rate_milk_cows = Milk_cows/AVERAGE_LIFETIME_MILK_COWS | animal/Year | This is the outflow from the stock of dairy cows. Dairy cows are slaughtered when they reach their average lifetime. |
| Herd structure | **Calf maturation rate** | calf_maturation_rate = Weaned_Calves/CALF_MATURING_TIME | animal/Year | This is the outflow from the stock of weaned calves. Calves are weaned |

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| | | | | when they reach the average calf maturing time. The number of weaned calves each year is subsequently allocated to either the breeder or the feeder stock. |
| Herd structure | **Calf weaning rate** | Calf_weaning_rate = DELAY3(Calf_birth_rate, WEANING_TIME) | animal/Year | The number of calves weaned each year after a delay equal to the average weaning time. |
| Herd structure | **Calves allocated to breeder stock** | Calves_allocated_to_breeder_stock = MIN(Desired_new_heifers_milk_production, Max_#_of_new_heifers_milk_cows) | animal/Year | The desired number of calves that are allocated to the breeding stock can be higher than the maximum possible number of new breeder calves given the existing herd structure. Under such extreme conditions, the minimum function makes sure that not more calves are allocated to the breeding stock than are physically available (the “maximum number of new heifers milk cows”). |
| Herd structure | **Calves allocated to feeder stock** | calves_allocated_to_feeder_stock = calf_maturation_rate-Calves_allocated_to_breeder_stock | animal/Year | The number of matured calves each year that are allocated to the feeder stock. the number is calculated from the total number of weaned calves. |

## Table A.3 List of Model Equations – Other Variables

| Where to find | Variable Name | Equation | Units | Interpretation |
|---|---|---|---|---|
| Herd structure | **Average fattening time feeder cattle** | average_fattening_time_feeder_cattle = initial_fattening_time_feeder_cattle*change_in_bovine_meat_consumption | Year | The average fattening time of feeder cattle depends on the demand for bovine meat. if demand increases, cattle are fattened for longer than if demand decreases. |
| Herd structure | **Bovine meat production** | "Bovine_meat_production_(without_suckler_cows)" = slaughtering_rate*meat_per_slaughtered_feeder_cattle | ton/Year | Tons per year produced by the slaughtered feeder cattle withing the bovine livestock but excluding the suckler cow line. |
| Herd structure | **Change in bovine meat consumption** | change_in_bovine_meat_consumption = current_pc_consumption_of_bovine_meat/baseline_pc_consumption_of_bovine_meat | Dmnl | The change in demand, i.e., the current demand relative to the baseline demand. in this simplified model, we assume that a change in consumption will lead to the same change in production. the more advanced version of this model considers a series of additional factors such as price elasticity of demand and supply, fodder availability and environmental regulations. |
| Herd structure | **Change in milk consumption** | change_in_milk_consumption = current_pc_consumption_of_milk/reference_pc_consumption_of_milk | Dmnl | The change in demand, i.e., the current demand relative to the reference demand. in this simplified model, we assume that a change in consumption will lead to the same change in production. the more advanced version of this model considers a series of additional factors such as price elasticity of demand and supply, fodder availability and environmental regulations. |
| Emissions | **CO2e emissions from bovine meat production** | CO2e_emissions_from_bovine_meat_production = CO2_emissions_per_ton_of_bovine_meat*Total_bovine_meat_production | ton co2/Year | The total number of tons of $CO_2$ equivalents per year resulting from bovine meat production. |

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| Emissions | **CO2e emissions from milk production** | CO2e_emissions_from_milk_production = CO2_emissions_per_ton_of_milk*Milk_production | ton co2/Year | The total number of tons of $CO_2$ equivalents per year resulting from milk production. |
| Meat demand | **Current per capita consumption of bovine meat** | current_pc_consumption_of_bovine_meat = ( IF TIME < demand_change_start_year THEN base-line_pc_consumption_of_bovine_meat ELSE (1-switch_consumption_recommendations_0_off_1_on)*baseline_pc_consumption_of_bovine_meat+recommended_pc_consumption_of_bovine_meat*switch_consumption_recommendations_0_off_1_on ) | ton/(person*Year) | The per capita consumption of bovine meat per year in the activated scenario. |
| Milk demand | **Current per capita consumption of milk** | current_pc_consumption_of_milk = ( IF TIME < demand_change_start_year THEN base-line_pc_consumption_of_milk ELSE (1-switch_consumption_recommendations_0_off_1_on)*baseline_pc_consumption_of_milk+recommended_pc_consumption_of_milk*switch_consumption_recommendations_0_off_1_on ) | ton/(person*Year) | The per capita consumption of milk per year in the activated scenario. |
| Herd structure | **Dairy cows meat production** | Dairy_cows_meat_production = Meat_per_slaughtered_dairy_cow*Slaughtering_rate_milk_cows | ton/Year | Tons of bovine meat per year produced by the slaughtered dairy cows. |
| Herd structure | **Desired number of milk cows** | Desired_#_milk_cows = Milk_cows*change_in_milk_consumption | animal | The desired number of milk cows is calculated by adjusting the current number of milk cows upward if the demand for milk products increases and downward if the demand for milk products decreases. in this simplified model, we assume that a change in consumption will lead to the same change in production. the more advanced version of this model considers a series of additional factors such as price elasticity of demand and supply, fodder availability and environmental regulations. |
| Herd structure | **Desired adjustment milk cow stock** | Desired_adjustment_milk_cow_stock = (Desired_#_milk_cows-Milk_cows)/Cattle_livestock_adjustment_time | animal/Year | The desired adjustment of the milk cow stock compares desired and available numbers of milk cows and adjusts this difference not immediately, but over the cattle livestock adjustment time. |
| Herd structure | **Desired_new_heifers milk production** | Desired_new_heifers_milk_production = MAX(0, De-sired_adjustment_milk_cow_stock+Replacement_of_milk_cows) | animal/Year | The desired new heifers are the sum of the calves needed for replacing the current milk cow stuck plus the desired adjustment of the milk cow stock. |
| Meat demand | **Indicated bovine meat production** | indicated_bovine_meat_production = to-tal_domestic_bovine_meat_consumption*MEAT_LOSS_AND_WASTE_FACTOR | ton/Year | indicated bovine meat production represents demand. in this simplified model, price does not mitigate desired consumption. total demand is the domestic consumption, adjusted for the meat loss and waste along the entire value chains. net exports in the case of bovine meat are negligible, especially compared to net milk exports. |

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| Milk demand | **Indicated milk production** | Indicated_milk_production = (total_domestic_milk_consumption+NET_MILK_EXPORTS+milk_consumption_by_animals)*MILK_LOSS_AND_WASTE_FACTOR | ton/Year | indicated milk production represents demand. in this simplified model, price does not mitigate desired consumption. total demand is the sum of domestic consumption, consumption by animals and exports, adjusted for the milk loss and waste along the entire value chains. |
| Initial values | **Initial calves in gestation** | initial_calves_in_gestation = Calf_birth_rate*PARTURITION_TIME | animal | The initial value of calves in gestation, calculated to initialize the model in equilibrium. |
| Herd structure | **Maximum number of new heifers milk cows** | Max_#_of_new_heifers_milk_cows = calf_maturation_rate*FRACTION_FEMALE_CALVES | animal/Year | The maximum number of new heifers is the number of female weaned calves each year. |
| Herd structure | **Meat per slaughtered feeder cattle** | meat_per_slaughtered_feeder_cattle = LOOKUP(effect_of_fattening_time_on_meat_yield, average_fattening_time_feeder_cattle) | ton/animal | The meat per slaughtered feeder cattle depends on the age of the animal and the value of meat per animal is read from the table “effect of fattening time on meat yield”. |
| Milk demand | **Milk consumption by animals** | milk_consumption_by_animals = (Calves+Weaned_Calves)*MILK_CONSUMPTION_PER_CALV_PER_YEAR | ton/Year | The amount of milk consumed by calves every year. in the more elaborate model, also pigs are fed with milk from dairy cows. |
| Herd structure | **Milk production** | Milk_production = Milk_cows*MILK_PRODUCTION_PER_COW_PER_YEAR | ton/Year | This variable calculates milk production per year as a function of both, the number of milk cows and the average milk production per cow per year. |
| Meat demand | **Ratio between bovine meat production and consumption** | Ratio_between_bovine_meat_production_and_consumption = Total_bovine_meat_production/indicated_bovine_meat_production | Dmnl | this ratio compares supply and demand. the total demand is adjusted for the bovine meat loss and waste along the entire value chains. net exports in the case of bovine meat are negligible, especially compared to net milk exports. |
| Milk demand | **Ratio between milk production and consumption** | Ratio_between_milk_production_and_consumption = Milk_production/Indicated_milk_production | Dmnl | this ratio compares supply and demand. the total demand is the sum of domestic consumption, consumption by animals and exports, adjusted for the milk loss and waste along the entire value chains. |
| Meat demand | **Recommended per capita consumption of bovine meat** | recommended_pc_consumption_of_bovine_meat = recommended_pc_consumption_of_bovine_meat_SFP*(1-switch_0_sfp_1_phd)+switch_0_sfp_1_phd*recommended_pc_consumption_of_bovine_meat_phd | ton/(Year*person) | The recommended per capita consumption of bovine meat for one of the two nutrition recommendation scenarios: Swiss Food Pyramid or Planetary Health Diet. |
| Milk demand | **Recommended per capita consumption of milk** | recommended_pc_consumption_of_milk = recommended_pc_consumption_of_milk_SFP*(1-switch_0_sfp_1_phd)+recommmended_pc_consumption_of_milk_PHD*switch_0_sfp_1_phd | ton/(person*Year) | The recommended per capita consumption of milk for one of the two nutrition recommendation scenarios: Swiss Food Pyramid or Planetary Health Diet. |
| Meat demand | **Reference per capita consumption of bovine meat** | reference_pc_consumption_of_bovine_meat = SMTH3(current_pc_consumption_of_bovine_meat, TIME_TO_REACT_TO_CONSUMPTION_CHANGES_MEAT, baseline_pc_consumption_of_bovine_meat) | ton/(person*Year) | The reference demand represents the per capita demand of bovine meat in the recent past. the time horizon over which demand changes are taken into consideration for adjusting pro-duction is indicated by the parameter "time to react to consumption changes meat". |
| Milk demand | **Reference per capita consumption of milk** | reference_pc_consumption_of_milk = SMTH3(current_pc_consumption_of_milk, TIME_TO_REACT_CONSUMPTION_CHANGES_MILK, baseline_pc_consumption_of_milk) | ton/(person*Year) | The reference demand represents the per capita demand of milk in the recent past. the time horizon over which demand changes are taken into consideration for adjusting production is indicated |

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| | | | | by the parameter "time to react to consumption changes milk". |
| Herd structure | **Replacement of milk cows** | Replacement_of_milk_cows = Slaughtering_rate_milk_cows | animal/Year | This variable calculates the number of dairy cows needed to replace the dairy cows that are slaughtered. |
| Meat demand, Milk demand | **Switch between Swiss Food Pyramid and Planetary Health Diet** | switch_0_sfp_1_phd = 0 | Dmnl | This is a scenario switch that allows alternating between the Swiss Food Pyramid recommendations (switch = 0) and the recommendations of the Planetary Health Diet (switch = 1). |
| Meat demand, Milk demand | **Switch between consumption recommendations** | switch_consumption_recommendations_0_off_1_on = 0 | Dmnl | This is a switch that allows alternating between current and recommended consumption pat-terns. 0 means current consumption patterns, 1 means recommended consumption patterns. |
| Population | **Switch between population growth and no growth** | switch_population_growth_0_off_1_on = 0 | Dmnl | This is a switch that allows alternating between a constant population size and a time-dependent population size. 0 means constant population, 1 takes population from historical and projected data. |
| Herd structure | **Total bovine meat production** | Total_bovine_meat_production = "Bo-vine_meat_production_(without_suckler_cows)"+Dairy_cows_meat_production | ton/Year | The total amount of bovine meat produced in one year. this variable only calculates bovine meat production from the dual-purpose meat/dairy stock but excludes bovine meat from the suckler cow line. |
| Emissions | **Total CO2e emissions** | total_CO2e_emissions = CO2_emissions_from_bovine_meat_production+CO2_emissions_from_milk_production | ton co2/Year | The total number of tons of $CO_2$ equivalents per year resulting from milk and bovine meat pro-duction. |
| Meat demand | **Total domestic bovine meat consumption** | total_domestic_bovine_meat_consumption = to-tal_population*current_pc_consumption_of_bovine_meat | ton/Year | The total amount of bovine meat consumed per year by the Swiss population. |
| Milk demand | **Total domestic milk consumption** | total_domestic_milk_consumption = total_population*current_pc_consumption_of_milk | ton/Year | the total amount of milk consumed per year by the Swiss population |
| Population | **Total population** | total_population = (1-switch_population_growth_0_off_1_on)*population_2020+switch_population_growth_0_off_1_on*population | person | The total population of Switzerland, used to calculate total milk and bovine meat consumption. |

## Table A.4 List of Model Equations – Parameters, their Values and Sources

| Where to find | Parameter name | Name in model | Value | Units | Interpretation | Source |
|---|---|---|---|---|---|---|
| Herd structure | **Average lifetime of milk cows** | AVERAGE_LIFETIME_MILK_COWS | 4 | Year | The number of years, on average, that a milk cow is kept on lactation | Agridea/FiBL, 2019, section Tierhaltung |
| Meat demand | **Baseline per capita consumption of bovine meat** | BASELINE_PC_CONSUMPTION_OF_BOVINE_MEAT | 0.01044 | ton/(person*Year) | Per capita consumption under baseline conditions. | SBV, 2021 |
| Milk demand | **Baseline per capita consumption of milk** | BASELINE_PC_CONSUMPTION_OF_MILK | 0.3189 | ton/(person*Year) | Per capita consumption under baseline conditions. | SBV, 2021 |

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|---|---|---|---|---|---|---|
| Herd structure | **Calf maturing time** | CALF_MATU-RING_TIME | 0.56 | Year | The time it takes for calves to fully mature. the constant assumes the value of the re-maining 205 days un-til calves reach the age of 1 year, where the female animals destined for milk pro-duction get insemi-nated for the first time | SBV, 2021 |
| Herd structure | **Calves per cow or heifer per year** | CALVES_PER_COW_OR_HEIFER_PER_YEAR | 1.02 | 1/Year | The number of calves that, on average, each cow and heifer produce per year. | Agridea/FiBL, 2019, section Tierhaltung |
| Herd structure | **Cattle livestock adjustment time** | CATTLE_LIVE-STOCK_ADJUST-MENT_TIME | 10 | Year | The long adjustment time is rooted in the long lifetime of cattle livestock buildings and related infra-structure, which limit the flexibility with which farmers enter and exit the cattle sector. | [BLINDED FOR REVIEW] |
| Emissions | **CO2e emissions per ton of bo-vine meat** | CO2E_EMIS-SIONS_PER_TON_OF_BO-VINE_MEAT | 13 | ton co2/ton | tons of CO2 equiva-lents produced per ton of bovine meat. | FAOSTAT, Climate Change, Emis-sion Intensities: https://www.fao.org/fao-stat/en/#data/EI |
| Emissions | **CO2e emissions per ton of milk** | CO2E_EMIS-SIONS_PER_TON_OF_MILK | 0.6 | ton co2/ton | tons of CO2 equiva-lents produced per ton of milk. | FAOSTAT, Climate Change, Emis-sion Intensities: https://www.fao.org/fao-stat/en/#data/EI |
| Meat de-mand, Milk de-mand | **Demand change start year** | DE-MAND_CHANGE_START_YEAR | 2022 | Year | this is a scenario vari-able that allows de-fining the year in which consumption changes start. | User choice. |
| Herd structure | **Fraction of fe-male calves** | FRACTION_FE-MALE_CALVES | 0.5 | Dmnl | The fraction, on aver-age, of calves that are female. | Agridea/FiBL, 2019, section "Tierhaltung". |
| Initial val-ues | **Initial number of calves** | INITIAL_CALVES | 304353 | animal | The initial value of calves | Calculated to initialize the model in equilibrium |
| Herd structure | **Initial fattening time feeder cat-tle** | INITIAL_FAT-TEN-ING_TIME_FEEDER_CATTLE | 0.43 | Year | An average of the av-erage fattening time for veal fattening and bull fattening, weighted by the live-stock units of calves and bulls in the initial year of the simulation and estimated to keep the model in equilibrium | Agridea/FiBL, 2019, section "Tierhaltung". |
| Initial val-ues | **Initial feeder cattle** | INI-TIAL_FEEDER_CATTLE | 240197 | animal | The initial number of feeder cattle | SBV, 2021<br>Cattle aged 365-730 days |
| Initial val-ues | **Initial heifers milk production** | INITIAL_HEIF-ERS_MILK_PRO-DUCTION | 135005 | animal | The initial value of heifers. | Milk production per dairy cow (7 ton/year; SBV, 2020) and livestock numbers (total of 677863 cows - of which 542857 must be dairy cows and the rest heifers for milk pro-duction; SBV, 2021). |

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| Initial values | **Initial number of milk cows** | INITIAL_MILK_COWS | 542857 | animal | The initial value of milk cows | SBV, 2021 |
| Initial values | **Initial number of weaned calves** | INITIAL_WEANED_CALVES | 391800 | animal | The initial value of weaned calves | Calculated to initialize the model in equilibrium |
| Meat demand | **Meat loss and waste factor** | MEAT_LOSS_AND_WASTE_FACTOR | 1.1 | Dmnl | calculated from SBV. (2021). | SBV, 2021 total production (incl. net exports) vs. total consumption 2020. |
| Herd structure | **Meat per slaughtered dairy cow** | MEAT_PER_SLAUGHTERED_DAIRY_COW | 0.3 | ton/animal | Meat yield is set at 38% of the live weight (700kg). | Agridea/FiBL, 2019, section "Tierhaltung". |
| Milk demand | **Milk consumption per calf per year** | MILK_CONSUMPTION_PER_CALF_PER_YEAR | 0.6 | ton/(animal*Year) | calculated from SBV (2021) | SBV, 2021 Kälber bis 160 Tage, Jungvieh 160-365 Tage; total milk consumption by calves and weaned calves: 400'000 ton/year. |
| Milk demand | **Milk loss and waste factor** | MILK_LOSS_AND_WASTE_FACTOR | 1.13 | | calculated from SBV (2021) | SBV, 2021 |
| Milk demand | **Milk production per cow per year** | MILK_PRODUCTION_PER_COW_PER_YEAR | 7 | ton/(animal*Year) | The amount of milk produced, on average, per cow and year | SBV, 2020 |
| Milk demand | **Net milk exports** | NET_MILK_EXPORTS | 189000 | ton/Year | the net amount of milk exported per year. | SBV, 2020 |
| Herd structure | **Parturition time** | PARTURITION_TIME | 1 | Year | The parturition time is 9 months but heifers and cows only get inseminated once per year. | Agridea/FiBL, 2019 |
| Population | **Population** | POPULATION_2020 | 8.67054e+06 | person | the population in Switzerland in 2020 | BfS, 2021 |
| Meat demand | **Recommended per capita consumption of bovine meat (Planetary Health Diet)** | RECOMMENDED_PC_CONSUMPTION_OF_BOVINE_MEAT_PHD | 0.006 | ton/(person*Year) | recommended per capita consumption of bovine meat according to the planetary health diet (feed no food configuration). | The data is from the integrated model developed in the NRP69 project, described in [BLINDED FOR REVIEW]. |
| Meat demand | **Recommended per capita consumption of bovine meat (Swiss Food Pyramid)** | RECOMMENDED_PC_CONSUMPTION_OF_BOVINE_MEAT_SFP | 0.00544 | ton/(person*Year) | per capita consumption in the Swiss Food Pyramid Scenario | The data is from the integrated model developed in the NRP69 project, described in [BLINDED FOR REVIEW]. |
| Milk demand | **Recommended per capita consumption of milk (Swiss Food Pyramid)** | RECOMMENDED_PC_CONSUMPTION_OF_MILK_SFP | 0.2788 | ton/(person*Year) | per capita consumption in the Swiss Food Pyramid Scenario | The data is from the integrated model developed in the NRP69 project, described in [BLINDED FOR REVIEW]. |
| Milk demand | **Recommended per capita consumption of milk (Planetary Health Diet)** | RECOMMMENDED_PC_CONSUMPTION_OF_MILK_PHD | 0.1818 | ton/(person*Year) | recommended per capita consumption of milk according to the planetary health diet (feed no food configuration) | The data is from the integrated model developed in the NRP69 project, described in [BLINDED FOR REVIEW]. |
| Milk demand | **Time to react to consumption change - milk** | TIME_TO_REACT_CONSUMPTION_CHANGES_MILK | 10 | year | the time horizon over which demand changes are taken into consideration for adjusting pro-duction. The lower value for | [BLINDED FOR REVIEW]Kopainsky et al., 2020. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | meat than for milk reflects the capital intensity of bovine meat production compared to milk production (stables and milking equipment) | |
| Meat demand | **Time to react to consumption change – meat** | TIME_TO_REACT_TO_CONSUMPTION_CHANGES_MEAT | 5 | Year | the time horizon over which demand changes are taken into consideration for adjusting pro-duction. | [BLINDED FOR REVIEW]. |
| Herd structure | **Weaning time** | WEANING_TIME | 0.44 | Year | The time it takes to wean calves | SBV, 2021<br>Calves aged up to 160 days. |

## Table A.5 List of Model Equations – Nonlinear Functions

| Where to find | Parameter name | Name in model | Points | Units | Interpretation | Source |
|---|---|---|---|---|---|---|
| Herd structure | **Effect of fattening time on meat yield** | effect_of_fattening_time_on_meat_yield = GRAPH(0+0) | (0.3400, 0.0800),<br>(0.4300, 0.1050),<br>(1.2000, 0.1970) | ton/animal | Meat yield is set at 38% of the live weight of animals. The low value is for veal fattening and the high value for bull fattening. | Agridea/FiBL, 2019, section "Tierhaltung". |
| Population | **Population** | population= GRAPH(TIME) | (2000.00, 7164440),<br>(2001.00, 7197640),<br>(2002.00, 7255650),<br>(2003.00, 7313850),<br>(2004.00, 7364150),<br>(2005.00, 7415100),<br>(2006.00, 7459130),<br>(2007.00, 7508740),<br>(2008.00, 7508740),<br>(2009.00, 7701860),<br>(2010.00, 7785810),<br>(2011.00, 7870130),<br>(2012.00, 7954660),<br>(2013.00, 8039060),<br>(2014.00, 8139630),<br>(2015.00, 8339510),<br>(2020.00, 8757650),<br>(2025.00, 9159870),<br>(2030.00, 9541470),<br>(2035.00, 9856970),<br>(2040.00, 10044300),<br>(2045.00, 10176100) | person | the total population in Switzerland | Historical data: BfS, 2021<br>Future projections: BfS, 2015; Referenzszenario A-00-2015. |

## 3 Information on model testing

Given that we initialize the model in equilibrium, we work with constant parameter values for consumption, livestock numbers—that translate into production quantities—, and population size throughout the simulation period.

For testing the model, we followed the standard procedure for assessing model structure and behavior (Sterman, 2000). We calculated analytically (e.g., in the case of initial calves in gestation) and/or numerically the initial values of those animal stocks for which no statistical data is available such that for each stock the inflow is equal to the outflow and thus ensures dynamic equilibrium.

## 4 Information on the validity of the simplified model

As stated in section 1, our model is a simplified version of the meat supply and demand policy model by [BLINDED FOR REVIEW], designed to specifically capture the biological link between milk and bovine meat production. Food demand is an input parameter and food production and environmental impacts are model outputs. For analytical clarity, we assume that milk and meat production react to recommended consumptions (converted into indicated production based on consideration of food waste and loss as well as consumption by animals in the case of milk) in a mechanistic way—i.e., without mitigation by economic mechanisms such as own- and cross-price elasticities.

Here, we elaborate on the validity of the simplified model. Following Saysel and Barlas (2006), we define model simplification as the process of distilling essential model structures that cause selected problems and of increasing understanding of models. This process is based on extensive experimentation with the simplified and the original models. Like Saysel and Barlas (2006), our simplified model also has a narrower model boundary and higher level of aggregation than the comprehensive model. We assess the usefulness of the simplification through indirect structural validity and scenario testing.

### Indirect structural validity tests

We start by applying an extreme condition test (as one example of an indirect structure test; Barlas, 1996; Forrester & Senge, 1980) in which milk demand is set twice as high as under reference condition whereas meat demand is reduced to zero (Table 1). Table 1 lists the final values (year 2050) for milk and meat production as percentages of the 2050 value in the reference scenario. A comparison between the comprehensive and the simplified model reveals that bovine meat production does not deviate considerably from the reference values (98% in the case of the comprehensive model and 104% in the case of the simplified model) while milk production increases by some 20% in both models. This extreme condition test demonstrates two things. First, that the two models generate very similar results and second, that the biological link between milk and meat production prevents meat production from declining when milk production increases.

*Table 1: Extreme conditions: twice as much milk, no meat. Percentages under extreme conditions relative to reference in the year 2050 (reference = 100%)*

| | Comprehensive model | Simplified model |
|---|---|---|
| bovine meat | 98% | 104% |

| | | |
|---|---|---|
| milk | 124% | 121% |

### Scenario runs

Further, we compare the results of the Swiss Food Pyramid scenario from the two models (Table 2). The simulation results from the two models differ from each other numerically (e.g., 85% of bovine meat production in the comprehensive model vs. 77% in the simplified model). However, the direction of change is identical and the absolute results lie within reasonably similar boundaries.

*Table 2: Swiss Food Pyramid values relative to reference values in 2050 (reference = 100%)*

| | Comprehensive model | Simplified model |
|---|---|---|
| bovine meat | 85% | 77% |
| milk | 92% | 90% |

Based on the analyses reported here, we conclude that the simplified model is a valid and useful simplification of the original one for the purposes reported in the manuscript.

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