# APPENDIX A: SCRIPTS FOR THE SYSTEM MAPPING WORKSHOPS Participants

* 11 farmers

# Place

* Førde 02.03. 2023
* Voss 03.03. 2023

# Contact with participants

* Organised by Statsforvalteren
* Organised by Fylkeskommunen

# Workshops objectives

* Improve our conceptual understanding of the current state of the farming system
* Get insights on farmers’ perception of challenges and opportunities in light of increased climate variability = *What are the elements and the features of the problem?*
* Elicit the type of decisions they make, when and how they execute them = this will help us to capture structure of the model we missed and leverage points where the model can be impacted
* Introduce them to causal loops diagramming and identifying the positive and negative relationships between variables = *taking us through the whole consequences of each decision and close loops*

# Workshop time plan

* **Introduction presentation (15 min)**
  + Climate futures
    - Climate variability
    - Extended range
    - Mention focus groups
  + Who we are
  + Objective of WS
    - (Improve our understand of state of the farming system)
    - Perception of challenges and opportunities in light of climate variability
    - Potential of forecasts in making better decisions
  + Plan for today
  + Consent forms (sign after the workshop, recording)
* **Seed Structure (5 min)**
  + Intro to system/structure
  + Decription of what to do
  + Hand out material
* **Workshop** 
  + **Listing the variables (45 min)**
    - How and when are they making decisions
    - Challenges
* **Break (10 min)**
  + **Mapping (45 min)**
    - Cluster variables
    - Make connections
    - Close loops
* **Break (10 min)**
* **Wrap up (15)**
  + Summary of loops
  + One of the participants does the talking
* **Outlook/next steps (10)**
  + Future meeting to present what we discussed
  + Forecasting through 2023, show the forecast material (temp, precip)

# Facilitation aspects

Two facilitators: Host and Modeler

Role: lead the session with training in system dynamics and facilitation skills.

Script for introduction

|  |  |
| --- | --- |
| Description | Explain to participants why they have been brought together, what process will follow, and what the workshop process will accomplish.  Introduce the seed structure |
| Context | At the beginning of the workshop where participants have limited knowledge of the task. |
| Time | Preparation time: 20 minutes. |
| Materials needed to complete script | Computer and projector |
| Outputs from this script | Participants understand what they are there to achieve. |
| Steps | **Welcome**  The host welcomes participants to the venue and thanks them for attending. The host introduces the facilitator.  **Describe context**  The host describes the problem setting (relevant context about the situation), and describes the goals of the workshop.  **Describe process**  The facilitator describes the process of the workshop, what the outputs of the workshop will be, and how the outputs will contribute to the intervention or to addressing the problem. |
| Evaluation criteria | Participants can describe a common understanding of why they have been brought together.  Participants can describe a common understanding of the outputs of the workshop.  Participants demonstrate willingness to participate in the planned process. |

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Script for problem identification and prioritization

|  |  |
| --- | --- |
| Description | A process for participants to reach shared understanding about the problems and prioritize variables |
| Context | After the introduction |
| Time | Approximately 45 minutes |
| Materials needed to complete script | Flipchart paper taped together on the table  Post-its  Markers |
| Outputs from this script | List of prioritized variables and label for clusters |
| Steps | * Facilitators introduce the activity and explains that participants should write down what are the most important things regarding the problem (3 most important variables per person) and they can assign one person to make the links between variables. * Participants write down their 3 most important variables on the post-its. * The first participants discuss one at time the variables he/she selected and place them in the center of the table. * Facilitator asks all participants whether they have the same thing. If yes, they put the post-its close to each other (thus beginning to cluster problems). * Discussion continues until all post-its are on the table. * Facilitator suggests labels for the biggest clusters. * Group agrees on the five (+/-) most important clusters. |
| Evaluation criteria | Participants have listed important variables relevant to the problem.  Participants have narrowed down the variable or created major clusters. |

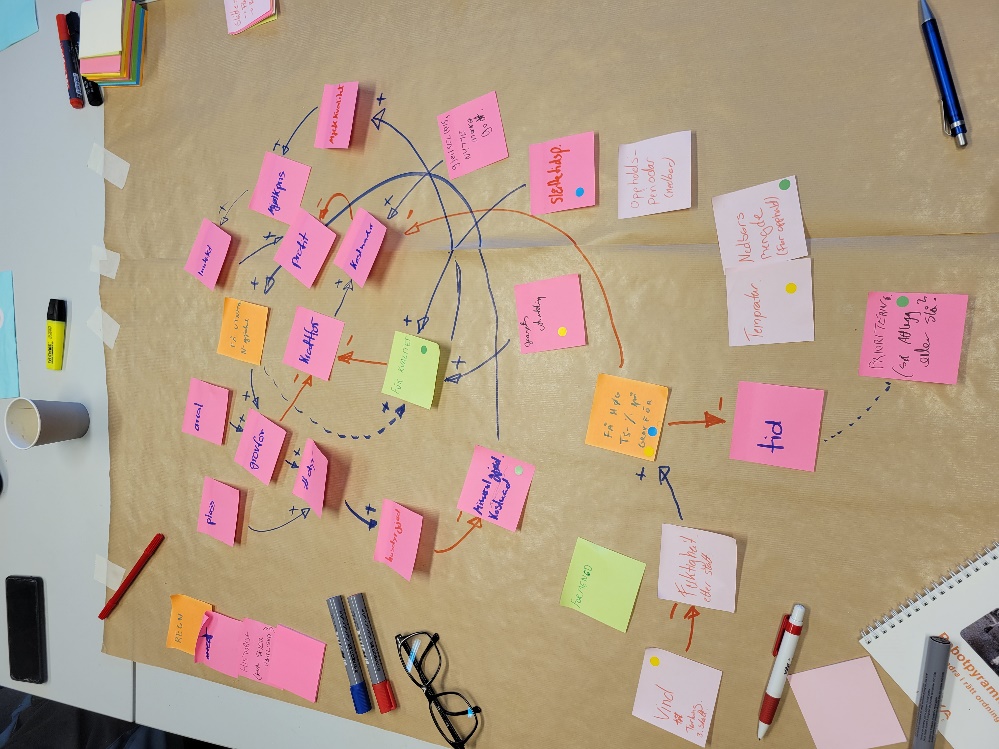
Script for constructing the causal loop diagram

|  |  |
| --- | --- |
| Description | A process for supporting participants to create their own causal loop diagram |
| Context | At the beginning of a causal loop diagramming workshop |
| Time | Approximately 45 minutes |
| Materials needed to complete script | Flipchart paper taped together on the table  Post-its  Markers |
| Outputs from this script | A CLD created by participants |
| Steps | * The facilitator begins by explaining, “We’re going to spend the next 45 minutes or so doing a causal mapping exercise [on the previously identified variables]." * The facilitator then explains that participants can talk about their own experience or what they see in the farming activity. * The facilitator asks questions that help identify impact and causal relations between identified key variables. * As someone suggests something, the participant in charge of taking notes draws the link between the variables on the big white sheet of paper. The facilitator will then encourage participants to add variables and relationships. * The facilitator will interject when the first feedback loop has been formed. * If the group begins to slow down and there is time, or no feedback loop has been formed, the facilitator will ask if there are any relationships between the identified variables that have not been discussed. Doing this will help create loops that might otherwise have been missed. |
| Evaluation criteria | A causal loop diagramming with multiple feedback loops that all participants agree on  Participants can describe the relationships between variables that are shown in the CLD |

# System mapping outcomes



Førde group



Voss group

APPENDIX B: SENSITIVITY ANALYSIS RESULTS

|  |  |  |
| --- | --- | --- |
| Parameter | Results | Comment |
| Forage sector | | |
| Yield plateau | Range: 4000 kg/ha -8000 kg/ha | Sensitive (Numerical sensitivity)  Based on the equation, the yield plateau serves as an upper limit within which the three effects occur. Modifying its value naturally leads to the behaviour depicted in the graph (on the left). |
| Maximum reference quality growth | Range: 0.5 -0.9 (dimensionless) | Sensitive (Numerical sensitivity)  Based on the equation, the maximum reference quality growth serves as an upper limit within which the fertilisers effect occurs. Modifying its value naturally leads to the behaviour depicted in the graph (on the left). |
| Optimal maturity | Range: 120-200 (degrees) | Sensitive, not significant  The change in the optimal maturity controls when and for how long the quality loss balancing loop is activated. This can be observed by the decline that starts early for lower values of optimal maturity. |
| Quality fractional loss rate | Range: 0.0001 – 0.3 (dimensionless/week) | Sensitive, not significant  The change in the fractional loss rate determines the strength of the quality loss balancing loop. Higher fractional rates can drag the forage quality to zero.  Ideally, it would be possible to obtain this parameter through empirical investigation, eliminating the need for a sensitivity test. However, since its value is an assumption within the model, it has been included in the sensitivity analysis to showcase the implications. |
| Proportion of retained fertiliser | Range: 0.1-0.9 (dimensionless) | Not sensitive for a specific reason  The reason for this lack of sensitivity is that fertilizer application never coincides with unsuitable weather conditions that would hinder proper retention of the fertilizers. |
| Time to adjust fertilisers nutrients | Range: 2-26 (weeks) | Sensitive  The change in the time values determines how aggressive the closing of the gap with the desired level. |
| Effect of cash on purchased fertilisers |  | Not sensitive  The effect of cash does not variate much because the relative cash liquidity ratio is in comfortable range. |
| Feed stock sector | | |
| Initial feed stock | Range: 0- 500000 FEm | Not sensitive |
| Minimum time for ordering and transportation | Range: 1 – 12 weeks    Combined sensitivity with initial value of feed | Sensitive  If combined with changes in the initial stock value of feed, the sensitivity becomes more pronounced. |
| Time to adjust expectations | Range: 1- 52 weeks | Not sensitive |
| Feed stock adjustment time | Range: 1- 52 weeks | Not sensitive |
| Livestock sector | | |
| Time to sell livestock | Range: 1- 8 weeks | Not sensitive |
| Initial heifers | Range: 5 – 15 heads | Sensitive when the system shifts to the new quota. |
| Desired heifers in the supply line | Range: 5-15 heads including a minus STEP(2, 53) | Sensitive  If the desired number of heifers in the supply line is low, the farmer wouldn’t be able to stabilise the cow stock at the level that is optimal to utilise the milk quota. |
| Financial sector | | |
| Initial cash liquidity | Range: 0 – 100 000 NOK | Not sensitive |
| Maintenance cost per head | Range: 100-300 Nok/head/week | Sensitive  Changes in the maintenance cost, whether it is related to energy costs, labour costs, or any other expenses, have an impact on the evolution of cash liquidity. This is because maintenance cost represents a significant expenditure in the financials. |
| Harvesting cost of 1kg of feed | Range: 5-25 Nok/FEm/week | Not significantly sensitive |
| Fertilisers price | Range: 2-15 Nok/kg | Sensitive  The simulation behaviour exhibits high sensitivity in bad harvest years where more money is allocated to feed purchase. |
| Price of feed | Range: 15-30 Nok/kg | Sensitive  The simulation behaviour exhibits high sensitivity to higher prices in bad harvest years, particularly when the harvest is significantly low and there is a greater quantity of purchased feed required. |
| Price of meat | Range: 60-70 Nok/kg | Not significantly sensitive |
| Support per hectare | Range: 60-70 Nok/ha/week | Not significantly sensitive |
| Support per cow | Range: 70-75 Nok/cow/week | Not significantly sensitive |
| Quality multiplier | Range: 1.01-1.1 | Not significantly sensitive |
| Ratio of compensation | Range: 10%-50% | Not significantly sensitive |

APPENDIX C: STELLA MODEL DOCUMENTATION

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Total | Count | | | Including Array Elements | | | |
| Variables | 215 | | | 230 | | | |
| Sectors | 6 | | |  | | | |
| Stocks | 16 | | | 16 | | | |
| Flows | 40 | | | 40 | | | |
| Converters | 159 | | | 174 | | | |
| Constants | 69 | | | 84 | | | |
| Equations | 130 | | | 130 | | | |
| Graphicals | 11 | | | 11 | | | |
| Macro Variables | 35 | | |  | | | |
|  | | | Equation | | | | | | |  | Units | Documentation | |  |
| Data\_of\_forage\_quality | | | GRAPH(TIME) Excel file attached | | | | | | |  | dmnl | Historical data of forage quality (source: interview data) | |  |
| Data\_of\_harvested\_yield | | | GRAPH(TIME) Excel file attached | | | | | | |  | FEm/ha/week | Historical data of harvested yield (source: interview data) | |  |
| Milk\_cow\_data | | | GRAPH(TIME) Excel file attached | | | | | | |  | head | Historical data of the number of milk cows in the farm (source: interview data) | |  |
| Total\_forage\_area | | | Owned\_forage\_area+Rented\_forage\_area | | | | | | |  | ha | It represents the forage field area, which is calculated as the total of the farmer's personal property and rented land. | |  |
| Feed\_stock\_sector\_in\_FEm | | | | | | | | | | | | |
| Actual\_feed\_orders\_in\_kg | | | "Feed\_orders,\_in\_energy\_terms"//Energy\_content\_in\_kg\_of\_purchased\_feed | | | | | | |  | Kilograms/Weeks | The actual quantity of feed orders is a simple conversion of the feed orders in energy terms to kilograms using the converter "Energy content in kg of purchased feed". | |  |
| Affordable\_feed\_orders\_in\_energy\_content\_terms | | | Affordable\_feed\_orders\_in\_kg\*Energy\_content\_in\_kg\_of\_purchased\_feed | | | | | | |  | FEm/week | It represents the amount of energy provided by the affordable feed orders in terms of energy content equivalence. It indicates the total energy value that can be obtained from the feed orders based on their energy contents per kg. | |  |
| Basic\_feed\_intake\_for\_maintenance\_per\_head | | | 248.3 | | | | | | |  | FEm/week/head | It represents the basic energy requirement for maintenance (metabolism required to breathe, maintain body temperature, walk and eat). It is based on the feeding regimes calculated in accordance with the new Nordic feed evaluation system (Source: Norfôr Plan https://www.norfor.info/files/Maria\_%C3%83%E2%80%A6kerlind\_NorFor\_model\_9th\_NorFor\_workshop\_7\_November\_2018.pdf) and on the assumed average weights of the livestock. | |  |
| Desired\_feed\_intake\_for\_milk\_production | | | Energy\_required\_to\_produce\_1l\_of\_milk\*Potential\_milk\_yield | | | | | | |  | FEm/week/head | It represented the target feed intake necessary to achieve the potential milk production, which is calculated by multiplying the potential milk yield by the energy needed to produce one litre of milk. | |  |
| Desired\_feed\_orders\_in\_energy\_terms | | | MAX(0, Desired\_replenishment\_rate-Total\_harvested\_feed\_in\_energy\_terms) | | | | | | |  | FEm/week | Desired feed orders quantify the difference between the desired replenishment rate and the total harvested feed | |  |
| Desired\_feed\_stock\_coverage | | | Safety\_Stock\_Coverage+Minimum\_time\_for\_ordering\_and\_transportation | | | | | | |  | week | It includes the minimum time needed for ordering and transporting the feed plus the additional safety stock. | |  |
| Desired\_level\_of\_feed\_stock | | | Desired\_feed\_stock\_coverage\*Expected\_livestock\_feed\_intake\_rate | | | | | | |  | FEm | It represents the level of feed stock desired depending on the desired feed stock coverage and the expected feed intake rate of livestock. | |  |
| Desired\_livestock\_feed\_intake | | | Total\_minimum\_feed\_intake+Milk\_cows\*(Desired\_feed\_intake\_for\_milk\_production) | | | | | | |  | FEm/week | The total feed intake for the livestock, encompassing both intake for maintenance (needed for all livestock) and intake required for milk production (only concerning cows) | |  |
| Desired\_replenishment\_rate | | | MAX(0, Expected\_livestock\_feed\_intake\_rate+"Stock\_of\_feed\_gap\_(surplus\_or\_shortage)"//Feed\_stock\_adjustment\_time) | | | | | | |  | FEm/week | It accounts for the shortage needed to be addressed in order to attain the desired level of feed stock and the expected outflow of the stock, which corresponds to the expected livestock feed intake rate. The Fuzzy MAX ensures that in case the stock of feed is in large surplus compared to the desired level, the replenishment does not take any negative value | |  |
| Energy\_content\_in\_kg\_of\_purchased\_feed | | | 13 | | | | | | |  | FEm/kg | It represents the energy content of one kilogram of feed (roughages, cereals, by-products and concentrates). The value is set at 13 same as assumed in the book Lockhart and Wiseman' s Crop Husbandry Including Grassland, A volume in Woodhead Publishing Series in Food Science, Technology and Nutrition Book • Tenth Edition • 2023. https://www.sciencedirect.com/topics/food-science/metabolizable-energy | |  |
| Energy\_required\_to\_produce\_1l\_of\_milk | | | 4.1 | | | | | | |  | FEm/l | It represents the energy needed to produce one litre of milk. It is based on findings presented in table 1 (conventional) in Philip Shine et al., ‘Energy Consumption on Dairy Farms: A Review of Monitoring, Prediction Modelling, and Analyses’, Energies 13, no. 5 (10 March 2020): 1288, with a simple assumption that one litre of milk is equal to 1 kilogram of energy content of milk (Kg ECM). | |  |
| Expected\_livestock\_feed\_intake\_rate | | | SMTH1(Livestock\_feed\_intake\_rate, Time\_to\_adjust\_expectations) | | | | | | |  | FEm/week | It represents the farmer's expectation of the livestock feed intake rate. It is formulated as a higher-order information delay (smooth function) to represent the process of the gradual update and adjustment of the expectations over the adjustment time of expectations. The use of higher order is justified by the fact that expectations can be affected by various delays, such as the time required to report results and any cognitive and decision-making process delays. | |  |
| Feed\_availability\_ratio | | | Livestock\_feed\_intake\_rate//Desired\_livestock\_feed\_intake | | | | | | |  | dmnl | It denotes the ratio of the livestock feed intake rate over the desired feed intake, used as an indicator of feed availability. | |  |
| "Feed\_orders,\_in\_energy\_terms" | | | MIN(Affordable\_feed\_orders\_in\_energy\_content\_terms, Desired\_feed\_orders\_in\_energy\_terms) | | | | | | |  | FEm/week | It represents the actual feed orders used to replenish the feed stock. The Min function ensures that the feed orders do not exceed what is economically affordable by taking the lower value between the desired feed orders and affordable feed orders, both in terms of energy content. | |  |
| Feed\_replenishment\_rate | | | Total\_harvested\_feed\_in\_energy\_terms+"Feed\_orders,\_in\_energy\_terms" | | | | | | |  | FEm/week | The rate at which the stock of feed is replenished every week; calculated as the sum of the total harvested feed and the feed orders. | |  |
| Feed\_stock\_adjustment\_time | | | 52 | | | | | | |  | week | It represents the time it takes to correct the discrepancy between the stock of feed and the desired level. (Source: interview data) | |  |
| Fulfilment\_ratio | | | GRAPH(Maximum\_feed\_intake\_rate//Desired\_livestock\_feed\_intake) Points: (0.000, 0.000), (1.250, 0.5924), (2.500, 0.8455), (3.750, 0.9537), (5.000, 1.000) | | | | | | |  | dmnl | It represents the fraction of the livestock feed intake rate that will be fulfilled. It is a graphical function of the ratio of the maximum feed intake and the desired livestock feed intake. The shape is referenced from Sterman's (2020) chapter 18 (order fulfilment as a function of inventory) and can be read as follows:  if the maximum feed intake is larger than the desired intake (the case where the feed stock is ample), the ratio takes the value of 1 meaning that the livestock intake can be equal to the desired level. Inversely, if the maximum feed intake falls below the desired intake, the ratio declines increasingly toward 0 to reflect the further reduction of stock feed availability. As a consequence, the livestock intake rate will be less than the desired intake. The minimum value of 0 ensures that the livestock feed intake rate falls to 0 when the stock of feed is completely depleted. | |  |
| Initial\_feed\_stock | | | 140000 | | | | | | |  | FEm | The initial value of the stock feed. With no prior data about its value, it was subject to testing. | |  |
| Livestock\_feed\_intake\_rate | | | Desired\_livestock\_feed\_intake\*Fulfilment\_ratio | | | | | | |  | FEm/week | The rate at which the stock of feed is drained; is determined by multiplying the desired livestock feed intake by the fulfilment ratio. | |  |
| Maximum\_feed\_intake\_rate | | | Stock\_of\_feed/Minimum\_time\_for\_ordering\_and\_transportation | | | | | | |  | FEm/week | The maximum feed intake rate depends on the current level of the stock of feed and the minimum time for ordering and transportation. | |  |
| Minimum\_time\_for\_ordering\_and\_transportation | | | 1 | | | | | | |  | week | The minimum time it takes to order and transport feed is based on expert judgement (interview data). | |  |
| N\_the\_order\_of\_information\_delay | | | 1 | | | | | | |  | dmnl | N denotes the order of the information delay. | |  |
| Safety\_Stock\_Coverage | | | 52 | | | | | | |  | weeks | It represents the period of time that should be covered by the stock of feed without incurring stock-outs or disruptions; is based on expert judgement (interview data) | |  |
| Stock\_of\_feed(t) | | | Stock\_of\_feed(t - dt) + (Feed\_replenishment\_rate - Livestock\_feed\_intake\_rate) \* dt | | | | | | | INIT Stock\_of\_feed = Initial\_feed\_stock | FEm | The total amount of stock feed in terms of nutritive value. With no prior data about the level of this stock, its initial value has been assumed and tested. | |  |
| "Stock\_of\_feed\_gap\_(surplus\_or\_shortage)" | | | Desired\_level\_of\_feed\_stock-Stock\_of\_feed | | | | | | |  | FEm | It calculates the gap between the actual level of stock feed and desired level; a negative value indicates a shortage, while a positive value indicates a surplus. | |  |
| Time\_to\_adjust\_expectations | | | 8 | | | | | | |  | week | The variable is initially set to 1 week, representing the shortest time step in the simulation. However, it will be subjected to sensitivity testing to assess its impact and potential need for adjustment. | |  |
| Total\_harvested\_feed\_in\_energy\_terms | | | Total\_harvest\_of\_forage\_area\*Forage\_energy\_content | | | | | | |  | FEm/week | It represents the overall harvest in terms of energy content by considering the energy content of the forage at the time of mowing and the amount of total harvest. | |  |
| Total\_minimum\_feed\_intake | | | Basic\_feed\_intake\_for\_maintenance\_per\_head\*Total\_livestock | | | | | | |  | FEm/week | It denotes the total feed intake necessary for the maintenance of the entire livestock, calculated as the based feed intake per head multiplied by the total number of animals | |  |
| Financial\_sector | | | | | | | | | | | | |
| Affordable\_feed\_orders\_in\_kg | | | Remaining\_cash/Price\_of\_feed | | | | | | |  | Kilograms/Weeks | It represents the maximum quantity of feed that can be ordered based on the remaining cash and the price of the feed. | |  |
| Available\_cash\_to\_spend | | | Cash\_liquidity//DT | | | | | | |  | nok/Weeks | It represents the cash liquidity available to be spent, calculated as the stock of cash over the time step used in the simulation. | |  |
| Carcass\_average\_weight[Future\_heifers] | | | 261.6 | | | | | | |  | kg/head | It represents the average carcass weights of the livestock at different cohorts over the past 5 years. (source: Animalia Norwegian Meat and Poultry Research Centre https://www.animalia.no/no/kjott--egg/klassifisering/klassifisering-av-storfe/) | |  |
| Carcass\_average\_weight[Cows] | | | 265.2 | | | | | | |  | kg/head |  |
| Carcass\_average\_weight[Male\_calves] | | | 127.6 | | | | | | |  | kg/head |  |
| Carcass\_average\_weight[Female\_calves] | | | 127.6 | | | | | | |  | kg/head |  |
| Carcass\_average\_weight[Weaned\_female\_calves] | | | 225.7 | | | | | | |  | kg/head |  |
| Carcass\_average\_weight[Weaned\_male\_calves] | | | 315.5 | | | | | | |  | kg/head |  |
| Cash\_liquidity(t) | | | Cash\_liquidity(t - dt) + (Income\_from\_milk\_sales + "State\_production/price\_support" + Income\_from\_livestock\_sales + Climate\_compensation - Feed\_orders\_expenditures - Livestock\_maintenance\_expenditure - Harvesting\_expenditure - Fertilisers\_expenditure - Land\_renting\_expenditure) \* dt | | | | | | | INIT Cash\_liquidity = Initial\_money\_liquidity | nok | The amount of cash money held by the farmers. The initial value has been subject to sensitivity test. The initial value has undergone a sensitivity test due to the lack of data. It is difficult to isolate the cash liquidity for farm purposes from other sources of cash liquidity, as many farmers or farming families have additional income from jobs outside of agriculture or other businesses. The interviewee confirms that liquidity is not a problem for them since they have relatively easy access to loans through banks or informal networks. | |  |
| Climate\_compensation | | | IF Percentage\_change\_in\_harvested\_yield <Percentage\_loss\_threshold THEN ABS(Gap\_in\_harvested\_yield\*Total\_forage\_area)\* Ratio\_of\_compensation \* Rate\_of\_compensation ELSE 0 | | | | | | |  | nok/Weeks | The rate computes the climate compensation only when the percentage change in harvest yield is below 30% (the percentage loss threshold). The calculation involves compensating 70% (the ratio of compensation) of the absolute value of yield the gap (as it is negative) by applying a compensation rate of 4.43 for every unit of FEm. | |  |
| Effect\_of\_quality\_on\_price | | | Quality\_multiplier\*Relative\_quality | | | | | | |  | dmnl | It represents the effect of quality on the milk price based on the value of relative quality and the fixed quality multiplier. | |  |
| Feed\_orders\_expenditures | | | MIN(Available\_cash\_to\_spend , Actual\_feed\_orders\_in\_kg\*Price\_of\_feed) | | | | | | |  | nok/Weeks | The money spent on feed orders every week. It is determined by the multiplication of the quantity of feed orders by the price of fertilisers. | |  |
| Fertilisers\_expenditure | | | MIN ( Available\_cash\_to\_spend, Quantity\_of\_purchased\_fertilisers\*Fertilisers\_price) | | | | | | |  | nok/Weeks | The expenditure of purchasing fertilisers is computed by multiplying the quantity of fertilisers needed by the price of fertilisers. By utilising the MIN function with available cash, it ensures that expenditures do not exceed the available amount and prevents the cash stock from falling below zero. | |  |
| Fertilisers\_price | | | 5.6 | | | | | | |  | Nok/kg | The price of one kilogram of nitrogen fertiliser, set at the levels recorded in March 2023 (source: Norsk Landbruksrådgiving) | |  |
| Gap\_in\_harvested\_yield | | | IF TIME =Mowing\_timing AND TIME>1 THEN MIN(0, Harvested\_yield\_in\_energy\_terms-Normal\_harvested\_yield\_for\_compensation) ELSE NAN | | | | | | |  | FEm/ha/week | It represents the gap in terms of energy contents between the actual total harvested yield and the total normal harvested yield. | |  |
| Harvested\_yield\_in\_energy\_terms | | | Total\_harvested\_feed\_in\_energy\_terms/Total\_forage\_area | | | | | | |  | FEm/ha/week | It represents the harvest yield for one hectare; computed by dividing the total harvest by the forage area. | |  |
| Harvesting\_cost\_of\_1kg\_of\_feed | | | 10 | | | | | | |  | Nok/kg | It denotes an approximation of the expenses involved in harvesting one kilogram of feed, encompassing costs such as tractor usage, labour costs, and bale wrapping expenses for preservation and storage. It was estimated to be 20 nok per kg based on the average sale price of one bale of grass/sillage/hay in finn.no. | |  |
| Harvesting\_expenditure | | | MIN ( Available\_cash\_to\_spend, Total\_harvest\_of\_forage\_area\*Harvesting\_cost\_of\_1kg\_of\_feed ) | | | | | | |  | nok/Weeks | The expenditure for harvesting the entire forage area; determined by multiplying the total harvested area by the unit cost of harvesting one kilogram. By utilising the MIN function with available cash, it ensures that expenditures do not exceed the available amount and prevents the cash stock from falling below zero. | |  |
| Income\_from\_livestock\_sales | | | (cows\_sales+cows\_emergency\_sales )\*Carcass\_average\_weight[Cows]\*Unit\_price\_of\_meat[Cows] + Weaned\_female\_calves\_sales \*Carcass\_average\_weight[Weaned\_female\_calves]\*Unit\_price\_of\_meat[Weaned\_female\_calves] + Weaned\_male\_calves\_sales\*Carcass\_average\_weight[Weaned\_male\_calves]\*Unit\_price\_of\_meat[Weaned\_male\_calves] | | | | | | |  | nok/Weeks | The total money receipts coming from selling the livestock each week, it is calculated by multiplying the rate of sales by their average carcass weight and their respective price. | |  |
| Income\_from\_milk\_sales | | | Milk\_delivery\_rate\*Milk\_price | | | | | | |  | nok/Weeks | The revenues generated from milk sales; calculated by multiplying the weekly volumes of delivered milk by the milk price. | |  |
| Initial\_money\_liquidity | | | 70000 | | | | | | |  | nok | This constant represents the initial value of the cash liquidity, estimated by judgement to fit the trend of the produced behaviour. | |  |
| Land\_renting\_expenditure | | | MIN ( Available\_cash\_to\_spend, Rented\_forage\_area\*Renting\_price\_per\_ha ) | | | | | | |  | nok/Weeks | It represents the weekly expenditure on rental payments for the leased forage area. By utilising the MIN function with available cash, it ensures that expenditures do not exceed the available amount and prevents the cash stock from falling below zero. | |  |
| Livestock\_maintenance\_expenditure | | | MIN ( Available\_cash\_to\_spend, Total\_livestock\*Maintenance\_cost\_per\_head) | | | | | | |  | nok/Weeks | The weekly expenditure for the overall livestock maintenance, excluding feed expenses, encompasses costs such as barn upkeep, energy expenses, and workers' wages; obtained by multiplying the total number of livestock by the maintenance cost per animal. By utilising the MIN function with available cash, it ensures that expenditures do not exceed the available amount and prevents the cash stock from falling below zero. | |  |
| Maintenance\_cost\_per\_head | | | 200 | | | | | | |  | nok/head/week | It represents an estimate of the cost required to maintain a single head of livestock for one week, encompassing expenses such as barn maintenance, energy consumption, worker wages, vaccinations, and veterinary care; (source | |  |
| Milk\_base\_price | | | GRAPH(Year\_counter) Points: (1.00, 6.000), (2.00, 6.000), (3.00, 6.000), (4.00, 6.000), (5.00, 6.000), (6.00, 6.000), (7.00, 6.000), (8.00, 6.000), (9.00, 6.000), (10.00, 6.000), (11.00, 6.000), (12.00, 6.000), (13.00, 6.000), (14.00, 3.300), (15.00, 6.050), (16.00, 6.050), (17.00, 6.050), (18.00, 6.050), (19.00, 6.050), (20.00, 6.050), (21.00, 6.050), (22.00, 6.050), (23.00, 6.050), (24.00, 6.050), (25.00, 6.050), (26.00, 6.050), (27.00, 6.000), (28.00, 6.000), (29.00, 6.000), (30.00, 6.000), (31.00, 6.200), (32.00, 6.200), (33.00, 6.200), (34.00, 6.200), (35.00, 6.200), (36.00, 6.200), (37.00, 6.200), (38.00, 6.200), (39.00, 6.200), (40.00, 5.880), (41.00, 5.880), (42.00, 5.880), (43.00, 5.880), (44.00, 5.880), (45.00, 5.880), (46.00, 5.880), (47.00, 5.880), (48.00, 5.880), (49.00, 5.880), (50.00, 5.880), (51.00, 5.880), (52.00, 3.500) | | | | | | |  | nok/l | It represents the quotation price according to TINE agreement for the year 2022/2023. (source: TINE, Endring av noteringsprisen i markedsordningen for melk avtaleåret 2022/2023) | |  |
| Milk\_price | | | Milk\_base\_price\*Effect\_of\_quality\_on\_price | | | | | | |  | nok/l | It represents the final price of the milk after taking into consideration the effect of quality | |  |
| Normal\_harvested\_yield\_for\_compensation | | | 3400 | | | | | | |  | FEm/ha/week | It represents the normal yield on the basis of which compensation is calculated; it is assumed to be equal to 3400 Fem/ha based on the value specified by regulation for group 3 that includes Vestland. According to the following source, the standard crops for forage are 5400 Fem per hectare to which 2000 Fem/ha has been deducted to represent the two-cut system simulated in the model.  (source: lovdata https://lovdata.no/dokument/SF/forskrift/2018-08-01-1215/KAPITTEL\_5#%C2%A714 , value for group 3) | |  |
| Percentage\_change\_in\_harvested\_yield | | | Gap\_in\_harvested\_yield/Normal\_harvested\_yield\_for\_compensation | | | | | | |  | dmnl | The percentage change measures the relative difference between total harvested yield and normal harvested expressed as a percentage. It is calculated by dividing the gap over the total normal harvested yield. | |  |
| Percentage\_loss\_threshold | | | -0.3 | | | | | | |  | dmnl | The threshold above which compensation takes place. (Source: Statsforvalteren) | |  |
| Price\_of\_feed | | | 20 | | | | | | |  | nok/kg | It represents the average price of one kg of feed. | |  |
| Quality\_multiplier | | | 1.06 | | | | | | |  | dmnl | This multiplier represents a linear relationship between the ratio of quality and milk price. It is assumed to equal 1.06, indicating that an increase in quality ratio by 10% results in an increase in the price of milk compared to the base price by 6%. | |  |
| Rate\_of\_compensation | | | 4.43 | | | | | | |  | NOK/FEm | It represents the rate of compensation; specified by regulation (source: lovdata https://lovdata.no/dokument/SF/forskrift/2018-08-01-1215/KAPITTEL\_5#%C2%A714 | |  |
| Ratio\_of\_compensation | | | 0.7 | | | | | | |  | dmnl | It represents the percentage covered by the compensation (source: Statsforvalteren) | |  |
| Reference\_cash\_threshold | | | 50000 | | | | | | |  | nok | This represents the minimum threshold below which the cash liquidity stock is considered to be in a state of distress. | |  |
| Relative\_cash\_liquidity | | | Cash\_liquidity//Reference\_cash\_threshold | | | | | | |  | dmnl | This ratio represents the cash liquidity level relative to the reference value. | |  |
| Remaining\_cash | | | MAX(0, Available\_cash\_to\_spend-(Fertilisers\_expenditure+Harvesting\_expenditure+Livestock\_maintenance\_expenditure)) | | | | | | |  | nok/Weeks | It represents the remaining cash liquidity after deducting expenditures related to livestock maintenance, harvesting costs, and savings set aside for fertilisers. | |  |
| Renting\_price\_per\_ha | | | 1960/52 | | | | | | |  | nok/ha/week | It represents the mean price for renting good quality land for grass cultivation in Vestland for the year 2023 (source:  https://www.landbruksdirektoratet.no/nb/statistikk-og-utviklingstrekk/utvikling-i-jordbruket/jordleiepriser) | |  |
| "State\_production/price\_support" | | | Milk\_cows\*Support\_per\_cow+Total\_forage\_area\*Support\_per\_ha | | | | | | |  | nok/Weeks | The amount of direct payment received from the State for each owned cow and every harvested hectare; presented on a weekly basis. | |  |
| Support\_per\_cow | | | 4290/52 | | | | | | |  | nok/head/week | It represents the premium provided to farmers per hectare of forage. It has been set at the rate approved in 2021 and paid during 2022. (source : Landbruksdirektoratet https://www.landbruksdirektoratet.no/nb/jordbruk/ordninger-for-jordbruk/produksjonstilskudd-og-avlosertilskudd-i-jordbruket/produksjonstilskudd-og-avlosertilskudd--endelige-satser-2021 | |  |
| Support\_per\_ha | | | 3300/52 | | | | | | |  | nok/ha/week | It represents the premium per hectare provided to forage farmers in zone 5B (Grovfôr). It has been set at the rate approved in 2021 and paid during 2022. (source : Landbruksdirektoratet https://www.landbruksdirektoratet.no/nb/jordbruk/ordninger-for-jordbruk/produksjonstilskudd-og-avlosertilskudd-i-jordbruket/produksjonstilskudd-og-avlosertilskudd--endelige-satser-2021) | |  |
| Unit\_price\_of\_meat[Future\_heifers] | | | 0 | | | | | | |  | NOK/kg | It denotes the average price at which one kilogram of meat (medium quality =R) is sold from various groups of livestock. (source : https://medlem.nortura.no/prislister/avregningspriser-storfe-vilkar-storfe-article46176-11969.html) | |  |
| Unit\_price\_of\_meat[Cows] | | | 66.17 | | | | | | |  | NOK/kg |  |
| Unit\_price\_of\_meat[Male\_calves] | | | 0 | | | | | | |  | NOK/kg |  |
| Unit\_price\_of\_meat[Female\_calves] | | | 0 | | | | | | |  | NOK/kg |  |
| Unit\_price\_of\_meat[Weaned\_female\_calves] | | | 66.23 | | | | | | |  | NOK/kg |  |
| Unit\_price\_of\_meat[Weaned\_male\_calves] | | | 67.59 | | | | | | |  | NOK/kg |  |
| Forage\_sector | | | | | | | | | | | | |
| Accumulated\_GDW(t) | | | Accumulated\_GDW(t - dt) + ("Growing\_degree\_weeks\_(GDW)" - set\_to\_0\_for\_new\_year) \* dt | | | | | | | INIT Accumulated\_GDW = 0 | Degrees | The stock accumulates the weekly growing degrees as an indicator of the length of the growing season. | |  |
| Average\_Manure\_produced\_per\_head | | | 20 | | | | | | |  | kg/head/week | The average amount of manure produced by one head of livestock in a week. (Souce : https://www150.statcan.gc.ca/n1/pub/16-002-x/2008004/article/10751-eng.htm) | |  |
| Average\_quality | | | 0.69 | | | | | | |  | dmnl | It represents the simple average of forage qualities observed in typical forages in mountains and valley villages (source:  https://nibio.brage.unit.no/nibio-xmlui/bitstream/handle/11250/2443202/NIBIO\_RAPPORT\_2017\_3\_73.pdf?sequence=1) | |  |
| Base\_temperature | | | 5 | | | | | | |  | degrees/week | The temperature threshold above which forage growth can happen (source: The Norwegian Centre for Climate Services (NCCS)report no. 1/2017, Climate in Norway 2100– a knowledge base for climate adaptation, https://www.miljodirektoratet.no/globalassets/publikasjoner/M741/M741.pdf) | |  |
| biomass\_growth\_rate | | | Yield\_plateau\* (1-10^-Lagged\_impact\_of\_rain\_on\_biomass\_growth) \* (1-10^-Lagged\_impact\_of\_GDW\_on\_biomass\_growth) \* (1-10^-Lagged\_impact\_of\_fertilisation\_on\_biomass\_growth) | | | | | | |  | kg/ha/week | The rate at which the above ground biomass increases every week. The formula follows a Mitscherlich-Baule equation and captures how yield reacts to changes in rain, growing degree weeks (temperature) and nutrients from fertilisers. | |  |
| Biomass\_response\_time | | | 6 | | | | | | |  | week | It represents the time it takes for the biomass to react to factors such as rainfall, temperature and fertilisation. The value is determined based onpreviouslyous validated model that specifically considered the influence of rainfall on biomass productivity (Source: Cecile Godde et al., ‘Climate Change and Variability Impacts on Grazing Herds: Insights from a System Dynamics Approach for Semi‐arid Australian Rangelands’, Global Change Biology 25, no. 9 (September 2019): 3091–3109) | |  |
| Converter\_to\_gross\_energy\_of\_digestibility | | | 0.82 | | | | | | |  | FEm/kg | The coefficient converts the quality, represented here as a percentage of digestibility, to feed energy unit (FEm). It is set to 0.82. (Source: according to the table 2 in NIBIO report, the digestibility is linearly correlated to the energy with an approximate calculated coefficient of 0.82 https://nibio.brage.unit.no/nibio-xmlui/bitstream/handle/11250/2443202/NIBIO\_RAPPORT\_2017\_3\_73.pdf?sequence=1) | |  |
| Desired\_nutrient\_uptake\_per\_ha | | | 250 | | | | | | |  | Nkg/ha | The desired level of Nitrogen nutrients in one hectare (source: Full report of the UK Agriculture and Horticulture Development Board on Nitrogen Recommendations for Grassland in light of costly fertilisers, https://ahdb.org.uk/nitrogen-recommendations-for-grassland) | |  |
| Desired\_nutrients\_from\_purchased\_fertilisers | | | MAX(0, Nutrients\_gap\_per\_ha-Nutrients\_from\_manure\_per\_ha)\*Effect\_of\_cash\_on\_purchased\_fertilisers | | | | | | |  | Nkg/ha/week | It indicates the additional nutrients needed to reach the desired nutrient level, taking into consideration the nutrients obtained from manure. The Max function ensures that the gap remains positive in case there is a surplus of nutrients provided by manure. | |  |
| Effect\_factor\_of\_fertilisation\_on\_forage\_quality | | | 0.00017 | | | | | | |  | dmnl/(Nkg/ha/week) | A parameter that quantifies the extent to which changes in fertilisation impacts the change in the forage quality, calibrated to fit data. | |  |
| Effect\_factor\_of\_fertilisersation\_on\_biomass\_growth | | | 0.0019 | | | | | | |  | dmnl/((Nkg/ha)/week) | A parameter that quantifies the extent to which changes in fertilisation impacts the change in above ground biomass, calibrated to fit data. | |  |
| Effect\_factor\_of\_rain\_on\_biomass\_growth | | | 0.72 | | | | | | |  | dmnl/(mm/week) | A parameter that quantifies the extent to which changes in rainfall impact the change in above ground biomass, calibrated to fit data. | |  |
| Effect\_factor\_of\_temperature\_on\_biomass\_growth | | | 0.9 | | | | | | |  | dmnl/(degrees/week) | A parameter that quantifies the extent to which changes in growing degree days (temperature) impact the change in above ground biomass, calibrated to fit data. | |  |
| Effect\_of\_cash\_on\_purchased\_fertilisers | | | GRAPH(Relative\_cash\_liquidity) Points: (0.000, 0.000), (0.500, 0.07251), (1.000, 0.917), (1.500, 0.991), (2.000, 1.000) | | | | | | |  | dmnl | It quantifies the impact of cash liquidity on the ability to fulfil the desired nutrient from the purchase of fertilisers. Under normal conditions, cash liquidity does not have a significant impact. However, if the cash liquidity drops below the reference threshold or approaches zero (in other words the relative cash liquidity is below 1), it indicates that no fertilisers can be purchased. The S-shaped is usually used to translate the effect of money/profitability on variables in Sterman's works. | |  |
| Fertilisers\_nutrients\_stock(t) | | | Fertilisers\_nutrients\_stock(t - dt) + (Nutrients\_addition - Nutrients\_application\_rate) \* dt | | | | | | | INIT Fertilisers\_nutrients\_stock = 0 | Nkg/ha | This variable represents the amount of nutrients that can be applied for fertilisation purposes. | |  |
| Fertilisers\_retention | | | IF TIME =Fertilisers\_application\_timing AND (Rainfall\_data > Heavy\_rainfall\_threshold OR Temperature\_data > Volatisation\_temperature\_max\_threshold OR Temperature\_data < Volatisation\_temperature\_min\_threshold ) THEN Proportion\_of\_retained\_fertilisers ELSE 1 | | | | | | |  | dmnl | It activates the effect of fertiliser retention (vs leaching) when one of the weather conditions is satisfied at the time of applying fertilisers. | |  |
| Forage\_above\_ground\_biomass(t) | | | Forage\_above\_ground\_biomass(t - dt) + (biomass\_growth\_rate - harvesting\_rate) \* dt | | | | | | | INIT Forage\_above\_ground\_biomass = 0 | kg/ha | It represents the level of growth reached for the above ground biomass. The initial value for the stock is set to 0 with the assumption that there is no biomass above ground at the beginning of the simulation which coincides with the first weeks of January. | |  |
| Forage\_energy\_content | | | Quality\_retained\_at\_the\_time\_of\_mowing\*Converter\_to\_gross\_energy\_of\_digestibility | | | | | | |  | FEm/kg | It represents the gross energy of the forage based on the quality level (digestibility) at the time of mowing, simply computed using the converter from quality percentage to gross energy of digestibility. | |  |
| Forage\_quality(t) | | | Forage\_quality(t - dt) + (Forage\_quality\_growth\_rate - Forage\_quality\_loss\_rate) \* dt | | | | | | | INIT Forage\_quality = Average\_quality | dmnl | The quality represents the percentage out of the forage biomass that can be digested by the livestock; made up of carbohydrates, proteins and lipids. A level of 50% means that half of the biomass can be digested by the livestock. The initial value issett to the average quality. | |  |
| Forage\_quality\_growth\_rate | | | IF Year\_counter=52 THEN Recovery\_after\_mowing ELSE Maximum\_reference\_quality\_growth\* (1-10^- Lagged\_impact\_of\_fertilisation\_on\_forage\_quality) | | | | | | |  | dmnl/week | It represents the rate at which forage quality increased on a weekly basis. It is calculated using a Mitscherlich-Baule equation while the conditional statement is formulated to reset the quality of the forage to the reference value after the mowing has occurred. | |  |
| Forage\_quality\_loss\_rate | | | IF Accumulated\_GDW >Optimal\_maturity THEN Forage\_quality\*Quality\_fractional\_loss\_rate ELSE 0 | | | | | | |  | dmnl/week | The rate at which forage quality is depleted per week. Once the accumulated growing degree weeks surpass the optimal and mowing has not yet occurred, the rate removes the specified fraction from the quality stock. | |  |
| "Growing\_degree\_weeks\_(GDW)" | | | MAX(0, Temperature\_data-Base\_temperature) | | | | | | |  | degrees/week | This rate represents the weekly heat above the base temperature that would allow growth to happen. It subtracts the base temperature from the average weekly temperature: if negative, the rate is set to zero, meaning no growth; otherwise, it takes the positive value. | |  |
| harvesting\_rate | | | IF TIME=Mowing\_timing THEN Forage\_above\_ground\_biomass//Time\_to\_mow\_the\_forage ELSE 0 | | | | | | |  | kg/ha/week | The rate at which the forage biomass is harvested each week on a hectare scale. Whethe n time reaches the mowing time, the rate depletes completely | |  |
| Heavy\_rainfall\_threshold | | | 20 | | | | | | |  | mm/week | The rainfall threshold above which fertilisers can be washed off, set to 20 mm based on an experimental study of nitrogen dynamics in the Broadbalk Wheat Experiment (soure : https://core.ac.uk/download/pdf/162121235.pdf) | |  |
| Lagged\_impact\_of\_fertilisation\_on\_biomass\_growth | | | SMTH1(Total\_nutrient\_uptake\_from\_fertilisers\*Effect\_factor\_of\_fertilisersation\_on\_biomass\_growth, Biomass\_response\_time) | | | | | | |  | dmnl | It calculates the impact of nutrients from fertilisers on biomass growth by considering the level of total nutrients uptake and the effect factor. The incorporation of a smooth function allows for a delay of the effect by six weeks, as the crop response is not immediate. | |  |
| Lagged\_impact\_of\_fertilisation\_on\_forage\_quality | | | SMTH1(Total\_nutrient\_uptake\_from\_fertilisers\*Effect\_factor\_of\_fertilisation\_on\_forage\_quality, Biomass\_response\_time) | | | | | | |  | dmnl | It calculates the impact of temperature on forage by considering the level of growing degrees weeks and the effect factor. The incorporation of a smooth function allows for a delay of the effect by six weeks, as the crop response is not immediate. | |  |
| Lagged\_impact\_of\_GDW\_on\_biomass\_growth | | | SMTH1("Growing\_degree\_weeks\_(GDW)"\*Effect\_factor\_of\_temperature\_on\_biomass\_growth, Biomass\_response\_time) | | | | | | |  | dmnl | It calculates the impact of temperature on biomass growth by considering the level of growing degrees weeks and the effect factor. The incorporation of a smooth function allows for a delay of the effect by six weeks, as the crop response is not immediate. | |  |
| Lagged\_impact\_of\_rain\_on\_biomass\_growth | | | SMTH1(Rainfall\_data\*Effect\_factor\_of\_rain\_on\_biomass\_growth, Biomass\_response\_time) | | | | | | |  | dmnl | It calculates the impact of rain on biomass growth by considering the level of precipitation and the effect factor. The incorporation of a smooth function allows for a delay of the effect by six weeks, as the crop response is not immediate. | |  |
| Manure\_application\_timing | | | TIME | | | | | | |  | week | The week decided by the farmers to utilise the manure (source: interview data). | |  |
| Manure\_production\_rate | | | Total\_livestock\*Average\_Manure\_produced\_per\_head | | | | | | |  | Kilograms/Weeks | The rate at which manure is produced each week; calculated as the livestock multiplied by the weekly average amount of the manure produced per head. | |  |
| Manure\_utilisation\_rate | | | IF TIME = Manure\_application\_timing THEN Stock\_of\_manure/Time\_to\_empty\_the\_stock\_of\_manure ELSE 0 | | | | | | |  | Kilograms/Weeks | The rate at which manure is utilised for fertilisation purposes, calculated by dividing the stock of manure by the time it takes to empty it when the application time of the fertilisers arrives | |  |
| Maximum\_reference\_quality\_growth | | | 0.75 | | | | | | |  | dmnl/week | This parameter serves as a maximum reference for the forage quality growth and is set above the values observed in typical forages in mountains and valley villages ( source: table 2  https://nibio.brage.unit.no/nibio-xmlui/bitstream/handle/11250/2443202/NIBIO\_RAPPORT\_2017\_3\_73.pdf?sequence=1) | |  |
| Nutrient\_content\_in\_1kg\_of\_purchased\_fertilisers | | | 0.39 | | | | | | |  | Nkg/kg | The nitrogen content in one kilogram of purchased fertilizers, set at 0.46 (source: based on Urea 46% the most commonly utilised nitrogenous fertiliser) | |  |
| Nutrient\_content\_per\_kg\_of\_manure | | | 0.005 | | | | | | |  | Nkg/kg | The amount of Nitrogen nutrients contained in one kg of manure (source: https://nibio.brage.unit.no/nibio-xmlui/bitstream/handle/11250/2627760/2019\_10.1016\_j.livsci.2019.03.004.pdf?sequence=2) | |  |
| Nutrients\_addition | | | Nutrients\_from\_manure\_per\_ha+Desired\_nutrients\_from\_purchased\_fertilisers | | | | | | |  | Nkg/ha/week | The rate at which nutrients are added to the stock of soil nutrients. It is calculated by summing nutrients coming from manure and from purchased fertilisers per hectare. | |  |
| Nutrients\_application\_rate | | | IF TIME =Fertilisers\_application\_timing THEN Fertilisers\_nutrients\_stock//Time\_to\_apply\_fertilisers ELSE 0 | | | | | | |  | Nkg/ha/week | The rate at which manure is utilised for fertilisation purposes, calculated by dividing the stock of manure by the time it takes to empty it when the application time of the fertilisers arrives | |  |
| Nutrients\_from\_manure\_per\_ha | | | Manure\_utilisation\_rate\*Nutrient\_content\_per\_kg\_of\_manure/Total\_forage\_area | | | | | | |  | Nkg/ha/week | The amount of nutrients coming from the livestock manure per hectare; obtained by dividing the stock of manure over the forage area in use. | |  |
| Nutrients\_gap\_per\_ha | | | (Desired\_nutrient\_uptake\_per\_ha-Fertilisers\_nutrients\_stock)/Time\_to\_adjust\_fertilisers\_nutrients | | | | | | |  | Nkg/ha/week | The gap between the desired nutrient levels and the stock of nutrients. | |  |
| Optimal\_maturity | | | 160 | | | | | | |  | Degrees | It represents the optimal growing degree weeks. The value is calibrated as the literature provides estimates based on daily accumulation rather than the weekly accumulation used in the model. | |  |
| Proportion\_of\_retained\_fertilisers | | | 0.6 | | | | | | |  | dmnl | It represents the percentage of fertilisers that would be retained by the plants depending on the weather conditions. It is assumed to be equal to 0.6, meaning that 40% of nutrients from fertilisers will be lost. (source: https://www.researchgate.net/post/Which-percentage-of-applied-fertilizer-leaches-to-the-groundwater) | |  |
| Quality\_fractional\_loss\_rate | | | 0.01 | | | | | | |  | dmnl/week | The fraction of the quality that is lost every week that the mowing timing is delayed. The delay is captured by comparing the accumulated growing degree weeks (GDW) with the optimal GDW; assumed to be 0.03%. | |  |
| Quality\_retained\_at\_the\_time\_of\_mowing | | | IF TIME>1 AND TIME=Mowing\_timing THEN Forage\_quality ELSE 0 | | | | | | |  | dmnl | It records the quality that is retained at the time of mowing. | |  |
| Quantity\_of\_purchased\_fertilisers | | | (Desired\_nutrients\_from\_purchased\_fertilisers//Nutrient\_content\_in\_1kg\_of\_purchased\_fertilisers)\*Total\_forage\_area | | | | | | |  | Kilograms/Weeks | The actual quantity of purchased fertilisers is determined by the nutrients from purchased fertilisers divided by the nutrient content in one kilogram of purchased fertilisers. | |  |
| Rainfall\_data | | | GRAPH(TIME) Excel file attached | | | | | | |  | mm/week | It represented the rainfall data recorded at Hovlandsdal weather station, the closest to the farm-case study. (source: https://seklima.met.no/) | |  |
| Recovery\_after\_mowing | | | (Average\_quality-Forage\_quality)//DT | | | | | | |  | dmnl/week | The converter enables a quick adjustment of the forage quality level by closing the gap almost immediately (over one DT). | |  |
| Relative\_quality | | | Forage\_quality//Average\_quality | | | | | | |  | dmnl | It represents the forage quality relative to the reference value. | |  |
| set\_to\_0\_for\_new\_year | | | IF Year\_counter=1 THEN Accumulated\_GDW//DT ELSE 0 | | | | | | |  | degrees/week | This rate initialises the stock of accumulated growing degree weeks to 0 to account for a new year, computed as the stock divided by DT when the year counter is equal to 1, denoting the first week of the year. | |  |
| Stock\_of\_manure(t) | | | Stock\_of\_manure(t - dt) + (Manure\_production\_rate - Manure\_utilisation\_rate) \* dt | | | | | | | INIT Stock\_of\_manure = 0 | kg | The cumulative manure produced by the livestock. | |  |
| Temperature\_data | | | GRAPH(TIME) Excel file attached | | | | | | |  | degrees/week | It represented the temperature data recorded at Hovlandsdal weather station, the closest to the farm-case study. (source: extracted from an internal model of NORCE-Climate-futures) | |  |
| Time\_to\_adjust\_fertilisers\_nutrients | | | 52/4 | | | | | | |  | week | The time it takes to adjust fertiliser nutrients ais ssumed to be one season (usually preparatiofor n the winter season). | |  |
| Time\_to\_apply\_fertilisers | | | DT | | | | | | |  | week | The time it takes to apply the fertilisers nutrients to the forage; set to the shortest time step (one DT) | |  |
| Time\_to\_empty\_the\_stock\_of\_manure | | | 1 | | | | | | |  | week | The time it takes to empty the stock of manure to use it as a fertiliser. It is set to one week according to interview data. | |  |
| Time\_to\_mow\_the\_forage | | | DT | | | | | | |  | week | The time it takes to mow the forage; set to the shortest time step (one DT) | |  |
| Total\_harvest\_of\_forage\_area | | | harvesting\_rate\*Total\_forage\_area | | | | | | |  | Kg/Weeks | It quantifies the overall quantity of harvested forage given to the total area of the forage. | |  |
| Total\_nutrient\_uptake\_from\_fertilisers | | | Nutrients\_application\_rate \*Fertilisers\_retention | | | | | | |  | (Nkg/ha)/week | The sum of nutrients coming from the livestock manure as well as purchased fertilisers. | |  |
| Volatisation\_temperature\_max\_threshold | | | 21 | | | | | | |  | Degrees/week | The temperature threshold beyond which fertilisers volatilise/evaporate. (source: Montana State University https://landresources.montana.edu/soilfertility/documents/PDF/pub/Urea%20vol%20factors%20BMP%20combo.pdf) | |  |
| Volatisation\_temperature\_min\_threshold | | | 1 | | | | | | |  | Degrees/week | The temperature threshold below which fertilisers cannot be absorbed due to reduced permeability of the soil. (source: Andrew N. Sharpley, ‘Agriculture, Nutrient Management and Water Quality’, in Reference Module in Life Sciences (Elsevier, 2018), B9780128096338207000, https://doi.org/10.1016/B978-0-12-809633-8.20758-9.) | |  |
| Yield\_plateau | | | 7500 | | | | | | |  | kg/ha/week | The maximum yield under perfect factor availability, is based on yield data for the County of Vestland for the year 2021. (source: https://www.ssb.no/en/statbank/table/13648/tableViewLayout1/) | |  |
| Livestock\_sector | | | | | | | | | | | | |
| Adjustment\_of\_heifers\_in\_the\_supply\_line | | | (Desired\_heifers\_in\_the\_supply\_line-Heifers) /Time\_to\_adjust\_livestock | | | | | | |  | head/Weeks | It represents the gap between the desired level of heifers and the actual level of the stock over the adjustment time. | |  |
| Adult\_mortality\_fraction | | | 0.03/52 | | | | | | |  | dmnl/week | It represents the proportion of death within adult calves per week. It is usually expressed in annual terms but in this model, it has been imposed on a weekly basis- divided by 52. It has been set at 3.2% in accordancewitho values reported otherers countries (British cattle; Brickell et al., 2007 and Austrian Fleckvieh cattle; Fuerst-Waltl et al. 2012) | |  |
| Average\_productive\_life\_of\_a\_cow | | | 312 | | | | | | |  | week | It represents the length of the productive life of the cow after which it is slaughtered, set at 6 years=312 weeks according to interview data. | |  |
| Average\_weight\_of\_livestock[Future\_heifers] | | | 494 | | | | | | |  | kg | It represents the average weights of the livestock in different cohorts. The calculation of these average weights is based on the average carcass weight, assuming that it generally accounts for 52% of the total weight of the livestock. (source:  Animalia Norwegian Meat and Poultry Research Centre https://www.animalia.no/no/kjott--egg/klassifisering/klassifisering-av-storfe/ and  https://www.geno.no/om-geno/om-norsk-rodt-fe/karakteristikk-hos-nrf/) | |  |
| Average\_weight\_of\_livestock[Cows] | | | 560 | | | | | | |  | kg |  |
| Average\_weight\_of\_livestock[Male\_calves] | | | 241 | | | | | | |  | kg |  |
| Average\_weight\_of\_livestock[Female\_calves] | | | 241 | | | | | | |  | kg |  |
| Average\_weight\_of\_livestock[Weaned\_female\_calves] | | | 426 | | | | | | |  | kg |  |
| Average\_weight\_of\_livestock[Weaned\_male\_calves] | | | 595 | | | | | | |  | kg |  |
| Basic\_feed\_shortfall\_accounting | | | SMTH1( (Livestock\_feed\_intake\_rate + HISTORY(Livestock\_feed\_intake\_rate, TIME-1)+ HISTORY(Livestock\_feed\_intake\_rate, TIME-2)+ HISTORY(Livestock\_feed\_intake\_rate, TIME-3) )/4 //Basic\_feed\_intake\_for\_maintenance\_per\_head , Time\_to\_adjust\_expectations) | | | | | | |  | head | The variable indicates the number of heads that can be fed based on their basic intake requirement, given the average feed intake rate during the past 4 weeks. It is computed to be compared to the actual number of livestock on the farm. | |  |
| births | | | IF Year\_counter=Calving\_time THEN Milk\_cows\*Number\_of\_offspring\_per\_cow ELSE 0 | | | | | | |  | head/Weeks | The rate at which calves are born per week, calculated as the product of the dairy cows and the number of offspring per cow. | |  |
| born\_female | | | New\_born\_calves\*Sex\_ratio//Time\_to\_report\_sex | | | | | | |  | head/Weeks | This rate directs a fraction of the newborn calves to the female calves stock, depending on the assumed sex ratio. | |  |
| Born\_male | | | New\_born\_calves\*(1-Sex\_ratio)//Time\_to\_report\_sex | | | | | | |  | head/Weeks | This rate directs a fraction of the newborn calves to the male calves stock, depending on the assumed sex ratio. | |  |
| Calves\_mortality\_fraction | | | 0.046/52 | | | | | | |  | dmnl/week | It represents the proportion of death within calves per week. It is usually expressed in annual terms but in this model, it has been imposed on a weekly basis- thus divided by 52. It has been set at 4.6% sourc : Gulliksen SM, Lie KI, Løken T, Osterås O. Calf mortality in Norwegian dairy herds. J Dairy Sci. 2009 Jun;92(6):2782-95. doi: 10.3168/jds.2008-1807. PMID: 19448012.) | |  |
| Calving\_time | | | 46 | | | | | | |  | week | The time of the year in which a cow gives birth, assumed to be in week 46 ( source: O. Flaten, A.K. Bakken, and Å.T. Randby, ‘The Profitability of Harvesting Grass Silages at Early Maturity Stages: An Analysis of Dairy Farming Systems in Norway’, Agricultural Systems 136 (June 2015): 85–95, https://doi.org/10.1016/j.agsy.2015.03.001.) | |  |
| Carrying\_capacity | | | Total\_forage\_area\*Regulatory\_livestock\_density | | | | | | |  | head | It indicates the maximum number of heads that can be accommodated or carried on the farm based on the available forage area; calculated by multiplying the total forage area by the regulatory density. | |  |
| Cow\_adjustment\_gap | | | MIN(Maximum\_cow\_adjustment, Cow\_gap\_to\_meet\_milk\_quota) | | | | | | |  | head | The MIN function is used to ensure that the cow adjustment rate is equal to the gap needed to meet the milk production target, up to a maximum limit set by the carrying capacity. | |  |
| Cow\_adjustment\_rate | | | Cow\_adjustment\_gap//Time\_to\_adjust\_livestock | | | | | | |  | head/Weeks | The cow adjustment rate is exactly proportional to the cow adjustment gap over the time it takesadjustment the livestock. | |  |
| Cow\_gap\_to\_meet\_milk\_quota | | | (Milk\_gap\_in\_weekly\_intervals//Potential\_milk\_yield) | | | | | | |  | head | It represents the number of cows that need to be added in order to fully meet the milk quota, considering their potential milk yield. This calculation is relevant only if the cumulative delivery of milk at the end of the year is below the annual milk quota. In other words, it determines the additional number of cows required to bridge the gap between the current milk production and the desired milk quota. | |  |
| Cow\_mating\_age | | | 80 | | | | | | |  | week | It represents the heifer breeding age. The estimated age is 2 years from which I subtracted 6 months for weaning. (source: https://animal.ifas.ufl.edu/beef\_extension/bcsc/1990/docs/short.pdf) | |  |
| Cows\_death\_rate | | | Milk\_cows\*Adult\_mortality\_fraction | | | | | | |  | head/Weeks | The number of natural deaths from the milk cows’ stock every week, calculated as the stock multiplied by the mortality rate. | |  |
| cows\_emergency\_sales | | | MIN(Milk\_cows//DT, (Livestock\_shortfall//Time\_to\_sell\_livestock)+ ABS( MIN(0, Cow\_adjustment\_rate))) | | | | | | |  | head/Weeks | The rate at which cows are sold in the event of an emergency shortage of feed. The rate is proportional to the livestock shortfall (in absolute terms) over the time it takes to sell livestock. The MIN function with milk cows stock prevents the cash stock from falling below zero. | |  |
| cows\_sales | | | MIN(Milk\_cows//DT, Milk\_cows//Average\_productive\_life\_of\_a\_cow) | | | | | | |  | head/Weeks | The rate at which cows are sold. It is calculated as the stock of over the average productive life of a cow. | |  |
| Desired\_heifers\_in\_the\_supply\_line | | | 13-STEP(2, 53) | | | | | | |  | head | It represents the desired number of heifers the farmer keeps in the pipeline. According to Sterman, the supply line adjustment is a sophisticated exercise and assumes a high degree of rationality, it must therefore depend on empirical investigation of the decision-making process. The desired level of heifers has been therefore calibrated to reproduce historical data. | |  |
| Dry\_cows(t) | | | Dry\_cows(t - dt) + (moving\_from\_lactation - returning\_to\_lactation) \* dt | | | | | | | INIT Dry\_cows = Initial\_dry\_cows | head | The cow that is not producing milk, between the end of the lactation period and the next calving. It is initialised at 8 to reproduce a realistic behaviour of the stock. | |  |
| Expected\_cow\_exits | | | SMTH1(Cows\_death\_rate+cows\_sales+cows\_emergency\_sales, Time\_to\_adjust\_expectations) | | | | | | |  | head/Weeks | The variable sums up all the exit rates from the stock of milk cows and which should be taken into consideration if the replacement rate (the farmer decision point). | |  |
| Female\_calves(t) | | | Female\_calves(t - dt) + (born\_female - female\_weaning - Female\_calves\_death\_rate) \* dt | | | | | | | INIT Female\_calves = Initial\_dry\_cows\*Sex\_ratio | head | The stock of female calves initialised at half of the dry cows. | |  |
| Female\_calves\_death\_rate | | | Female\_calves\*Calves\_mortality\_fraction | | | | | | |  | head/week | The rate at which the female calves die naturally (e.g. from disease) per week, calculated as the stock multiplied by a mortality fraction. | |  |
| female\_weaning | | | Female\_calves/Weaning\_age | | | | | | |  | head/Weeks | The rate at which the female calves mature to become weaned female calves per week, calculated by dividing the stock by the weaning age (residence time). | |  |
| Future\_heifers\_death\_rate | | | Heifers\*Adult\_mortality\_fraction | | | | | | |  | head/Weeks | The number of natural deaths from the future heifers stock per week, calculated as the stock multiplied by the mortality rate. | |  |
| Heifers(t) | | | Heifers(t - dt) + (Replacement\_rate - Maturing\_to\_cow - Future\_heifers\_death\_rate) \* dt | | | | | | | INIT Heifers = initial\_future\_heifers | head | The number of female cattle that are kept on the farm but didn't give birth to offspring yet. | |  |
| Initial\_cows | | | 40 | | | | | | |  | head | This constant represents the initial value of milk cows, extracted from historical data. | |  |
| Initial\_dry\_cows | | | 8 | | | | | | |  | head | This constant represents the initial value of dry cows, calibrated to produce plausible behaviour. | |  |
| initial\_future\_heifers | | | 13 | | | | | | |  | head | This constant represents the initial value of the heifers, calibrated to produce plausible behaviour. | |  |
| Lactation\_period | | | 43 | | | | | | |  | weeks | It represents the time period during with a cow produced milk. It typically lasts 305 days ≈ 43.6 weeks (source: Kidane et al., ‘Milk Production of Norwegian Red Dairy Cows on Silages Presumed Either Low or Optimal in Dietary Crude Protein Content’.) | |  |
| Livestock\_shortfall | | | MAX(0, Total\_livestock-Basic\_feed\_shortfall\_accounting) | | | | | | |  | head | The variable accounts for the negative difference between the current level of livestock and the basic feed requirements. If the number of livestock exceeds the capacity to feed them with basic requirement, it implies that the farm needs to sell the gap that cannot be adequately fed. | |  |
| Male\_calves(t) | | | Male\_calves(t - dt) + (Born\_male - male\_weaning - Male\_calves\_death\_rate) \* dt | | | | | | | INIT Male\_calves = Initial\_dry\_cows\*(1-Sex\_ratio) | head | For the stock of male calves, I initialised at half of the dry cows. | |  |
| Male\_calves\_death\_rate | | | Male\_calves\*Calves\_mortality\_fraction | | | | | | |  | head/Weeks | The rate at which the male calves die naturally (e.g. from disease) per week, calculated as the stock multiplied by a mortality fraction. | |  |
| male\_weaning | | | Male\_calves//Weaning\_age | | | | | | |  | head/Weeks | The rate at which the male calves mature to become weaned female calves per week, calculated by dividing the stock by the weaning age (residence time). | |  |
| Maturing\_to\_cow | | | Heifers//Cow\_mating\_age | | | | | | |  | head/Weeks | The rate at which the future heifers become cows per week, calculated by dividing the stock by the cow maturing age (residence time). | |  |
| Maximum\_cow\_adjustment | | | Carrying\_capacity-Milk\_cows | | | | | | |  | head | This variable calculates the difference between the number of heads permitted by the carrying capacity of the farm and the actual level of livestock. | |  |
| Milk\_cows(t) | | | Milk\_cows(t - dt) + (Maturing\_to\_cow + returning\_to\_lactation - cows\_sales - moving\_from\_lactation - cows\_emergency\_sales - Cows\_death\_rate) \* dt | | | | | | | INIT Milk\_cows = Initial\_cows | head | The number of cow cattle that gave birth and produce milk. It is initialised according to historical data provided by the interviewee. | |  |
| moving\_from\_lactation | | | Milk\_cows//Lactation\_period | | | | | | |  | head/Weeks | The rate at which the cows move to the dry period every week, calculated by dividing the stock of cows by the lactation period (residence time). | |  |
| New\_born\_calves(t) | | | New\_born\_calves(t - dt) + (births - born\_female - Born\_male) \* dt | | | | | | | INIT New\_born\_calves = Initial\_dry\_cows | head | It represents the number of newborn calves. It is initialised at the same level at the same level as that ory cows, as the latter are the ones responsible for giving birth to the former. | |  |
| Number\_of\_offspring\_per\_cow | | | 1 | | | | | | |  | head/head/week | In Norway, a cow gives birth on average to 1 offspring a year. (source: Nortura) | |  |
| Owned\_forage\_area | | | 18 | | | | | | |  | ha | It represents the field area, which belongs to the farmer (source: interview data). | |  |
| Regulatory\_livestock\_density | | | 1 | | | | | | |  | head/ha | It indicates the maximum number of cows per one hectare of land. (source: Statsforvalteren) | |  |
| Rented\_forage\_area | | | GRAPH(TIME) Points: (1.0, 22.000), (52.0, 22.000), (53.0, 17.000), (187.2, 17.000), (249.6, 17.000), (312.0, 17.000) | | | | | | |  | ha | It represents the field area that is rented land (source: interview data). | |  |
| Replacement\_rate | | | MIN( Weaned\_female\_calves//DT, MAX(0, Expected\_cow\_exits+Adjustment\_of\_heifers\_in\_the\_supply\_line+ MAX(0, Cow\_adjustment\_rate) )) | | | | | | |  | head/Weeks | The replacement rate includes the replacement of the milk cows exiting the stock, adjusting the heifers in the supply live and the cow by closing the gap between the desired and actual level. The MIN function prevents from withdrawing from the “Weaned female calves” when the stock is empty and the MAX ensure that the cow adjustment is positive so that the replacement rate equation is robust and does not display a negative value for an inflow. | |  |
| returning\_to\_lactation | | | Dry\_cows//(52-Lactation\_period) | | | | | | |  | head/Weeks | The rate at which the dry cows return to a cow producing milk every week, calculated by dividing the stock of cows by the lactation period (residence time). | |  |
| Sex\_ratio | | | 0.5 | | | | | | |  | dmnl | The fraction of births of each sex, assumed for simplicity to be equal to 0.5 meaning that 50% of newborn calves are male and the other half is female (half chance). | |  |
| Time\_to\_adjust\_livestock | | | 4\*4 | | | | | | |  | week | The time it takes to adjust livestock; assumed to be 16 weeks, the equivalent of one season. | |  |
| Time\_to\_report\_sex | | | DT | | | | | | |  | week | The time it takes to know the sex of the newborn calves, assumed to be equal to DT. | |  |
| Time\_to\_sell\_livestock | | | 3 | | | | | | |  | week | The time it takes to sell livestock, assumed to be one week; based on expert judgement (interview data) | |  |
| Total\_livestock | | | (Milk\_cows+Dry\_cows)\*Average\_weight\_of\_livestock[Cows]/Average\_weight\_of\_livestock[Cows] + Heifers\*Average\_weight\_of\_livestock[Future\_heifers]/Average\_weight\_of\_livestock[Cows] + Weaned\_female\_calves\*Average\_weight\_of\_livestock[Weaned\_female\_calves]/Average\_weight\_of\_livestock[Cows] + Female\_calves\*Average\_weight\_of\_livestock[Female\_calves]/Average\_weight\_of\_livestock[Cows] + Male\_calves\*Average\_weight\_of\_livestock[Male\_calves]/Average\_weight\_of\_livestock[Cows] + Weaned\_male\_calves\*Average\_weight\_of\_livestock[Weaned\_male\_calves]/Average\_weight\_of\_livestock[Cows] | | | | | | |  | head | The total sum of livestock. Since the main focus is on cows, the calculations have been anchored on cows, based on average carcass weights data: a heifer is equal to 0.75 cow and a calve is equal to 0.42 cow | |  |
| Weaned\_female\_calves(t) | | | Weaned\_female\_calves(t - dt) + (female\_weaning - Replacement\_rate - Weaned\_female\_calves\_sales) \* dt | | | | | | | INIT Weaned\_female\_calves = 0 | head | The stock of female calves that completed the weaning period and can be sold or retained in the farm, initialised at 0 | |  |
| Weaned\_female\_calves\_sales | | | MIN( Weaned\_female\_calves//DT, (Weaned\_female\_calves//Time\_to\_sell\_livestock)) | | | | | | |  | head/Weeks | The rate at which weaned female calves are sold, calculated at the stock divided by the time it takes to sell livestock. This outflow depletes the remaining weaned female calves in the stock that are not selected for replacement. | |  |
| Weaned\_male\_calves(t) | | | Weaned\_male\_calves(t - dt) + (male\_weaning - Weaned\_male\_calves\_sales) \* dt | | | | | | | INIT Weaned\_male\_calves = 0 | head | The stock of male calves that completed the weaning period and can be sold or retained in the farm, initialised at 0 | |  |
| Weaned\_male\_calves\_sales | | | MIN( Weaned\_male\_calves//DT, Weaned\_male\_calves//Time\_to\_sell\_livestock) | | | | | | |  | head/Weeks | The rate at which weaned male calves are sold. It is calculated as the stock of weaned mmalesover the time it takes to sell livestock. All the stock is depleted as the main activity of the farm is dairy production and not meat production. | |  |
| Weaning\_age | | | 24 | | | | | | |  | week | The time the calves remain with their mother before they are weaned. It varies between 6 to 9 months period (source: European Commission, Scientific Committee on Animal Health and Animal Welfare) and is assumed in this model to be 6 months- the minimum. | |  |
| Milk\_production\_sector: | | | | | | | | | | | | |
| Annual\_milk\_quota | | | GRAPH(TIME) Points: (0.0, 350000.0), (52.0, 350000.0), (53.0, 300000.0), (156.5, 300000.0), (208.333333333, 300000.0), (260.166666667, 300000.0), (312.0, 300000.0) | | | | | | |  | l | It represents the maximum milk quota allocated to the farm (source: interview data) | |  |
| Calves\_Milk\_intake\_proportion\_based\_on\_their\_weight | | | 0.01\*7 | | | | | | |  | (l/kg)/week/head | It represents the requirement for milk intake based on the average weight of the calves. Typically, calves consume around 10% of their body weight in milk per day (source: College of Veterinary Medicine, Cornell University, https://www.vet.cornell.edu/animal-health-diagnostic-center/programs/nyschap/modules-documents/LiquidFeedManagement#:~:text=Calves%20should%20be%20fed%20daily,feeding%20when%20fed%20twice%20daily.) | |  |
| Cumulative\_delivered\_milk(t) | | | Cumulative\_delivered\_milk(t - dt) + (Milk\_delivery\_rate - set\_to\_0\_for\_next\_year\_quota) \* dt | | | | | | | INIT Cumulative\_delivered\_milk = 0.001 | l | It represents the cumulative volume of milk delivered. This accumulation is necessary for comparison with the annual quota. At the start of the year, the initial value for the stock is set to 0, as there is no prior count. | |  |
| Effect\_of\_feed\_availability\_on\_milk\_yield | | | GRAPH(Feed\_availability\_ratio) Points: (0.000, 0.000), (0.500, 0.9276), (1.000, 1.000) | | | | | | |  | dmnl | This variable computes the magnitude of the effect on milk yield based on the value of the feed availability ratio. It assumed that as the feed ratio (feed intake relative to the desired intake) drops below 50%, the milk yield quickly approaches zero because the feed intake is insufficient for the cow's sustenance and survival and the effect factor of feed availability grows linearly. Beyond the 50% feed ratio, the effect factor slowly plateaus towards 1 (there is a biological limit to how much a cow can be fed and produce milk). This implies that the incremental gain in milk yield becomes smaller as the feed ratio approaches 1. At a feed ratio of 1, the potential maximum yield is reached, and the marginal gain is close to zero. ( source: the new Nordic feed evaluation system, Norfôr Plan https://www.norfor.info/files/Maria\_%C3%83%E2%80%A6kerlind\_NorFor\_model\_9th\_NorFor\_workshop\_7\_November\_2018.pdf) | |  |
| End\_of\_the\_year\_Annual\_milk\_gap | | | IF Year\_counter=52 THEN Annual\_milk\_quota-Cumulative\_delivered\_milk ELSE 0 | | | | | | |  | l | It calculates the difference between the annual milk quota allocated to the farm and the amount of milk delivered since the beginning of the year. | |  |
| Milk\_delivery\_rate | | | MAX(0, Milk\_production\_rate-Milk\_fed\_to\_baby\_calves) | | | | | | |  | l/week | It is the weekly rate at which milk is delivered, which is determined by subtracting the milk consumed on the farm for feeding baby calves from the overall milk production rate. | |  |
| Milk\_fed\_to\_baby\_calves | | | Calves\_Milk\_intake\_proportion\_based\_on\_their\_weight\*(Male\_calves\*Average\_weight\_of\_livestock[Male\_calves]+Female\_calves\*Average\_weight\_of\_livestock[Female\_calves]) | | | | | | |  | l/week | It refers to the total amount of milk needed to meet the nutritional needs of calves. It is calculated as the sum of calves multiplied by the milk intake proportion and their respective body weights. | |  |
| Milk\_gap\_in\_weekly\_intervals | | | End\_of\_the\_year\_Annual\_milk\_gap//Weekly\_converter | | | | | | |  | l/week | It converts the annual milk gap into weekly intervals to align with the frequency at which the model is running. | |  |
| Milk\_production\_rate | | | Milk\_cows\*Milk\_yield | | | | | | |  | Liters/Weeks | It represents the rate of produced milk taking into account the entire stock of stock and based on their milk yield. | |  |
| Milk\_yield | | | Potential\_milk\_yield\* Effect\_of\_feed\_availability\_on\_milk\_yield | | | | | | |  | l/week/head | It represents the actual milk yield of a cow, considering the impact of feed availability. | |  |
| Potential\_milk\_yield | | | 164.8 | | | | | | |  | l/head/week | It represents the maximum amount of milk that a dairy cow can produce to fulfil the milk quota, calculated by dividing the yearly quota by the number of cows and then dividing that result by 52 to determine the weekly yield. | |  |
| set\_to\_0\_for\_next\_year\_quota | | | IF Year\_counter=1 THEN Cumulative\_delivered\_milk//DT ELSE 0 | | | | | | |  | l/week | This rate initialises the stock of cumulative delivered milk to 0 to account for a new year, computed as the stock divided by DT when the year counter is equal to 1, denoting the first week of the year. | |  |
| scenario\_switches | | | | | | | | | | | | |
| Alternative\_fertilisers\_application\_timing | | | IF weeks\_time\_gap=1 THEN "Fertilisers\_application\_timing\_+1" ELSE IF weeks\_time\_gap = 2 THEN "Fertilisers\_application\_timing\_+2" ELSE IF weeks\_time\_gap=3 THEN "Fertilisers\_application\_timing\_+3" ELSE IF weeks\_time\_gap=4 THEN "Fertilisers\_application\_timing\_+4" ELSE IF weeks\_time\_gap=-1 THEN "Fertilisers\_application\_timing\_-1" ELSE IF weeks\_time\_gap=-2 THEN "Fertilisers\_application\_timing\_-2" ELSE 0 | | | | | | |  | week | The converter allows to switch between the different timings of applying fertilisers. | |  |
| Alternative\_mowing\_timing | | | IF weeks\_time\_gap=1 THEN "Mowing\_timing\_+1" ELSE IF weeks\_time\_gap = 2 THEN "Mowing\_timing\_+2" ELSE IF weeks\_time\_gap=3 THEN "Mowing\_timing\_+3" ELSE IF weeks\_time\_gap=4 THEN "Mowing\_timing\_+4" ELSE IF weeks\_time\_gap=-1 THEN "Mowing\_timing\_-1" ELSE IF weeks\_time\_gap=-2 THEN "Mowing\_timing\_-2" ELSE 0 | | | | | | |  | week | The converter allows to switch between the different mowing timings. | |  |
| Fertilisers\_application\_timing | | | IF SWITCH\_to\_Forecasts=0 THEN History\_of\_fertilisers\_application\_timing ELSE Alternative\_fertilisers\_application\_timing | | | | | | |  | week | It represents either the actual week in which fertilisers were applied or the alternative timings, depending on the value of the switch. | |  |
| "Fertilisers\_application\_timing\_+1" | | | TIME | | | | | | |  | week | It represents an advanced timing of fertilisers application by one week compared to the actual application time. | |  |
| "Fertilisers\_application\_timing\_+2" | | | TIME | | | | | | |  | week | It represents an advanced timing of fertilisers application by 2 weeks compared to the actual application time. | |  |
| "Fertilisers\_application\_timing\_+3" | | | TIME | | | | | | |  | week | It represents an advanced timing of fertilisers application by 3 weeks compared to the actual application time. | |  |
| "Fertilisers\_application\_timing\_+4" | | | TIME | | | | | | |  | week | It represents an advanced timing of fertilisers application by 4 weeks compared to the actual application time. | |  |
| "Fertilisers\_application\_timing\_-1" | | | TIME | | | | | | |  | week | It represents a delayed timing of fertilisers application of one week compared to the actual application time. | |  |
| "Fertilisers\_application\_timing\_-2" | | | TIME | | | | | | |  | week | It represents a delayed timing of fertilisers application of two weeks compared to the actual application time. | |  |
| History\_of\_fertilisers\_application\_timing | | | TIME | | | | | | |  | week | It represents the actual timings of applying fertilisers decided by the farmer (source: interview data) | |  |
| History\_of\_mowing\_timing | | | TIME | | | | | | |  | week | It represents the actual mowing timings (source: interview data) | |  |
| Mowing\_timing | | | IF SWITCH\_to\_Forecasts=0 THEN History\_of\_mowing\_timing ELSE Alternative\_mowing\_timing | | | | | | |  | week | It represents either the actual week in which the forage area was harvested or the alternative timings, depending on the value of the switch. | |  |
| "Mowing\_timing\_+1" | | | TIME | | | | | | |  | week | It represents an advanced mowing timing by one week compared to the actual mowing time. | |  |
| "Mowing\_timing\_+2" | | | TIME | | | | | | |  | week | It represents an advanced mowing timing by two weeks compared to the actual mowing time. | |  |
| "Mowing\_timing\_+3" | | | TIME | | | | | | |  | week | It represents an advanced mowing timing by 3 weeks compared to the actual mowing time. | |  |
| "Mowing\_timing\_+4" | | | TIME | | | | | | |  | week | It represents an advanced mowing timing by 4 weeks compared to the actual mowing time. | |  |
| "Mowing\_timing\_-1" | | | TIME | | | | | | |  | week | It represents a delayed mowing timing of two weeks compared to the actual mowing time. | |  |
| "Mowing\_timing\_-2" | | | TIME | | | | | | |  | week | It represents a delayed mowing timing of two weeks compared to the actual mowing time. | |  |
| SWITCH\_to\_Forecasts | | | 0 | | | | | | |  | dmnl | This converter allows to switch between the actual timing and alternative timings, with 0 representing the actual timing. | |  |
| Weekly\_converter | | | 52 | | | | | | |  | Week | It represents the number of weeks in one year for conversion purposes. | |  |
| weeks\_time\_gap | | | 1 | | | | | | |  | dmnl | The converter allows to navigate between the different alternative timings | |  |
| Year\_counter | | | COUNTER(1, 53) | | | | | | |  | week | The built-in function enables to define a cycle of years. It increases linearly from 1 and runs up to 52 (the total number of weeks in a year) and then repeats itself throughout the simulation period. | |  |
| Run Specs | | | | | | |
| Start Time | | | | | | 0 |
| Stop Time | | | | | | 312 |
| DT | | | | | | 1 |
| Fractional DT | | | | | | False |
| Save Interval | | | | | | 1 |
| Sim Duration | | | | | | 0 |
| Time Units | | | | | | week |
| Pause Interval | | | | | | 0 |
| Integration Method | | | | | | Euler |
| Keep all variable results | | | | | | True |
| Run By | | | | | | Run |
| Calculate loop dominance information | | | | | | True |
| Exhaustive Search Threshold | | | | | | 1000 |
| Array Dimension | | Indexed by | | | Elements | | | |
| cattle\_type | | Label (6) | | | Future\_heifers Cows Male\_calves Female\_calves Weaned\_female\_calves Weaned\_male\_calves | | | |

APPENDIX D: RESULTS OF SIMULATION EXPERIMENTS

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Harvested yield 1st cut (FEm/ha) | | | | | | | |
| Outcome | Baseline results | -2 weeks results | -1 weeks results | +1 weeks results | +2 weeks results | +3 weeks results | +4 weeks results |
| 2017 | 2420 | 2015 | 2224 | 2510 | 2572 | 2628 | 2679 |
| 2018 | 2300 | 2238 | 2287 | 2305 | 2361 | 2373 | 2371 |
| 2019 | 4667 | 4639 | 4660 | 4842 | 4818 | 4807 | 4800 |
| 2020 | 3468 | 1661 | 3093 | 3581 | 3578 | 3561 | 3541 |
| 2021 | 3797 | 2710 | 3659 | 3938 | 3942 | 3917 | 3898 |
| 2022 | 4242 | 3642 | 3906 | 4358 | 4376 | 4373 | 4355 |
| Harvested yield 2nd cut (FEm/ha) | | | | | | | |
| Outcome | Baseline results | -2 weeks results | -1 weeks results | +1 weeks results | +2 weeks results | +3 weeks results | +4 weeks results |
| 2017 | 1280 | 1252 | 1266 | 1293 | 1305 | 1316 | 1328 |
| 2018 | 2471 | 2533 | 2513 | 2491 | 2495 | 2488 | 2481 |
| 2019 | 1584 | 1598 | 1586 | 1540 | 1541 | 1528 | 1516 |
| 2020 | 1657 | 1036 | 1666 | 1650 | 1654 | 1643 | 1638 |
| 2021 | 1510 | 1575 | 1508 | 1491 | 1489 | 1481 | 1472 |
| 2022 | 1286 | 1294 | 1068 | 1312 | 1301 | 1106 | 1290 |
| Forage quality 1st cut (dmnl) | | | | | | | |
| Outcome | Baseline results | -2 weeks results | -1 weeks results | +1 weeks results | +2 weeks results | +3 weeks results | +4 weeks results |
| 2017 | 78.6% | 78.4% | 78.5% | 78.7% | 78.8% | 78.8% | 78.9% |
| 2018 | 77.2% | 77.2% | 77.2% | 77.2% | 77.3% | 77.3% | 77.3% |
| 2019 | 78.2% | 78.2% | 78.2% | 78.4% | 78.4% | 78.4% | 78.4% |
| 2020 | 78.8% | 76.5% | 78.8% | 78.8% | 78.8% | 78.8% | 78.8% |
| 2021 | 78.7% | 78.7% | 78.7% | 78.8% | 78.8% | 78.8% | 78.8% |
| 2022 | 77.7% | 77.7% | 77.7% | 77.9% | 77.9% | 77.9% | 77.9% |
| Forage quality 2nd cut (dmnl) | | | | | | | |
| Outcome | Baseline results | -2 weeks results | -1 weeks results | +1 weeks results | +2 weeks results | +3 weeks results | +4 weeks results |
| 2017 | 81.7% | 81.4% | 81.6% | 81.9% | 82.0% | 82.2% | 82.3% |
| 2018 | 82.2% | 82.2% | 82.2% | 82.3% | 82.4% | 82.4% | 82.4% |
| 2019 | 82.1% | 82.0% | 82.0% | 82.2% | 82.2% | 82.2% | 82.1% |
| 2020 | 82.5% | 78.9% | 82.5% | 82.5% | 82.5% | 82.5% | 82.5% |
| 2021 | 82.2% | 82.1% | 82.1% | 82.2% | 82.2% | 82.2% | 82.2% |
| 2022 | 80.8% | 80.7% | 80.1% | 80.9% | 80.9% | 80.2% | 80.9% |
| Feed expenditure (NOK per year) | | | | | | | |
| Outcome | Baseline results | -2 weeks results | -1 weeks results | +1 weeks results | +2 weeks results | +3 weeks results | +4 weeks results |
| 2017 | 1791602 | 1995518 | 1958296 | 1783575 | 1777868 | 1634268 | 1632967 |
| 2018 | 2076970 | 2094255 | 2084959 | 2072148 | 2062621 | 2055452 | 2052742 |
| 2019 | 1825582 | 1833907 | 1830139 | 1822288 | 1818693 | 1814816 | 1811059 |
| 2020 | 1819781 | 2169388 | 1820956 | 1817550 | 1813892 | 1810859 | 1807451 |
| 2021 | 1792677 | 1796704 | 1797889 | 1789661 | 1786386 | 1782594 | 1778996 |
| 2022 | 1919409 | 1928062 | 1966373 | 1916359 | 1914654 | 1953644 | 1908885 |
| Fertilisers expenditure (NOK per year) | | | | | | | |
| Outcome | Baseline results | -2 weeks results | -1 weeks results | +1 weeks results | +2 weeks results | +3 weeks results | +4 weeks results |
| 2017 | 276458 | 273775 | 275885 | 278312 | 279373 | 278248 | 278254 |
| 2018 | 158025 | 157099 | 157104 | 160666 | 161877 | 163071 | 163000 |
| 2019 | 168539 | 166580 | 166521 | 169855 | 169203 | 168393 | 167568 |
| 2020 | 157915 | 163592 | 158799 | 156910 | 156687 | 155512 | 154778 |
| 2021 | 159393 | 156429 | 157505 | 160051 | 159532 | 158998 | 158558 |
| 2022 | 163765 | 162862 | 162110 | 164811 | 163869 | 162883 | 162657 |
| Fertilisers +Feed expenditures (NOK per year) | | | | | | | |
| Outcome | Baseline results | -2 weeks results | -1 weeks results | +1 weeks results | +2 weeks results | +3 weeks results | +4 weeks results |
| 2017 | 2068060 | 2269293 | 2234181 | 2061888 | 2057241 | 1912516 | 1911222 |
| 2018 | 2234995 | 2251354 | 2242063 | 2232814 | 2224498 | 2218523 | 2215743 |
| 2019 | 1994121 | 2000486 | 1996660 | 1992144 | 1987896 | 1983209 | 1978627 |
| 2020 | 1977696 | 2332980 | 1979755 | 1974460 | 1970579 | 1966371 | 1962229 |
| 2021 | 1952070 | 1953133 | 1955394 | 1949712 | 1945918 | 1941592 | 1937555 |
| 2022 | 2083174 | 2090924 | 2128483 | 2081170 | 2078522 | 2116527 | 2071542 |
| Climate compensation (NOK per year) | | | | | | | |
| Outcome | Baseline results | -2 weeks results | -1 weeks results | +1 weeks results | +2 weeks results | +3 weeks results | +4 weeks results |
| 2017 | 138617 | 321999 | 290383 | 132347 | 127605 | 0 | 0 |
| 2018 | 119373 | 126094 | 120754 | 118845 | 112750 | 111473 | 111685 |
| 2019 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2020 | 0 | 374204 | 0 | 0 | 0 | 0 | 0 |
| 2021 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2022 | 134818 | 136459 | 189231 | 135006 | 137008 | 187434 | 139564 |