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Description of cost: benefit model developed for low-input dairy systems typical of developing countries


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Description of cost: benefit model developed for low-input dairy systems typical of developing countries

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International Livestock Research Institute

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Introduction

This model was developed to simulate low-input dairy systems in Senegal to determine the profit and cost: benefit ratios of different types of household dairy enterprise, under the Senegal dairy genetics project (Marshall et al. 2016). The model is flexible and thus likely to be suitable for simulating low-input dairy systems located in other parts of Africa and elsewhere.

Overview

The cost: benefit model accounts for all revenue (benefits) and costs associated with keeping of dairy cattle in low-input dairy systems typical of developing countries. Revenue and costs are calculated on a **per cow per annum** basis, where a cow is considered a breeding female attached to followers (her progeny). Economies of scale (on labour, animal housing and water) are taken into account by setting a herd size as the number of breeding cows in the herd. The currency of the revenue and costs is that used for the inputted economic parameters.

It is assumed that all animals are born in the herd (except in relation to breeding bulls under a specific reproductive scenario, see below). For parameter estimation and modelling, animals are grouped into age-classes as: calf, less than 12 months of age; young, 12 or more and less than 36 months of age; and mature, 36 or more months of age, with the maximum age of mature animals allowed to differ between mature males and mature females. The fate of male animals born into the herd is death (which occurs over all age-classes) or sale as calves, young or mature. The fate of female animals born into the herd is death (which occurs over age-classes, calf and young), sale at the end of the young period, or kept as replacement breeding animals followed by sale as cull for age cows.

Three reproductive scenarios are considered in relation to the breeding bulls: (1) the breeding bull is used for free (e.g. male in own herd used for breeding, borrowed at no cost), (2) the breeding bull is purchased at the start of the time-period and used for breeding, and then sold at the end of the time-period and used for breeding (as a cull for age bull), and (3) the bull is used at a cost (e.g. artificial insemination, hire), but no breeding bull is kept.

See Figure 1 for the overall schema of the model (for the reproductive scenario of breeding bulls used for free). See Figure 2 for an example lifecycle of a cow retained as a breeding animal.

Note that opportunity costs (loss of other alternatives when one alternative is chosen) are not included in this model, but the model could easily be modified to incorporate opportunity costs if required,

The overall model for revenue is:

$$R_{total,pcpa} = R_{milk,pcpa} + R_{male\ calves,pcpa} + R_{young\ males,pcpa} + R_{mature\ males,pcpa} + R_{cull\ for\ age\ purchased\ breeding\ bulls} + R_{young\ females\ ,pcpa} + R_{cull\ for\ age\ females,pcpa}$$

where:

- R is revenue and the subscript $pcpa$ per cow per annum;
- $R_{total,pcpa}$ is the total revenue (per cow per annum) over all revenue sources;
- $R_{milk,pcpa}$ is the revenue (per cow per annum) from milk, included milk sold, milk consumed in the home, milk wasted and milk suckled by calves (all valued at milk sale price);

- $R_{male\ calves,pcpa,}$ $R_{young\ male,pcpa,}$ $R_{mature\ male,pcpa}$ is the revenue (per cow per annum) from the sale of male calves, young male animals and mature male animals, respectively. It was assumed that male calves, young males and mature males sold uniformly across the time period were in that category;
- $R_{cull\ for\ age\ purchased\ breeding\ bull}$ is the revenue (per cow per annum) from the sale of a breeding bull that is now being culled for age. Only applied in reproductive scenarios where the breeding bull is purchased; and
- $R_{young\ females,pcpa,}$ $Rc_{ull\ for\ age\ females,pcpa}$ is the revenue from the sale of young females not required as replacement breeders and the sale of cull for age cows, respectively (per cow per annum). Note that it is assumed that all females not required as replacement breeders were sold as at the end of the young period. It was further assumed that the remaining females were raised to be breeders (i.e. there were no sales for emergency reasons, or mortalities, of the breeding females).

The overall model for costs is:

$$C_{total,pcpa} = C_{health-care,pcpa} + C_{feed,pcpa} + C_{water,pcpa} + C_{animal\ housing,pcpa} + C_{labour,pcpa} + C_{female\ reproduction,pcpa} + C_{purchased\ breeding\ bulls} + C_{marketing\ and\ transport,pcpa}$$

where:

- C is cost and the subscript $pcpa$ per cow per annum;
- $C_{health-care,pcpa,}$ $C_{feed,pcpa}$ is the cost (per cow per annum) of health care and feed, respectively. Calculated as sum of the costs of health care, or feed, for male calves, young males, mature males, purchased breeding bulls (when used), female calves, young female and mature females;
- $C_{water,pcpa,}$ $C_{animal\ housing,\ pcpa,}$ $C_{labour,pcpa}$ is the cost (per cow per annum) of water, animal housing and labour, respectively. Calculated as the cost of the particular item (water, animal housing, or labour) for the whole herd, and then divided by the number of cows (herd size);
- $C_{female\ reproduction,pcpa}$ is the cost (per cow per annum) of female reproduction. Only applied in reproductive scenarios where artificial insemination is used;
- $C_{purchased\ breeding\ bull,pcpa}$ is the cost (per cow per annum) of a breeding bull. Only applied in reproductive scenarios where the breeding bull is purchased; and
- $C_{marketing\ and\ transport,pcpa}$ is the cost (per cow per annum) associated with the marketing and transport of milk and animals sold.

Terms commonly used in the description of the model

- *NFC,NFY,NFM,NMC,NMY,NMM are used for the number of female calves, female young, mature females, male calves, male young, and mature males, respectively.*
- $NFC_{born,pcpa}$ *and* $NMC_{born,pcpa}$ and is the number of female and male calves born, respectively, (per cow per annum), calculated as:

$$NFC_{\boldsymbol{born,pcpa}} = NMC_{\boldsymbol{born,pcpa}} = 0.5\ x \left(\frac{1}{calving\ interval}\right)\ x\ calving\ rate\ x\ (1 - stillbirth\ rate),$$

  assuming an equal sex ratio of progeny born and where 0.5 accounts for the equal sex ratio of progeny, the calving interval is in years (not necessarily a whole number) and '1/calving interval' gives the number of calvings per year, the calving rate is the number of progeny born (alive or dead) per calving, and the stillbirth rate is the number of progeny born dead (or who died within 24 hours after birth) per calving; and

- $M_{female\ calves,}$ $M_{young\ female,}$ $M_{mature,females}$ $M_{male\ calves,}$ $M_{young\ males,}$ $M_{mature\ males}$ is mortality rate per annum of female calves, young females, mature females, male calves, young males and mature males, respectively.

Revenue component calculations

1. $R_{\boldsymbol{milk,pcpa}} = (milk\ offtake_{pcpa} + milk\ suckled\ by\ calves_{pcpa})\ x\ milk\ sale\ price$

where:

- *milk of f take*$_{pcpa}$ is the milk offtake (per cow per annum) in litres, calculated as:

  $$milk\ offtake_{pcpa} = \frac{milk\ offtake\ per\ lactation_{per\ cow}}{calving\ interval}$$

  where *milk of f take per lactation*$_{per\ cow}$ is in litres and calculated as the weighted mean milk offtake per lactation over the first and later parities, per cow; and

  where calving interval is the time between two calving events in years.

- *milk suckled by claves*$_{pcpa}$ is the amount of milk suckled by calves (per cow per annum) in litres, calculated as:

  $$milk\ suckled\ by\ calves_{pcpa} = (daily\ milk\ suckled\ by\ female\ calves\ x\ days\ female\ calves\ are\ suckling_{pcpa}) + (daily\ milk\ suckled\ by\ male\ calves\ x\ days\ male\ calves\ are\ suckling_{pcpa})$$

  where *daily milk suckled by female/male calves* is the daily milk intake, in litres, of female or male calves averaged over the suckling period; and

  where *days female calves are suckling*$_{pcpa}$ is the number of days that female calves are suckling (per cow per annum), calculated as:

  $$days\ female\ calves\ are\ suckling_{pcpa} = \left(NFC_{born,pcpa} - \left(0.5\ x\ NFC_{pre-weaning\ mortality,pcpa}\right)\right)\ x\ (months\ birth\ to\ weaning\ x\ 30.42)$$

- where *NFC*$_{pre-weaning\ mortality,pcpa}$ is the number of female calves lost to pre-weaning mortality (per cow per annum), calculated as:

  $$NFC_{pre-weaning\ mortality,pcpa} = NFC_{born,pcpa}\ x\ M_{female\ calf} x\ (\frac{months\ birth\ to\ weaning}{12})$$

- where the term '$x\ (\frac{months\ birth\ to\ weaning}{12})$' accounts for the weaning period comprising part of the year,
- where the 0.5 in the term '$(0.5\ xNFC_{pre-weaning\ mortality,pcpa})$' accounts for the pre-weaning mortalities occurring uniformly over the time of the pre-weaning period,
- where *milk sale price* is the sale price of milk per litre (also applied to milk consumed in the home, given away etc.).
- where *months birth to weaning* is the number of months between birth and weaning (i.e. the calf suckling period), and 30.42 is the average number of days per month.
- where days *male calves are suckling*$_{pcpa}$ is the number of days that male calves are suckling (per cow per annum), calculated as:

$$days\ male\ calves\ are\ suckling_{pcpa} = \left(NMC_{born,pcpa} - \left(0.5\ x\ NMC_{pre-weaning\ mortality,pcpa}\right) - \left(0.5\ x\ NMC_{pre-weaning\ sales,pcpa}\right)\right)\ x\ (months\ birth\ to\ weaning\ x\ 30.42)$$

- which is analogous to *days female calves are suckling*$_{pcpa}$ except for males instead of females, but with the additional term '$(0.5\ x\ NMC_{pre-weaning\ sales,pcpa})$'
- where $NMC_{pre-weaning\ sales,pcpa}$ is the number of calves lost to pre-weaning sales (per cow per annum), calculated as:

$$NMC_{pre-weaning\ sales,pcpa} = NMC_{sold,pcpa}\ x\ \left(\frac{months\ birth\ to\ weaning}{12}\right)$$

- where $NMC_{sold,pcpa}$ is the number of male animals sold as calves (per cow per annum) explained in further detail below and where the term '$x\ \left(\frac{months\ birth\ to\ weaning}{12}\right)$' accounts for the weaning period comprising part of the year
- where the 0.5 used in the term '$(0.5\ x\ NMC_{pre-weaning\ sales,pcpa})$' accounts for the pre-weaning sales occurring uniformly over the time of the pre-weaning period
- where *milk sale price* is the sale price of milk per litre (also applied to milk consumed in the home, given away etc.).

where:

2. $R_{male\ calves,pcpa} = NMC_{sold,pcpa}\ x\ male\ calf\ sale\ price$

where

- $NMC_{sold,pcpa}$ is the number of male animals sold as calves (per cow per annum), calculated empirically for age class 0 such that the proportion sold for the age-groups (calf, young and mature) is as specified by the user, and taking into account animal exits via mortalities (see Table 1 for an example); and

Table 1. Example of empirical derivation of number of male animals sold. Based on number of animals born =1, mortality rate = 0.04, proportion sold as age class calf (0 years), young (1 and 2 years) and mature (3,4, and 5 years) = 0.1, 0.4, and 0.5, respectively

Age class	Number at start of year	Number lost to mortality	Number lost to sale	Proportion sold	Number at end of year after mortality and sale
0	1.0000	0.0400	0.0860	0.0999	0.8740
1	0.8740	0.0350	0.1710	0.3971	0.6680
2	0.6680	0.0267	0.1710		0.4703
3	0.4703	0.0188	0.1444		0.3071
4	0.3071	0.0123	0.1444	0.5030	0.1504
5	0.1504	0.0060	0.1444		0.0000
Total died		0.1388			
Total sold			0.8612		

- the *male calf sale price* is the sale price of a single male calf.

3. $R_{young\ females,pcpa} = NFY_{sold,pcpa}\ x\ young\ female\ sale\ price$

where:

- $NMY_{sold,pcpa}$ is the number of male animals sold as young (per cow per annum), calculated empirically for age classes 1 and 2 such that the proportion sold for the age-groups (calf, young and mature) is as specified by the user, and taking into account animal exits via mortalities (see Table 1 for an example); and
- the *young male sale price* is the sale price of a single young male.

4. $R_{mature\ male,pcpa} = NMM_{sold,pcpa}\ x\ mature\ male\ sale\ price$

where:

- $NMY_{sold,pcpa}$ is the number of male animals sold mature (per cow per annum), calculated empirically for age classes 3 onwards (until last male sale age) such that the proportion sold for the age-groups (calf, young and mature) is as specified by the user, and taking into account animal exits via mortalities (see Table 1 for an example); and
- the *mature male sale price* is the sale price of a single mature male.

5. $R_{cull\ for\ age\ purchased\ breeding\ bulls,pcpa} = \frac{cull\ for\ age\ bull\ sale\ price}{number\ years\ of\ bull\ use\ x\ number\ of\ cows\ in\ herd}$ only applied for the reproductive scenario where breeding bulls are purchased.

6. $R_{young\ females,pcpa} = NFY_{sold,pcpa}\ x\ young\ female\ sale\ price$

where:

- $NFY_{sold,pcpa}$ is the number of young female sold at the end of the young period (per cow per annum), calculated as:

  $NFY_{sold,pcpa} = NFC_{born,pcpa} x\ (1 - M_{female\ calves}) x\ (1 - M_{young\ females})^2 - NFC_{kept\ as\ breeders,pcpa}$

- where the term $(1 - M_{female\ calves}) x\ (1 - M_{young\ females})^2$, unts for loss of female animals due to mortalities over the calf period (of one year) and young period (of two years).
  where $NFC_{kept\ as\ breders,pcpa}$ is the number of female calves kept as replacement breeders (per cow per annum) calculated as:

  $$NFC_{kept\ as\ breeders,pcpa} = \frac{1}{productive\ lifetime\ of\ females}$$

  where the productive lifetime of females is calculated in years as:

  $$productive\ lifetime\ of\ female = \frac{age\ at\ female\ culling\ in\ months\ - age\ at\ first\ calving\ in\ months}{12}$$

- the *young female sale price* is the sale price of a single young female

7. $R_{cull\ for\ age\ females,pcpa} = NFM_{cull\ for\ age,pcpa}\ x\ cull\ for\ age\ cow\ sale\ price$

where:

- $NFM_{cull\ for\ age,pcpa}$ is the number of mature females (cows) culled for age (per cow per annum): the same as $NFC_{kept\ as\ breeders,pcpa}$
- the *cull for age cow sale price* is the sale price of a single cull for age cow.

Cost component calculations

1. $C_{health-care,pcpa} = C_{health-care,male\ calves,pcpa} + C_{health-care,young\ males,pcpa} + C_{health-care,mature\ males,pcpa} + C_{health-care,purchased\ bulls,pcpa} + C_{health-care,female\ calves,pcpa} + C_{health-care,young\ female,pcpa} + C_{health-care,mature\ females,pcpa}$

where:

- $C_{health-care,male\ calves,pcpa}$ is the cost of health care of male calves (per cow per annum), calculated as:

  $C_{health-care,male\ calves,pcpa} = NMC_{calf,pcpa}\ x\ male\ calf\ health-care\ cost$

  where $NMC_{calf,pcpa}$ is the average number of male calves (per cow per annum) over the calf time period of one year, calculated as:

  $NMC_{calf,pcpa} = NMC_{born,pcpa} - 0.5\ x\ NMC_{born,pcpa}\ x\ M_{male\ calves} - 0.5\ x\ NMC_{sold,pcpa}$

  where the 0.5 terms account for male calf mortalities and sales occurring uniformly over the year; and

  where the *male calf health-care cost* is the annual health-care cost for a single male calf.

- $C_{health-care,young\ males,pcpa}$ is the cost of health care of young males (per cow per annum), calculated as:

  $C_{health-care,young\ males,pcpa} = (NMY_{young\ 1,pcpa} + NMY_{young\ 2,pcpa})\ x\ young\ male\ health-care\ cost$

  where $NMY_{young\ 1,pcpa}$ is the average number of young males (per cow per annum) over the first year of the young time period (of two years), calculated as:

  $NMY_{young1,pcpa} = NMC_{sur,pcpa} - 0.5\ x\ NMC_{sur,pcpa.}\ x\ M_{young\ males} - 0.5\ x\ \frac{NYM_{sold,pcpa}}{2}$

  where $NMC_{sur.}$ is the number of male calves surviving the calf period to become young (per cow per annum), calculated as:

  $NMC_{sur,pcpa} = NMC_{born,pcpa} - NMC_{born,pcpa} * M_{male\ calf} - NMC_{sold,pcpa}$

  where the 0.5 terms account for young male mortalities and sales occurring uniformly over the year

- where $NMY_{young2,pcpa}$ is the average number of young males (per cow per annum) over the second year of the young time period (of two years), calculated as:

  where $NMY_{sur.young\ 1}$ is the number of young males surviving the first year of the young time period to enter the second year of the young time period (per cow per annum), calculated as:

  $NMY_{young2,pcpa} = NMC_{sur.young1,pcpa} - 0.5\ x\ NMC_{sur.young1,pcpa}\ x\ M_{young\ males} - 0.5\ x\ \frac{NYM_{sold,pcpa}}{2}$

  where the 0.5 terms account for male calf mortalities and sales occurring uniformly over the year

  where the *young male health-care cost* is the annual health-care cost for a single young male

- $C_{health-care,mature\ males,pcpa}$ is the cost of health care of mature males (per cow per annum), calculated analogous to the above (cost of health care of young males), but for mature males rather than young males, and for the number of years of the mature time period for male animals (i.e. the maximum age at sale–age at start of mature period, in years) rather than the number of years of the young time period.

- $C_{health-care,purchased\ bulls,pcpa}$ only applied for the reproductive scenario where breeding bulls are purchased, is the cost of health care of bulls purchased for breeding purposes (per cow per annum), calculated as:

$$C_{health-care,purchased\ bulls,pcpa} = \frac{mature\ male\ health-care\ cost}{number\ of\ cows\ in\ herd}$$

where *the mature male health-care cost* is the annual health-care cost for a single mature male.

- $C_{health-care,female\ calves,pcpa}$ is the cost of health care of female calves (per cow per annum), calculated as:

$$C_{health-care,female\ calves,pcpa} = NFC_{calf,pcpa}\ x\ female\ calf\ health-care\ cost$$

where $NFC_{calf,pcpa}$ is the average number of female calves (per cow per annum) over the calf time period of one year, calculated as:

$$NFC_{calf,pcpa} = NFC_{born,pcpa} - 0.5\ x\ NFC_{born,pcpa}\ x\ M_{female\ calves}$$

where the 0.5 term account for female calf mortalities occurring uniformly over the year
where the *female calf health-care cost* is the annual health-care cost for a single female calf.

- $C_{health-care,young\ females,pcpa}$ is the cost of health care of young females (per cow per annum), calculated as:

$$C_{health-care,young\ females,pcpa} = (NFY_{young\ 1,pcpa} + NFY_{young\ 2,pcpa})\ x\ young\ female\ health-care\ cost$$

where $NFY_{young\ 1,pcpa}$ is the average number of young females (per cow per annum) over the first year of the young time period (of two years), calculated as:

$$NFY_{young1,pcpa} = NFC_{sur.} - 0.5\ x\ NFC_{sur.}\ x\ M_{young\ females}$$

where $NFC_{sur.}$ is the number of female calves surviving the calf period to become young, calculated as:
where $NFY_{young2,pcpa}$ is the average number of young females over the second year of the young time period (of two years), calculated as:

$$NFY_{young2,pcpa} = NFC_{sur.young1} - 0.5\ x\ NFC_{sur.young1}\ x\ M_{young\ females}$$

where $NMY_{sur.young\ 1}$ is the number of young females surviving the first year of the young time period to enter the second year of the young time period, calculated as:

$$NFY_{sur.\ young1} = NFC_{sur} - NFC_{sur} * M_{young\ female}$$

where the *young female health-care cost* is the annual health-care cost for a single young female.

- $C_{health-care,mature\ female,pcpa}$ is the cost of health care of mature females per annum, calculated as:

$$C_{health-care,mature\ females,pcpa} = C_{health-care\ females\ 36\ months\ to\ AFC} + C_{health-care\ cow\ per\ annum}$$

where $C_{health-care\ females\ 36\ months\ to\ AFC}$ is the cost of health-care of female animals (kept as breeder replacements) from 36 months of age (the start of the mature period) to age at first calving calculated as:

$$C_{healht-care\ females\ 36\ months\ to\ AFC} = \frac{1}{productive\ lifetime\ of\ females} x \frac{months\ 36\ to\ AFC}{12} x\ mature\ female\ health-care\ cost$$

where *months 36 to AFC* is the number of months between 36 and age at first calving (AFC)
where *mature female health–care cost* is the annual health-care cost of a single mature female
where $C_{health-care\ cow\ per\ annum}$ is the cost of health-care of a cow (a female animal in her productive life) per annum, equal to *mature female health-care cost.*

2. $$C_{feed,pcpa} = C_{feed,male\ calves,pcpa} + C_{feed,young\ males,pcpa} + C_{feed,mature\ males,pcpa} + C_{feed,purchased\ bulls,pcpa} + C_{feed,female\ calves,pcpa} + C_{feed,young\ female,pcpa} + C_{feed,cows,pcpa}$$

where:

- $C_{feed,male\ calves,pcpa}$ is the cost of feed of male calves (per cow per annum), calculated as:

$$C_{feed,male\ calves,pcpa} = NMC_{calf,pcpa}\ x\ male\ calf\ \ feed\ cost + cost\ of\ milk\ suckled\ by\ male\ calves_{pcpa}$$

where the *male calf feed cost* is the annual feed cost for a single male calf
where the cost of milk suckled by male calves (per cow per annum) is calculated as:

$$cost\ of\ milk\ suckled\ by\ male\ calves_{pcpa} = \left(\ daily\ milk\ suckled\ by\ male\ calves\ x\ \ days\ male\ calves\ are\ suckling_{pcpa}\right)\ x\ milk\ sale\ price$$

- $C_{feed,young\ males,pcpa}$ is the cost of feed of young males (per cow per annum), calculated as:
  $C_{feed,young\ males,pcpa} = (NMY_{young\ 1,pcpa} + NMY_{young\ 2,pcpa})\ \ x\ young\ male\ feed\ cost$

  where the *young male feed cost* is the annual feed cost for a single young male.

- $C_{feed,mature\ males,pcpa}$ is the cost of feed of mature males (per cow per annum), calculated analogous to the above (cost of feed of young males), but for mature males rather than young males, and the mature male time period (calculated as the maximum sale age of mature males less 36 months) rather than the young time period.

- $C_{feed,purchased\ bulls,pcpa}$ only applied for the reproductive scenario where breeding bulls are purchased , is the cost of feed of bulls purchased for breeding purposes (per cow per annum), calculated as:
  $$C_{feed,purchased\ bulls,pcpa} = \frac{mature\ male\ feed\ cost}{number\ of\ cows\ in\ herd}$$
  where *the mature male feed cost* is the annual feed cost for a single mature male.

- $C_{feed,female\ calves,pcpa}$ is the cost of feed of female calves (per cow per annum), calculated as:

  $$C_{feed,female\ calves,pcpa} = NFC_{calf,pcpa}\ x\ female\ calf\ \ feed\ cost + cost\ of\ milk\ suckled\ by\ female\ calves_{pcpa}$$

  where the *female calf feed cost* is the annual feed cost for a single female calf
  where the cost of milk suckled by female calves (per cow per annum) is calculated as:
  $$cost\ of\ milk\ suckled\ by\ female\ calves_{pcpa} = \left(daily\ milk\ suckled\ by\ female\ calves\ x\ \ days\ female\ calves\ are\ suckling_{pcpa}\right)\ x\ milk\ sale\ price$$
  $C_{feed,young\ females,pcpa}$ is the cost of feed of young females (per cow per annum), calculated as:

  $$C_{feed,young\ females,pcpa} = ((NFY_{young\ 1,pcpa} + NFY_{young\ 2,pcpa} - NFC_{kept\ as\ breeders,pcpa})\ x\ young\ non-replacement\ female\ feed\ cost) + (NFC_{kept\ as\ breeders,pcpa}\ x\ 2\ x\ young\ replacement\ female\ feed\ cost)$$

  where the *young non-replacement female feed cost* is the annual feed cost for a single young female (not pregnant), where the 2 in the term
  '$NFC_{kept\ as\ breeders,pcpa}\ x\ 2\ x\ young\ replacement\ female\ feed\ cost$' accounts for replacement calves for breeders passing through both the first and second year of the young period,

  where the *young replacement female feed cost* is the feed cost for a single young female that may be pregnant for part of this period (dependent on the age of first calving).

- $C_{feed,mature\ females,pcpa}$ is the cost of feed of mature females per annum, calculated as:
  $$C_{feede,mature\ females,pcpa} = C_{feed\ females\ 36\ months\ to\ AFC} + C_{feed\ per\ cow\ per\ annum}$$
  where $C_{feed\ females\ 36\ months\ to\ AFC}$ is the cost of feed of female animals (kept as breeder replacements) from 36 months of age (the start of the mature period) to age at first calving calculated as:
  where *months 36 to AFC* is the number of months between 36 and age at first calving (AFC),
  where *mature female feed cost* is the annual feed cost of a single mature female (taking into account pregnancy and lactation status),
  $$C_{feed\ females\ 36\ months\ to\ AFC} = \frac{1}{productive\ lifetime\ of\ females}\ x\ \frac{months\ 36\ to\ AFC}{12}\ x\ mature\ female\ feed\ cost$$
  where $C_{health-care\ cow\ per\ annum}$ is the cost of feed a cow (a female animal in her productive life) per annum, equal to *mature female feed cost.*

3. $C_{water,pcpa} = \frac{annual\ cost\ of\ water\ per\ herd}{number\ of\ cows\ in\ herd}$ where the *annual cost of water per herd* includes all costs associated with water (e.g. annual depreciation cost of water equipment; annual access fees to water).

4. $C_{animal\ housing,pcpa} = \frac{annual\ cost\ of\ animal\ housing\ per\ herd}{number\ cows\ in\ herd}$ where the *annual cost of animal housing per herd* includes all costs associated with animal housing (e.g. the annual depreciation cost of the building/structure/fence; annual maintenance costs).

5. $C_{labour,pcpa} = \frac{annual\ cost\ of\ labour\ per\ herd}{number\ cows\ in\ herd}$ where the *annual cost of labour per herd* includes all costs associated with labour (e.g. hired labour, family labour).

6. $C_{female\ reproduction,pcpa} = 0$ if natural mating is used.
$C_{female\ reproduction,pcpa} = \frac{cost\ of\ AI}{calving\ interval} + \frac{cost\ of\ AI}{productive\ lifetime\ of\ females}$ if artificial insemination is used

where:

- the *cost of AI* is the cost of artificial insemination per cow per pregnancy, inclusive of all associated costs (hormones, semen, payment to the service provider etc.);
- the term '*cost of AI/calving interval*' is the reproductive cost of a cow per annum; and
- the term '*cost of AI/productive lifetime of females*' accounts for the reproductive cost of heifers.

7. $C_{purchased\ breeding\ bulls,pcpa} = \frac{breeding\ bull\ purchase\ price}{number\ years\ of\ bull\ use\ x\ number\ of\ cows\ in\ herd}$, only applied for the reproductive scenario where breeding bulls are purchased and where the breeding bull purchase price is inclusive of the buying price and any other costs involved in acquiring the bull.

8. $$C_{marketing\ and\ transport,pcpa} = \begin{array}{c}(C_{mt,milk\ per\ litre}\ x\ litres\ milk\ sold_{pcpa}) + \\ (C_{mt,female\ calf\ sale}\ x\ NFC_{sold,pcpa}) + (C_{mt,male\ calf\ sale}\ x\ NMC_{sold,pcpa}) + \\ (C_{mt,young\ female\ sale}\ x\ NFY_{sold,pcpa}) + (C_{mt,young\ male\ sale}\ x\ NMY_{sold,pcpa}) + \\ (C_{mt,cull\ for\ age\ cow\ sale}\ x\ NFM_{sold,pcpa}) + (C_{mt,mature\ male\ sale}\ x\ NMM_{sold,pcpa}) + \\ (C_{mt,purchased\ breedine\ bull}\ x\ N_{purchased\ breeding\ bulls\ sold,pcpa})\end{array}$$

where:

- C_{mt} is the cost of marketing and transport for the various products indicated; and
- $N_{purchased\ breeding\ bulls\ sold,pcpa}$ is the number of purchased breed bulls sold (per cow per annum) and applies only if purchased breeding bulls are used.

Figure 1. Overall schema of the model (for the reproductive scenario of breeding bulls used for free)

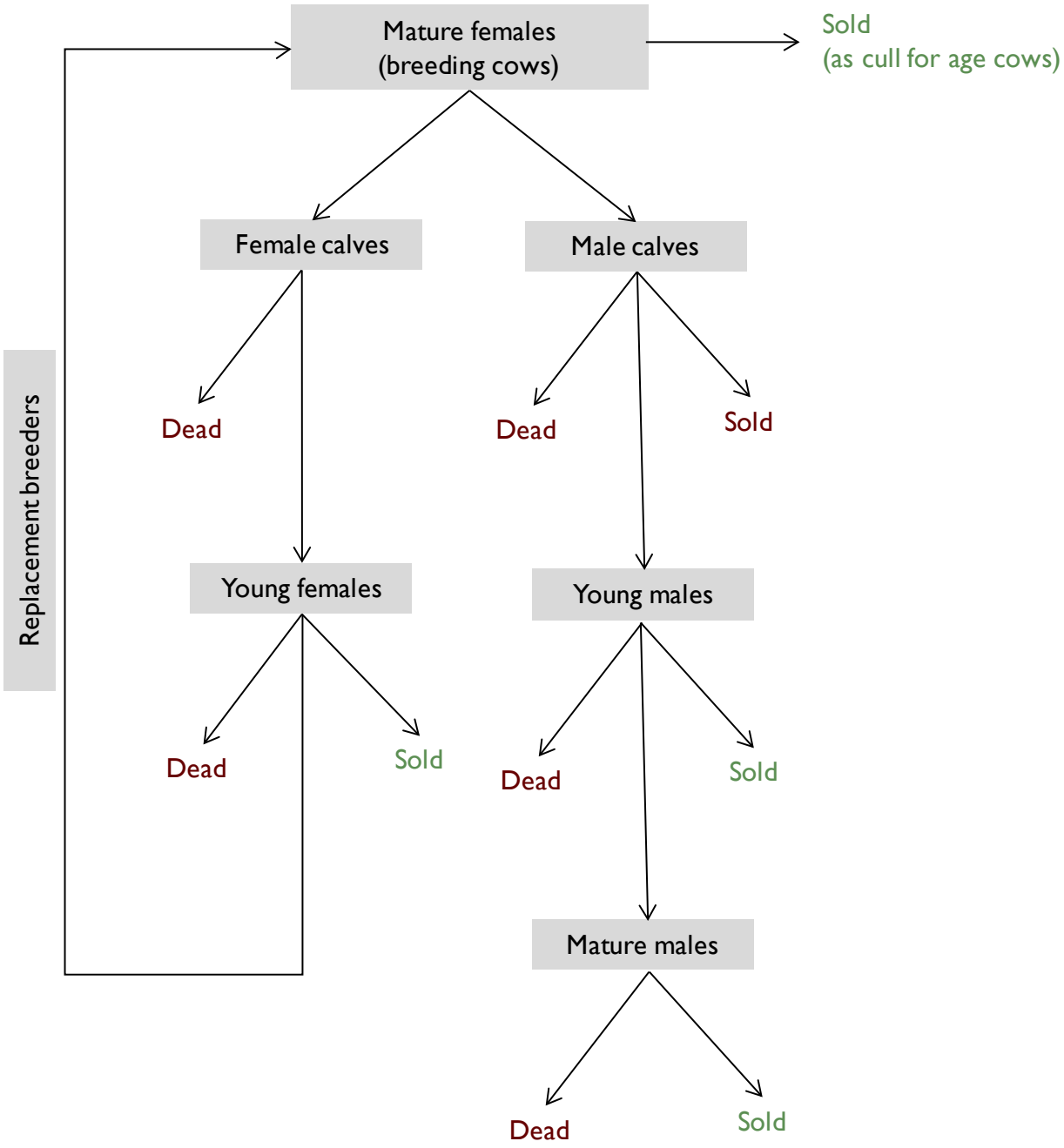
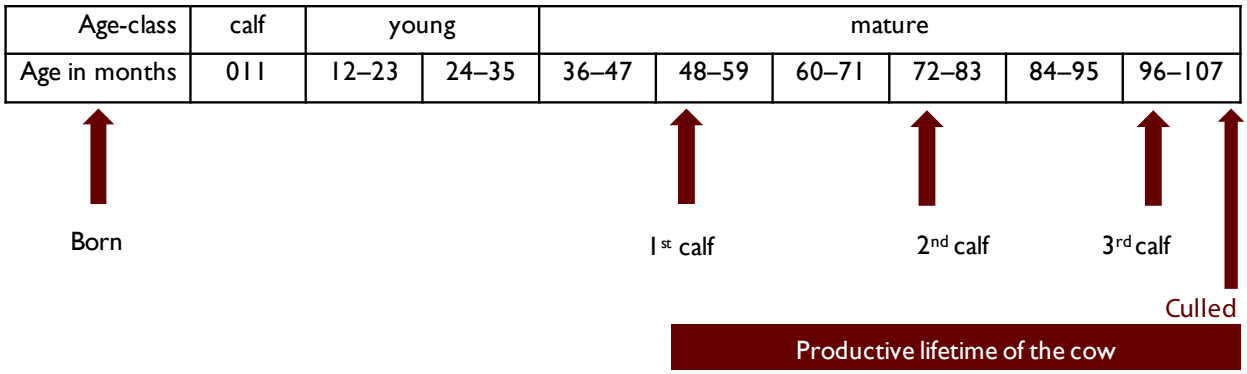


Figure 2. Example lifecycle of a cow retained as a breeding animal, and with age at first calving at 48 months, age at culling at 108 months, and a calving interval of 2 years. The productive lifetime of the cow is highlighted. The model calculates revenue and costs for an average year of the productive lifetime of the cow.



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