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iSAGE Innovation for Sustainable Sheep and Goat Production in Europe

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New holistic model that can be used to redesign terrestrial small ruminant's livestock systems

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Table 1 – Key information

Country	**Spain**
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Abstract

A framework integrating a whole-farm mathematical simulation model and a linear programming model for sheep and goat farms has been developed. The new framework allows simulating how changes aimed at optimising one farm component (e.g. genetics at the animal level) can impact on sustainability issues in other components and the overall system (e.g. GHG, labour requirements, profit). This deliverable is used to describe the development of the whole framework and provides details of how each model operates. The main relationships amongst components of the farm system are also explained in detail. This modelling framework mostly incorporates new information and functions specific to small ruminant farming systems and uses some of the main principles of successful existing approaches. Also, the model incorporates some of the information that has been analysed in other WPS (e.g. WP3: modelling heat stress effect on animals). In order to parameterise the model there has been a rigorous collection of information from both literature and from consultation to the iSAGE industry partners**.** Due to the diversity of small ruminants farming systems, there is still an ongoing effort to try to parameterize the largest combinations comprising farm typologies, animal breeds, agro-climatic regions and countries. The practicality of the framework will be demonstrated and evaluated for the scenario testing in order to analyse potential future trajectories of typical European farms towards improving the sustainability of small ruminants farming systems considering the future challenges (e.g. climate change, price shocks) and current or theoretical opportunities (e.g. innovations).

Contents

1 Terminology and Symbols used

a = constant for NE_g calculation

AET = actual evapotranspiration, mm

ASH = the ash content of feed calculated as a fraction of the dry matter feed intake (fraction)

b= constant for NE_g calculation

B_0 = maximum CH_4 producing capacity, m^3 kg VS^{-1}

BW_i = the live bodyweight at weaning, kg

BW_f = the live bodyweight at 1-year old or at slaughter (live-weight) if slaughtered prior to 1 year of age, kg

BF_{milk} = fat content in milk, %

C_a = coefficient corresponding to animal's feeding situation, MJ day^{-1} kg^{-1}

Cf_i = a coefficient which varies for each animal category, MJ day^{-1} kg^{-1}

$C_{pregnancy}$ = pregnancy coefficient for $NE_{pregnancy}$ calculation

$days_{lact}$ =days of lactation, days

DE = digestibility of the feed (% of GE)

DMD = digestibility of the feed (% of DM)

DUP, [DUP] = digestible undegraded protein, g day^{-1}, g kg DM^{-1}

ERPD= Effective rumen degradable protein

ETc = potential evapotranspiration, mm

ETo = reference crop evapotranspiration, mm

EV_{milk} = the net energy required to produce 1 kg of milk.

EV_{wool} = the energy value of each kg of wool produced (weighed after drying but before scouring), MJ kg^{-1}.

FME, [FME] = fermentable ME of a diet, MJ/d or MJ/kg DM in a feed

GE = gross energy intake, MJ day^{-1}

$k_{c=}$ Efficiency for growth of the concepta

k_l =Efficiency for lactation

k_m = Efficiency for maintenance

KMCF_Factor = CH_4 emission potential of liquid manure

k_f = Efficiency for growth (during growth)

k_g = Efficiency for growth (during lactation)

k_t= Efficiency for utilisation of mobilised body tissue for lactation

LEVEL= level of feeding (e.g. maintenance=1)

MCP, [MCP] = microbial crude protein supply, g day^{-1} or g kg DM^{-1}

Milk = amount of milk produced, kg of milk day^{-1}

MP=metabolizable protein, kg day^{-1}

ME = metabolisable energy, MJ day^{-1}

MP_c =MP requirements for pregnancy, kg day^{-1}

MP_f =MP requirements for liveweight gain, kg day^{-1}

MP_g =MP for liveweight change in lactating animals, kg day^{-1}

MP_l =MP requirements for lactation, kg day^{-1}

MP_m =MP requirements for maintenance, kg day^{-1}

NDF = neutral detergent fiber

NE_m = net energy required by the animal for maintenance, MJ day^{-1}

NE_a = net energy for animal activity, MJ day^{-1}

NE_g = net energy needed for growth, MJ day^{-1}

NE_L = net energy for lactation, MJ day^{-1}

$NE_{pregnancy}$= net energy required for pregnancy, MJ day^{-1}

NE_{wool} = net energy required to produce wool, MJ day^{-1}

$Production_{wool}$ = annual wool production per sheep/goat, kg yr^{-1}

QDP, [QDP] = quickly degradable protein, g day^{-1}, g kg DM^{-1}

q_m = metabolisability of the GE of the feed at maintenance level

SDP, [SDP] = slowly degradable protein, g day^{-1}, g kg DM^{-1}

TAW = water soil capacity, mm

W_l = lamb birthweight, kg

W_0= total weights of lambs at birth, kg

VS_{LOAD} = volatile solid excretion per day on a dry-organic matter basis, kg VS day^{-1}

Weight = live-weight of animal, kg

$WG_{lamb/kids}$ = the weight gain (BWf – BWi), kg yr^{-1}

Y_m = methane conversion factor, % of GE

2 Rationale

There are already existing economic and market signals that forecast both substantial challenges but also opportunities for the small ruminant production sector in Europe. The sector is faced with the need for a comprehensive 're-engineering' in order to meet market, animal welfare and environmental targets in the context of government policy for an internationally competitive industry. Innovation (currently and in the future) will have to play an important role to help small ruminants' farmers stay in business.

Thus, integral to the new policy context is a requirement to both sustain and enhance the rural environment whilst promoting and developing the rural economy. More sustainable systems, based on holistic farming principles that can be implemented in a cost-effective manner, are seen as the route towards sustainability.

In practice, however, the identification and implementation of holistic production systems require research to explore a wide range of alternatives, and to show how far the negative environmental impact of production can be reduced or eliminated without having a negative effect on the economic viability of the farm. This must carried out considering the current but also future challenges and opportunities (e.g. innovations). The use of simulation models is the only way possible to fully explore the economic, environmental and social performance of small ruminant production systems that it would be feasible to develop along evolutionary trajectories from our predominant systems currently operating. This is due to the extreme complexity of the biological, physical and chemical controls and their interactions on the ways dairy systems operate as well as the impacts of weather and the farmers' management of nutrient inputs, sward growth and stock feeding. Moreover, the diversity of small ruminant production systems requires a systemic approach. For this, there is a need to develop models that allow us to study new scenarios for small ruminants' systems in Europe towards more sustainable systems. Moreover, accounting for the numerous threats that the sector is facing (e.g. climate change…).

Therefore, this task was undertaken to specify new small ruminant production systems for operating under European conditions and to investigate the feasibility and likely impacts of their implementation.

Why is there a need for yet another modelling approach?

Whole farm models to study farm sustainability have been developed for livestock in many different forms. Most, however, have been developed for animals other than small ruminant systems (e.g. dairy cattle and pigs: GAMEDE: Vayssières eta al., 2009; SIMSDAIRY: Del Prado et al., 2011; MELODIE: Chardon et al., 2012, Özkan Gülzari et al., 2017; Dairy-CropSyst: Khalil et al., 2019) or/and cannot capture the interlinkages between all climate change dimensions or/and are too simplistic or/and do not include economics or/and do not have optimisation capabilities.

There is no single whole-farm modelling approach that comprises and integrates in a balanced way all of the ideal elements that define a sustainable farm under climate change conditions. Moreover; all approaches have a certain bias towards more complex representation of specific elements. Some integrated modelling approaches have been developed that consider both biophysical and socio-economic approaches (e.g. Janssen and van Ittersum, 2007; Mosnier et al., 2017; Wall et al., 2018). However, they generally lack process-based mechanisms and thereby, lack sensitivity to major factors that affect sustainability and show a partial reflection of the complex chain of causes and effects and they lack of ways to simulate the introduction of future plants or animal types.

The topic of exiting whole-farm models for studying climate change mitigation and adaptation in temperate grassland ruminant-based farming systems was thoroughly analysed in a recent review paper by Del Prado et al. (2013), which complemented existing reviews (Schils et al., 2007; Crosson et al., 2011; Denef et al.,2012; Van Wijk et al.,2012) by analysing (i) the limitations and strengths of different approaches for modelling farm-scale GHG mitigation and (ii) identifying potential challenges for linking existing models with the simulation of impacts and adaptation measures under climate change scenarios and impacts on other ecosystem services. Predictive tools and models to estimate GHG emissions from livestock systems have been developed in the form of process-based simulation (e.g. Schils et al., 2007), emission factor calculation (Amani and Schiefer, 2011) and LCA-based approaches (e.g. Cowie et al., 2012). In contrast to the emission factor and LCA approaches, simulation farm models attempt to represent the flows and transformation of carbon (C) and nitrogen (N) using mechanistic processes and thus, predict resulting losses and GHG emissions.

Farm models have been developed and applied worldwide to quantify GHG emissions and test GHG mitigation strategies (see aforementioned existing reviews) or analyse adaptation/climate change impacts in isolation (Rivington et al., 2007; Martin, 2015, Martin and Magne, 2015) and few, none to our knowledge on small ruminant farming systems except for Bell et al. (2012), have also been used for simulating livestock production and GHG emissions under climate change scenarios (Del Prado et al., 2009; Moran et al., 2009; Cullen and Eckard 2011; Graux et al., 2012, 2013) that can represent a limited number of adaptation measures. A very limited number of farm-scale models also consider other ecosystem services in addition to GHG mitigation too.

Some models have a sophisticated approach to simulate the small ruminants herd dynamics (e.g. Pulina et al., 1999; Tedeschi et al., 2005; Guimarães et al., 2009; Tedeschi et al., 2011; Amole et al., 2017; Villalba et al., 2019), nutrition and feed allocation dynamics (e.g. Bohan et al., 2016; Cannas et al., 2019), are fully comprehensive to simulate overall sustainability of a dairy farm (e.g. Van Calker et al. 2004), pastures dynamics (e.g. Richardson et al., 2007; Bryant et al., 2008; Gregorini et al., 2013; Oniki et al., 2018) or policy strategies (Matthews et al., 2006; Ciaian et al., 2018; Reidsma et al., 2018), however, they are too simplistic to simulate environmental losses from the plant-animal-soil interactions.

Moreover, many farm modelling approaches are very limited in modelling the interactions between monthly weather conditions, soil texture, fertilisation and grazing management and their effect on GHG emissions (e.g. Wheeler et al., 2013, Olesen et al., 2006; Schils et al., 2007; Vayssières et al., 2009). As it was achieved in $SIMS_{DAIRY}$ (e.g. del Prado et al., 2010), our new iSAGE $SIMS_{SR}$ model approach simulates processes for most of the soil-plant and animal mechanisms that control environmental N losses and animal productivity. For example, emissions of N_2O and NO_x and NO_3^- leaching are simulated through the competition of soil NO_3^- and NH_4^+ between the biological processes of plant uptake, denitrification, nitrification and mineralisation and the physical process of solute leaching.

Optimisation is a key capability for finding optimal solutions in a solution space as complex and vast as it is characteristic for multi-effect problems needs faster approaches. For example, the existing SIMS$_{DAIRY}$ optimisation is carried out through a simple iterative approach (Del Prado et al., 2011) and its main limitation is the computational speed. Other methods such as linear programming (e.g. LP: Hengsdijk and Van Ittersum, 2003) or multi-agent system (MAS: Becu et al., 2004) allow both assessment of sustainability and optimisation at the level of farming systems. These methods are restricted in their number of objectives, between 5 and 8 (Payraudeau and Van der Werf, 2005).

Water footprinting and other environmental risks due to pesticides or pathogens are out of the scope of this project but could potentially be incorporated in the future in a simple way using indicators for example (e.g. for pesticides: Pacini et al. 2004) or existing tools (e.g. water footprinting: Toro-Mújica et al., 2016) or pathogens: Oliver et al., 2009).

Lastly, as in SIMS$_{DAIRY}$ (Del Prado et al., 2011), it is interesting that the new modelling approach has a modular construction, with each module carrying out calculations at different farm levels. Other approaches also integrate partial existing models for the animal, nutrient flows and economics (e.g. Beukes et al., 2010), but there is still a challenge in how to integrate partial models into a coherent global whole-farm model (Vayssières et al., 2009).

3 General methodology of the modelling framework

3.1 Framework overview

The framework integrates 2 models: a whole-farm mathematical simulation model ($SIMS_{SR}$) and a linear programming model (iSAGE LP model). Both models operate at farm scale and their complementary results are relevant at the farm typology level. The whole framework ($SIMS_{SR}$+iSAGE LP model) operates separately using the characteristics of a virtual farm representing a particular farm typology and including the main typical features of a farm in a particular context (e.g. defined by region, animal breed, feeding, reproduction management, land use…).

The new $SIMS_{SR}$ model whole-farm model´s structure is flexible and versatile so that it can simulate farms from the typologies in WP1 representing different production systems in Europe and breeds. The $SIMS_{SR}$ model can simulate the main interactions between the animal, management, prices and local conditions (including climate-driven responses from WP3) at the farming systems level. The structure of the new model integrates equations/meta-models from different work packages (e.g. WP3).

The iSAGE LP model uses using linear programming to optimise the annual operations of a sheep or goat farming system throughout the year using an economic-based objective to maximise gross margin and using different management and land use constraints.

3.2 Calculations within the modelling framework

The first step of the modelling framework operations is the definition of a sheep or goat production system comprising information about the herd structure, production and reproduction objectives per animal type, land uses (e.g. available field types, soil types…) and management of the farm at different levels (e.g. animal, feeding, land use, manure) and weather conditions. The $SIMS_{SR}$ calculates energy and protein requirements for a given herd structure and potential grassland and crops yields on a per ha basis. Using this information as input the iSAGE LP model optimises management for maximising gross margin. The following iteration the $SIMS_{SR}$ model will use selected management inputs (e.g. number of adult animals) optimised by the iSAGE LP model and will simulate monthly the farm in terms of N and C emissions under the selected farm strategy.

On the following sections we explain how both the SIM_{SR} and the iSAGE LP model work.

3.3 Description of $SIMS_{SR}$

In order to explore strategic management options for the dairy farming systems, flexible, robust and yet simple (i.e. with easily available user-inputs) tools are needed. Simulation models with a systems approach can fulfil this role as they can study the interactions between the key variables and processes in a holistic way.

Sustainable and Integrated Management Systems for Small Ruminants production systems ($SIMS_{SR}$) is a new model to study small ruminants' sustainability. Its development is inspired on the existing modelling framework for dairy cattle systems ($SIMS_{DAIRY}$: Del Prado et al., 2011, DEFRA, 2009). $SIMS_{SR}$ simulates the interactions between flock and land management and characteristics, climate and genetic traits (both from animals and plants) and their effect on:

i. Farm environmental performance (losses of N and C in the soil-plant-animal system of a sheep/goat farming system)
ii. Basic economics
iii. Qualitative attributes of sustainability (biodiversity, landscape aesthetics, food quality for human health and product saleability, soil quality and animal welfare).

$SIMS_{SR}$ main objective is to be able to simulate current and future farming scenarios for sustainability assessment.

The new whole-farm model´s structure is flexible and versatile so that it can simulate farms from the typologies in WP1 representing different production systems in Europe and breeds. The model can simulate the main interactions between the animal, management and local conditions (including climate-driven responses from WP3) at the farming systems level. The structure of the new model integrate equations/meta-models from different work packages (e.g. WP3).

In order to develop the new whole-farm model we have both used principles from existing models and new specific information from existing literature on sheep and goat production systems in Europe. The modelling approach has a system-based principle by which changes in the system that are simulated in one component of the farm will influence across the whole farm. It integrates multiple farm aspects and functional units from different disciplines into a systems approach aiming at capturing the key factors and key processes that affect dairy farm sustainability. This allow us to simulate how changes in the system that benefit one farm component (e.g. genetics at the animal level) can affect sustainability issues in other components and the overall system (e.g. GHG, water availability, animal welfare, labour requirements, profit).

$SIMS_{SR}$ is a whole farm scale modelling research tool for strategic studies to advance fundamental understanding of how small ruminant production systems can become more sustainable/or not as a reaction of potential environmental and economic challenges and opportunities. $SIMS_{SR}$ includes submodels with different characteristics (e.g. weekly, monthly and seasonal time steps).

The effect of management practices on N, P and CH_4 losses are predicted within different components and through different processes in the soil-plant-animal system using a monthly time-step and applying the principle of mass conservation. These practices can be defined in terms of management for instance of: (i) manure (i.e. straw or slurry-based system, storage type, application method, incorporation time and technique, timing of application, rate, manure dry matter (DM) g/kg content and spatial distribution), (ii) mineral fertiliser (e.g. rate, type and spatial distribution), (iii) animal (i.e. milk target/cow, fat content target in milk, protein content target in milk, calving month, grazing time, diet profile, animal breeds) and (iv) forage area (i.e. spatial distribution, sward age, history, tillage, plant varieties).

$SIMS_{SR}$ sensitivity applies not only to management but also to climate (specific models at the herd and land level where we can simulate the effect of climate change and exercise potential adaptation measures at different levels).

$SIMS_{SR}$, as its predecessors, has a modular construction, with each module carrying out calculations at different farm levels. These modules are either modifications of existing models or new developments.

The whole framework operates automatically and has been coded into a program compiled with Delphi 2009. Graphs in the section have been produced in Microsoft EXCEL.

$SIMS_{SR}$ is divided into different compartments. Each compartment handles imports, exports and its own operations. The compartments communicate through flows of mass (e.g. nitrogen) and energy.

Figure 1 gives a schematic representation of the structure of WP4-farm model and the order of calculations. This can be summarised in 12 steps):

(1) User inputs: the program starts by entering all the relevant user-defined inputs that describe a dairy farm (e.g. herd structure, management, climate, soil type and genetic traits). The program also initializes parameters and link the main interactions among submodules.

(2) Animal calculations: prediction of DM intake per animal type and, nutrient and energy requirements for housing and grazing.

(3) $SIMS_{SR}$ simulates the soil water balance and productivity of forage and crop yields per ha (DM, protein, digestibility…) without manure application (1st iteration) and with calculated manure on the subsequent iterations. Soil N emissions and losses to waters via leaching/run-off are simulated. Emissions associated to fertiliser manufacturing are estimated.

(4) $SIMS_{SR}$ balances nutrients and energy requirements with feed availability (yields and hectares) Potential nutrient and energy misbalances are corrected by adjusting the concentrates characteristics (at energy and protein level). Emissions associated to concentrates production are estimated.

(5) Enteric CH_4 output is calculated for each animal type and herd group

(6) Excreted N, C and volatile solids (VS) is estimated. The model estimates manure produced during housing.

(7) Methane and N losses are calculated for the manure phases prior to application in the soil.

(8) Manure application is estimated per ha in each field area and the model goes back to step (3) unless a steady state between iterations is reached. Manure N content

(input to field areas) is affected by protein content of herbage and contributes to the productivity of land.

(9) the model makes a simple estimation of the amount of energy used on- farm and the emissions associated to them.

(10) the model calculates a simplified economic balance to estimate economic performance.

(11) Different sustainability attributes are scored through indices in relation to their contribution to farm sustainability.

(12) SIMSSR includes results in text files for different outputs.

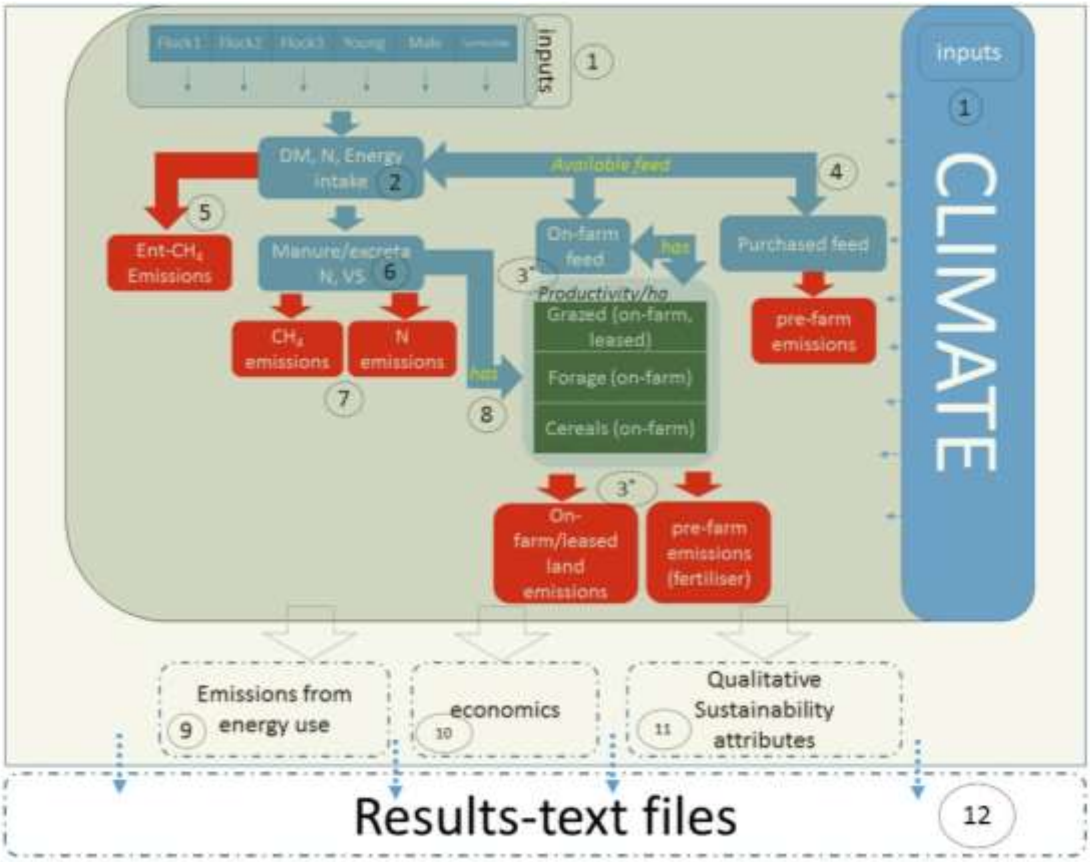


Figure 1. Diagram illustrating the main calculations in SIMSSR

SIMSSR uses default values already present in our database of breeds developed with the help of iSAGE industy partners (see section 3.3). This is an ongoing task across the duration of the project.

3.3.1 Animal and herd characteristics

The herd is described by some combination of six possible animal groups: 3 potential separate groups of adult females that simulates flocks of adult females that become pregnant, lactating and become dry at different times of the year; a group of replacement female animals; a group of male animals and a group of lambs/kids. The replacement group characteristics are assumed as one with weighted average of the characteristics. Each group assumes a representative animal for ration balancing and estimation. Nursing lambs and kids receive their diet from their mother's milk for a number of days after birth (this value is set upon breed and system information). The model user sets the initial number of groups, and main characteristics and values for a specific breed.

Animal characteristics are described as a function of breed and its specific context (e.g. Spanish laucane breed systems may differ from the French ones). On this version at this stage 20 and 6 breeds are predefined for sheep and goats, respectively: sheep: Assaf, Churra, Lacaune, Latxa, Manchega, Frizarta, Chios, Manech Red France, Awassi, Merino, Rasa Aragonesa, North Country Mule, Scotish Blackface, Welsh Mountain, Swaledale, Lleyn, Texel, Vendeems, Romane and BMC; goats: Murciano-granadina, Florida, Saanen, Alpine, Damascus and Hair Goat (Anatolian Black). Several more breeds are expected to be incorporated once data become available in subsequent future model versions.

The user can modify these characteristics or define another breed or crossbreed. The primary characteristics used to define a breed are: average milk yield, prolificity, fertility, number of birth/year, days of lactation, % fat, % protein, age of 1st birth, years of reproductive live, liveweight, wool produced, replacement rate… Typical values for these characteristics for the selected breeds have been obtained by either consultation with industry partners from the project or available public data. They have been collated for the different combinations of animal breeds, systems and regions in Europe. These values are listed in Tables 1- 6.

REPRODUCTIVE ANIMALS: EWES AND GOATS

Table 1. Input data for dairy sheep breeds.

		Assaf	Churra	Lacaune	Latxa	Manchega	Frizarta	Chios	Lacaune	Manech Red Face	Awassi
Country		Spain	Spain	Spain	Spain	Spain	Greece	Greece	France	France	Turkey
Prolificity	lambs alive/birth	1.8	1.38	1.65	1.27	1.5	1,6 ± 0,1	1.8-2.2	1.59	1.3	1
Fertility	%	96	96	96	96	96	>90	>90	94.4	90	87
Birth/year	nº/year	1.2	1.2	1	1	1.5	1	1	1	1	1
Lactation	days	180	120	150	140	150	190 ± 10	193 ± 35	170	165	162
Milk	litres	400	120	350	180	187.5	260 ± 30	308 ± 96	320	240	243
Fat	%	6.65	6.8	7.04	7.4	7.5	6.4	5-6	7.5	7.05	7.47
Protein	%	5.4	5.6	5.56	5.6	5.96	5.6	5.5	5.6	5.35	5.74
1st birth	month	15	15	14	19	17.6	13	9-10	13	14	15
Milking	number	6	5	6	3	7	6				6
Reproductive live	years	5	6		3.2		6	5-6	3.2	3.9	5
Liveweight	kg	65	50	70	50	70	65	58	75	50	50-55
Wool	kg	2.8	2	2.1	1.75	2	2	1.85	0.8	1.8	2.5
Replacement rate	%	25	20	25	20	20	25		28		25

Table 2. Input data for sheep meat breeds.

		Merino	Rasa Aragonesa	North Country Mule	Scotish Blackface	Welsh Mountain	Swaledale	Lleyn	Texel	Merino	Vendeens	Romane	BMC
Country		Spain	Spain	UK	UK	UK	UK	UK	UK	France	France	France	France
Prolificity	lambs alive/birth	1.4	1.33	1.8	1.35/1.5	1.25	1.35	1.85	1.65	1.2	1.75	1.8	1.5
Fertility	%	96	96	96	92	92	92	96	94	96	96	96	96
Birth/year	nº/year	1.5	1.5	1	1	1	1	1	1	0.9	1.04	1.01	1.27
Lactation	days	60	60										
1st birth	month	17	18	24	24/18	24	24	24	24	17	14	13	15
Reproductive live	years	12.5	6	4	4/6	4	4	4	4	6	5	5	5
Liveweight	kg	80	50	75	60/65	45	55	70	85	55	70	80	55
Wool	kg	3.4	1.8	3	2.5	2	2.5	3	3.5	1.5	2	2.5	1
Replacement rate	%	20	15	20	20	20	20	20	20	17	23	20	19

Table 3. Inputs data for goat breeds.

		Murciano-Granadina	Florida	Saanen	Alpine	Damascus	Hair Goat (Anatolian Black)
Country		Spain	Spain	France	France	Turkey	Turkey
Main production		Milk	Milk	Milk	Milk	Milk	Meat
Prolificity	kids/birth	1.8	1.8	1.8	1.8	1.8	1.8
Fertility	%	90	90	90	93	89	93
Birth/year	nº/year	1	1	0.8	1	1	1
Liveweight	kg	50	60	75	65	60	72.5
Milk production	litres	530	575	920	933	540	98.38
Milking	Days	250	247	300	310	270	183.43
Fat	%	5.6	4.8	3.68	3.8		3,98-5,21
Protein	%	3.6	3.4	3.36	3.4		3.76
Age 1st lambing	months		14	12	13	13	18
milking	number	6	7	3.2	4	7	5
Replacement rate	%	20	20	30	25	25	20

LAMBS AND KIDS

Table 4. Input data for lambs from dairy sheep systems.

		Assaf	**Churra**	**Lacaune**	**Latxa**	**Manchega**	**Frizarta**	**Chios**	**Lacaune**	**Manech Red Face**	**Awassi**
		Spain	Spain	Spain	Spain	Spain	Greece	Greece	France	France	Turkey
Born liveweight	kg	4	3.5	2.75	4	4.5	3.5	3.8	4	4	4.4
Liveweight gain	g/day	38	250		250	290	227	227	300	200	320
Mortality	%	10	10	10	10	10	10		10	10	10
Wean	n days	30	30	30	30	35	35	52	30	35	60
Sacrificie liveweight	kg	12	12	12	11	11.5	12	14.5	13	11	35
Feeding	type	milk	milk	milk	milk	milk	milk	milk	milk	milk	milk

Table 5. Input data for lambs from sheep meat systems.

		Merino	Rasa Aragonesa	North Country Mule	Scotish Blackface	Welsh Mountain	Swaledale	Lleyn	Texel	Merino	Vendeens	Romane	BMC
		Spain	Spain	UK	UK	UK	UK	UK	UK	France	France	France	France
Born weight	kg	4	4	4	3.45	3.5	3.5	4	4.5	4	4	4	4
Weight gain	g/day	300	220	250	175	180	180	250	320	242	329	330	267
Mortality	%		9	12	12	12	12	12	12	10	15	16	11
Sacrificie	months	2.5	3	4.3	5.3	5.3	5.3	4.3	3.3	4.0	3.7	3.3	4.0
Feeding	type	G + C	G + C	G	G	G	G	G	G	M +FMF	M +FMF	M +FMF	M +FMF
Sacrificie weight	kg	25	22	38	36/40	36	36	38	40	34.5	38.5	37	36
Carcass weight	kg									16.5	18.5	17.8	17.3
Carcass efficienvy	%	49	48							0.48	0.48	0.48	0.48

G: Grazing; G + C: Grazing + Concentrates ; M +FMF: Milk and farm mix feed

Table 6. Input data for kids from goat systems.

		Murciano-Granadina	**Florida**	**Saanen**	**Alpine**	**Damascus**	**Hair Goat (Anatolian Black)**
		Spain	Spain	France	France	Turkey	Turkey
Born weight	kg	3.08	3.5	4	4	3.8	2.94
Liveweight gain	g/day	166	180	240	240	201	161
Mortality	%	10	10	10	10	10	6
sacrifice	Month	1	1	1	1	5	5
Carcass weight	kg	5	4.8	5.6	5.6	35	11.84
Carcass efficiency	%	65	60	56	56	55	45.83

.3.3.1.1 *Calendar according to reproduction strategy and simplification of the herd structure and dynamics*

Different interpretation of calendar flock management, explanations on how we define batches and different categories of animals.

We have distinguished four different type of farms due to its productivity orientation and its small ruminant specie.

1. Dairy sheep systems.
2. Meat sheep systems.
3. Dairy goat systems.
4. Meat goat systems.

There are a set of variables, which will change within farms, within breeds, or could be useful to draw strategies of sustainable innovation as an output of the model developed.

Flocks are divided in: batches of reproductive sheep or goats (sometimes will be just one, two or three, depending mainly in the number of birth periods in the farm); the groups of rams; the group of replacement and the group of lambs. In milking systems, lambs do not usually spend more than 30 days in the farms, in meat production systems, the groups of lambs could be in the farm until 160 days as in the case of some UK systems.

Some aspects affect the reproductive design of the farms: the availability of grassland resources, the variability of milk and lamb/kids prices in the market and the level of intensification of the farms. Traditionally farms have been following a 1:1 reproductive strategy; following the natural cycle of ewes or goat reproduction with means 1 birth per year. Although this strategy still on small ruminant systems; the intensification of the systems have been modified this strategy to 3:2; 4:3 and 5:3 systems, mainly in sheep farms. 3:2 means three births in 2 years; 4:3 four births in 3 years and 5:3 5 births in 3 years. In the case of goat systems, the reproductive strategy is generally 1:1, with the separation of the flock in several groups in order to get milk around all the year with a greater number of birth periods.

The following four figures (Fig 2-5) illustrate the general dynamic of the farm that have been design as a start point of the development of the model and the input data necessary.

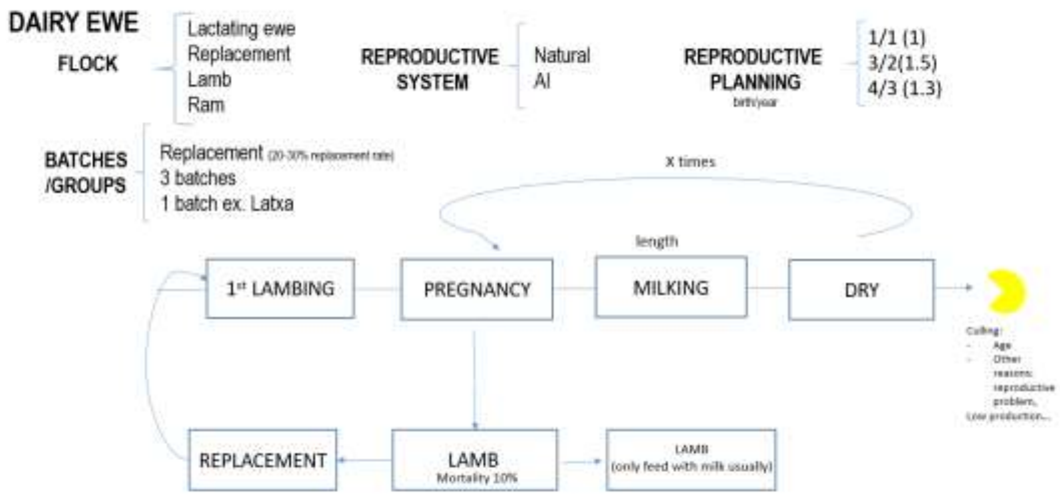


Figure 2. Dairy sheep systems defined for the model

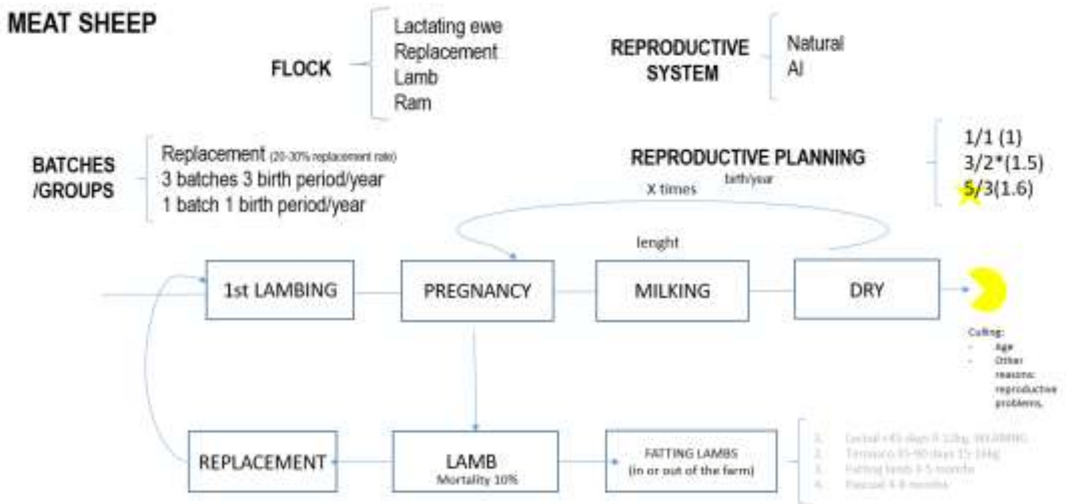


Figure 3. Meet sheep systems defined for the model

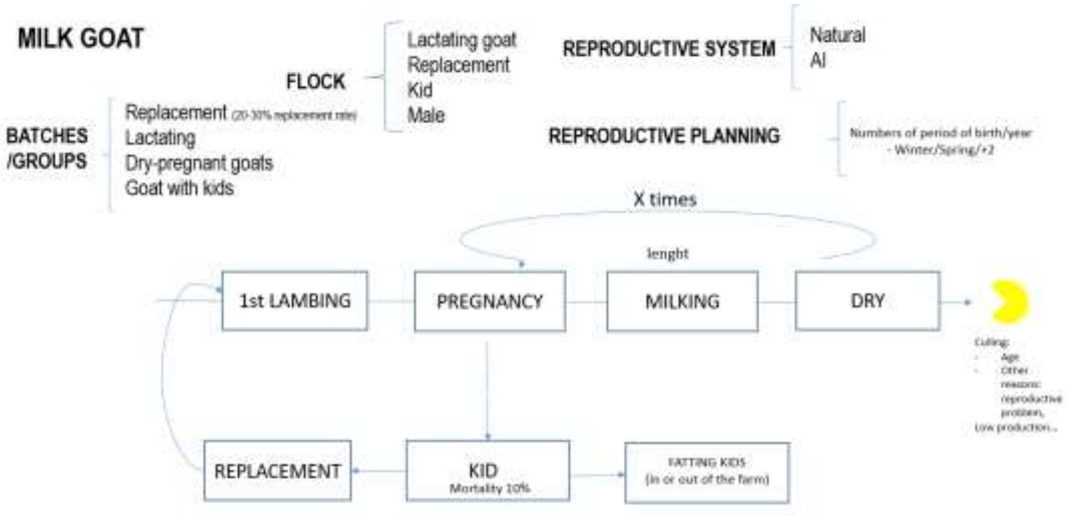


Figure 4. Dairy Goat systems defined for the model

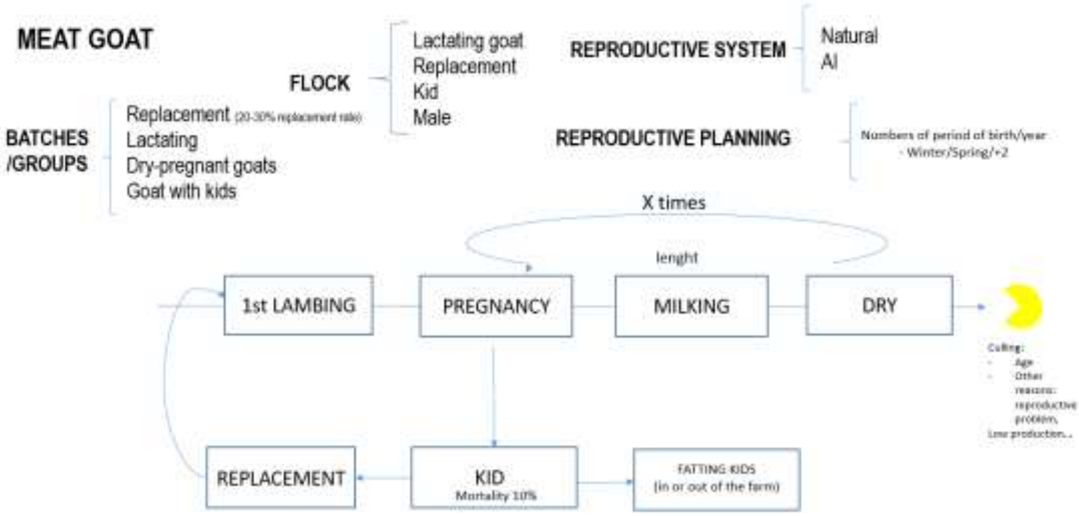


Figure 5. Goat meat systems

CALENDARS

Farm calendar is defined by some variables, especially for reproductive planning, number of lambing/kidding groups (if necessary) and the duration of the milking period.

In a 1:1 system the mating and birth period are likely to depend on the grazing resources, trying to adapt the maximum of grazing resources to maximum flock requirements, or in some cases just depend to the natural period of mating of the ewes or does. When the size of the flock is large enough, it is possible to find farms with a 1:1 reproductive strategy but with two lambing/kidding periods; this means that reproductive animals are divided in two groups. The objective of this strategy will result in a longer milking period for dairy systems, and two periods of lamb sales with more chances of being on the market and get better lamb prices. The mating period of these systems is long, 3 months in most cases to increase the fertility of the flock. This results in a longer period of births.

In 3:2, 4:3 and 5:3 systems, farms are more intensified management-wise, labour and feed supplementation. One of the main changes we have to consider is that greatest grazing resources will not necessarily have a synchrony with the calendar of the reproductive cycle.

The 3:2 systems (1.5 births/ year) is a typical strategy for semi-extensive meat systems mainly. Flocks are usually divided into two groups, with a period of four months between lambing/kidding each. This method allows transferring non-pregnant mums from one group to the other group and its mating period. Following the 3:2 planning, the weaning will be at 6-8 weeks with supplementation with concentrates, fodder or other resources.

The 4:3 system (1.33 births/year) is mainly used by dairy sheep systems with the aim of extending the milking period and a general tendency of early weaning of the lambs.

The 5:3 system (1.8 births/year) is mainly used by intensive dairy sheep systems with three ewes grouping and with a total of 5 mating periods per year and, 5 births periods per year. 2.4 months between births and 73 days from birth to the new mating. In these systems there is generally no synchrony between the reproductive strategy of the farms and the grassland resources availability.

The following information has been collated through literature review and iSAGE industry partners consultation for the description of some of the main systems from sheep and goat breeds studied in the ISAGE project. This is an ongoing process that will allow us to have most of the relevant combinations of systems, breeds, countries and agroclimatic regions.

DAIRY SHEEP SYSTEMS IN NORTHERN SPAIN. The *latxa* case study

Sheep milk systems in Northern Spain are based in flocks of Latxa breed, which is an autochthonous breed well adapted to the geographical conditions of the Basque Country. The reproductive planning of these systems follows the 1:1 strategy due mainly to the high seasonality of the breed (the mating period during summer). There is a certain synchronism between the reproductive strategy and the availability of natural resources for feeding the flock. During mating and first months of pregnancy, the flock is grazing upland grasslands. During winter, births and milking periods occurs. Feeding is based in fodder from spring production and concentrates due to the highest energy requirements of the flock during this period. During spring and autumn, animal graze lowland grasslands. Lambs are weaned at around 25-30 days and are sold directly to markets. The average production of this breed is around 150 litres in 150 days of lactation.

DAIRY SHEEP SYSTEMS IN CENTRAL SPAIN. The *assaff* case study

The dairy sheep sector has undergone an intensification process in the central region of Spain during the last decades. More productive breeds, such as Assaf, currently predominate in this region. These systems are following an intensive reproductive planning, usually 4:3, but we can find farms that follow a 5:3 reproductive strategy. Flocks are divided in different groups to lamb all-year round, thus allowing milk production all along the year. The proportion of concentrates in diet is higher than in other systems, with a forage to concentrate ratio of around 40:60.

SHEEP MEAT SYSTEMS IN UK.

In general UK systems can be divided in hill, upland and lowland systems. Although each farm is different, they have some common characteristics. These systems follow a

1:1 reproductive strategy. In general, mating period starts on October. Like that lamb period will be around March-April. These dates variate a little depending on the breed or the system. The slaughter weight for lambs is around 36-40 kg after 150 days. It is common to find outdoor systems with grass-based feeding but we can find differences.

SHEEP MEAT SYSTEMS IN SPAIN. The *rasa aragonesa* case study

In general, some meat sheep systems have been undergone a semi intensification transition, especially in their reproductive planning, with births every 1.5 years. Flocks are usually divided in batches to obtain different births periods during the year, and get a presence in the market during more time. Lambs are usually milking around 45 days with the ewes, and after weaning farmers use fodder and concentrates to feed them until 23 kg.

DAIRY GOAT SYSTEMS IN FRANCE. *Saanen and Alpine* case studies

In France, there are too main breeds raised in goat systems, Saanen and Alpine, with an average of 1 birth/ year. Milk production is the main source of income. Saanen and Alpine systems are managed mostly intensively and semi-intensively. Most of the flocks are confined, but in the case of Alpine we can find farms under a more extensive systems with highland grazing periods. In general, we can assume a typical ratio of forage: concentrate in the diet of around 70: 30. Fodder harvested allows farms to intensify goat systems.

GOAT MEAT SYSTEMS IN TURKEY. The *hair goat (Anatolian Black)* case study.

These systems are in general described as dual purposed breeds. In general, kidding period is once a year. After weaning (about 90days) goats are milked by hand and milk is also an important economic output of the farm.

After weaning all male kids have been fed with concentrates during the fattening period. The forage: concentrate feed ratio is about 20:80. On the other hand some farms are breeding the goat on extensive breeding system (it means that the goats are grazing nearly all year).

The slaughter age of kids is between 4 and 6 months. This depends on consumer demands and market situation.

The following tables show the typical calendar schemes depending on reproduction strategy.

DAIRY SHEEP SYSTEMS CALENDARS

REPRODUCTIVE PLANNING 1:1 1 birth/ year

1 flock E.g. Latxa. Northern Spain.

System	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Flock 1 Group	Births/Milking	Births/ Milking	Births/ Milking	Milking	Milking	Milking	Mating	Mating	Mating	Mating		Births/Milking
Feeding	**Grassland and alfalfa silo**		**Spring grazing + reserves grassland and alfalfa silo**				**Communal pasture areas grazing**				**Winter grasslands + grassland and alfalfa silo**	
	Supplementation with concentrates											**Concentrates**

Greek system

System	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Flock 1 Group	Births/Milking	Milking	Milking	Milking	Milking	Mating/Milking	Mating/Milking	Mating		Birth	Birth/Milking	Birth/Milking
				Grazing + alfalfa hay								

Winter feeding: Concentrate, alfalfa hay, wheat straw

3 flocks E.g Spanish Meseta Systems

System	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Group 1	Births	Births/ Milking	Milking	Milking	Milking	Milking	Miking/Dry	Mating				
Group 2	Mating				Births	Births/ Milking	Milking	Milking	Milking	Milking	Miking/Dry	Mating
Group 3	Milking	Milking	Miking/Dry	Mating					Births	Births/ Milking	Milking	Milking
Feeding	**Fallow land**	**Fallow land**	**Spring pastures + Fallow land**							**Sunflower , grapevine, beetroot crop residues + autumn regrowth**		

REPRODUCTIVE PLANNING 4:3 4 birth ever 3 years

Year 1

System	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Group 1	Births		Milking	Milking	Milking/Mating	Mating				Births		Milking
Group 2				Births		Milking	Milking	Milking/Mating	Mating			
Group 3	Milking	Milking/Mating	Mating				Births		Milking	Milking	Milking/Mating	Mating
Feeding	**Fallow land**	**Fallow land**	**Spring pastures + Fallow land**							**Sunflower , grapevine, beetroot crop residues + autumn regrowth**		

Year 2

System	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Group 1	Milking	Milking/Mating	Mating				Births		Milking	Milking	Milking/Mating	Mating
Group 2	Births		Milking	Milking	Milking/Mating	Mating				Births		Milking
Group 3				Births		Milking	Milking	Milking/Mating	Mating			
Feeding												

Year 3

System	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Group 1				Births		Milking	Milking	Milking/Mating				
Group 2	Milking	Milking/Mating	Mating				Births		Milking	Milking	Milking/Mating	
Group 3	Births		Milking	Milking	Milking/Mating	Mating				Births		Milking
Feeding												

	J	F	M	A	My	Jn	Jl	Au	S	O	N	D	J	F	M	A	My	Jn	Jl	Au	S	O	N	D	J	F	M	A	My	Jn	Jl	Au	S	O	N	D
Group 1																																				
Group 2																																				
Group 3																																				

Births	Mating	Milking

MEAT SHEEP SYSTEMS CALENDARS

REPRODUCTIVE PLANNING 1:1 1 birth every year

System	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Dehesa	Births/Milking	Milking	Milking	Milking	Mating/Milking	Mating	Mating	Mating		Birth	Birth/Milking	Birth/Milking
Lambs	Lamb breeding		Lamb grazing							Lamb breeding		
Feeding	**Concentrates**	**Concentrates/Spring pastures**	**Spring pastures**			**Dry pasture + Stubble + Low concentrate input**				**Autumn regrowth + concentrates**		
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Meseta/Ebro	Mating			Births/Milking	Births/Milking	Births/Milking	Weaning	Weaning	Weaning		Mating	Mating
Lambs 90 days				**Milk + 250-300 g/day concentrate. Some fodder (usually straw)**			**700 g/day**	**700 g/day**	**700 g/day**	**3 months to slaughter**		
Feeding	**Stubble**			**Spring pastures**			**Cereal stubbles**			**Autumn regrowth + concentrates + Crops residues**		
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
UK		Births/Milking	Births/Milking	Births/Milking					Mating	Mating	Mating	
Lambs 160 days				**8 weeks weaning**	**8 weeks weaning**	**8 weeks weaning**	**160 days slaughter**	**160 days slaughter**	**160 days slaughter**			
Feeding	**Grazing**	**Grazing**	**Grazing**	**Grazing**	**Grazing**	**Grazing**	**Grazing**	**Grazing**	**Grazing**	**Grazing**	**Grazing**	**Grazing**

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Block 1					Mating					Births		
Block 2				Births							Mating	

REPRODUCTIVE PLANNING 3:2 3 births every 2 years

Year 1

	January	February	March	April	May	June	July	August	September	October	November	December
Group 1	Births	Births/Weaning	Weaning	Mating					Births	Births/Weaning	Weaning	Mating
Group 2	Mating				Births	Births/Weaning	Weaning	Mating				
Lambs												

Year 2

	January	February	March	April	May	June	July	August	September	October	November	December
Group 1					Births	Births/Weaning	Weaning	Mating				
Group 2	Births	Births/Weaning	Weaning	Mating					Births	Births/Weaning	Weaning	Mating

	J	F	M	A	My	Jn	Jl	Au	S	O	N	D	J	F	M	A	My	Jn	Jl	Au	S	O	N	D
Block 1																								
Block 2																								

Births	Mating	Weaning

REPRODUCTIVE PLANNING 5:3 5 births every 3 years

5 mating/year	5 births/year	2,4 moths between births	73 days from birth to new mating

Year 1

	January	February	March	April	May	June	July	August	September	October	November	December
Group 1	Births		Mating					Births		Mating		
Group 2			Births			Mating				Births		
Group 3	Mating					Births		Mating				

Year 2

	January	February	March	April	May	June	July	August	September	October	November	December
Group 1			Births			Mating				Births		
Group 2	Mating					Births		Mating				
Group 3	Births		Mating					Biths		Mating		

Year 3

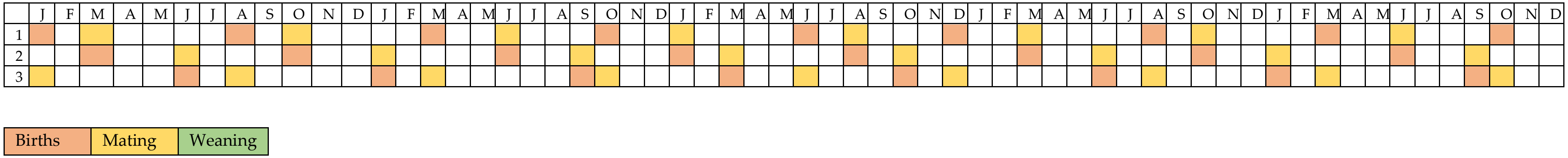
	January	February	March	April	May	June	July	August	September	October	November	December
Group 1	Mating					Births		Mating				
Group 2	Births		Mating					Births		Mating		
Group 3			Biths			Mating				Births		

Year 4

	January	February	March	April	May	June	July	August	September	October	November	December
Group 1	Births		Mating					Births		Mating		
Group 2			Births			Mating				Births		
Group 3	Mating					Births		Mating				

Year 5

	January	February	March	April	May	June	July	August	September	October	November	December
Group 1			Births			Mating				Births		
Group 2	Mating					Births		Mating				
Group 3	Births		Mating					Biths		Mating		



In the case of goat systems, most of them have a reproductive planning 1:1, it means 1 birth per year. In these systems, the intensification is caused mainly with the increasing of kids per goat per birth and the extension of the milking periods.

In general, the periods of births in the farm depend of the farmer management, but it can be considered one only period, two periods (one in autumn and another one in spring generally) or in the case of the most intensive farms, flocks are divided in various groups with different birth periods in order to maintain milk production levels all around the year.

DAIRY GOAT SYSTEMS CALENDARS

REPRODUCTIVE PLANNING 1:1 1 birth/ year

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Flock 1 group	Births										Births	
Grazing	**Natural Pasture**											
	Cultivated pasture						**Stubble**					

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Group 1		Mating	Mating				Births	Births				
Group 2					Mating	Mating				Births	Births	
Group 3		Births	Births						Mating	Mating		
Grazing	**Natural scrub , natural pasture (during summer: stubble and crop residues)**											

.3.3.1.2 *Herd Production curves*

Milk production for each particular adult female group and day is estimated to follow a typical pattern using default milk (L, protein and fat) curves (see below). For lambs&kids, liveweight gain (growth) also follows specific patterns depending on breed selected. For adult female, liveweight gain/loss is linked to their daily stage. An example is provided below (Figure 6). For replacement female animals and male animals, we have assumed an average weight without changes for the whole year.

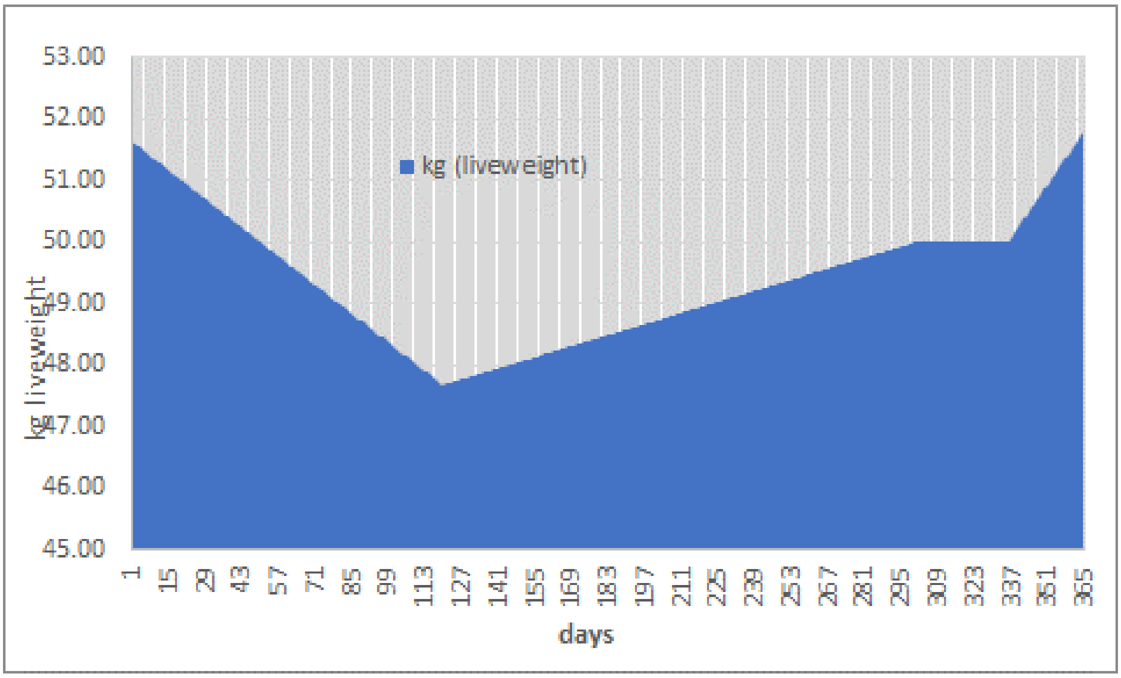


Figure 6. Simulated live-weight changes for an adult female (*latxa* breed sheep) from a group lambing in January.

There are different models to estimate lactation curves for sheep and goats. Although many methods have been used for different breeds, the Wood function (Wood, 1967) generally is the most commonly used one.

SIMS$_{SR}$, using as an input the total milk production per lactation and protein and fat in the milk objective, estimates how milk volume, milk protein and fat % are distributed within the lactation period based on Wood (1967) equation coefficients for lactation. The results using the Wood equation are normalised for the value used as input of total milk production. The lactation curves allow us, to estimate milk yields along the lactation period, as well as protein and fat curves during the milking of the sheep/goat.

The general Wood function is as follows:

Daily production day (kg/day) = $a\,day^{b}e^{-c\,day}$ ***Eq 1***

Where a, b, c are breed-specific parameters

Fat and protein milk content.

Similarly, $SIMS_{SR}$ calculates curves of fat and protein milk content can be estimated with Wood functions.

Also, George's equations (1984) can be used for protein and fat curves.

Fat milk content

Daily fat content in milk day (g/kg) = $1.01*\%\text{peak milk fat}*(((day+1)/7^{)-0.13})e^{(0.02*((day+1)/7))})$

Eq 2

Protein milk content

Daily protein content in milk day (g/kg) = $1.14*\%\text{peak milk protein}*(((day+1)/7)^{-0.12})\,e^{(0.01*((t+1)/7))})$ ***Eq 3***

Where day is lactation day and peak milk fat and peak milk protein are maximum % fat and protein content, respectively.

The following tables (Tables 7-9) show the specific parameters to estimate the Wood functions for different breeds. Figures (Figs 7-16) illustrate for different breeds how these curves change.

Table 7. Estimated parameters for Wood function in different sheep breeds.

Breed	Function	a	b	c	Milking days	Reference
Lacaune	Wood	1.173	0.352	0.011	234	Elvira, L. (2016)
Manchega	Wood	1.544	0.185	-0.0089	180	Ramón, M. (2018)
	Fat	7.338	-0.056	0.0028		
	Protein	5.557	-0.023	0.0018		
Awassi	Wood	1.462	0.218	-0.062	164	Koluman, N. (2018)

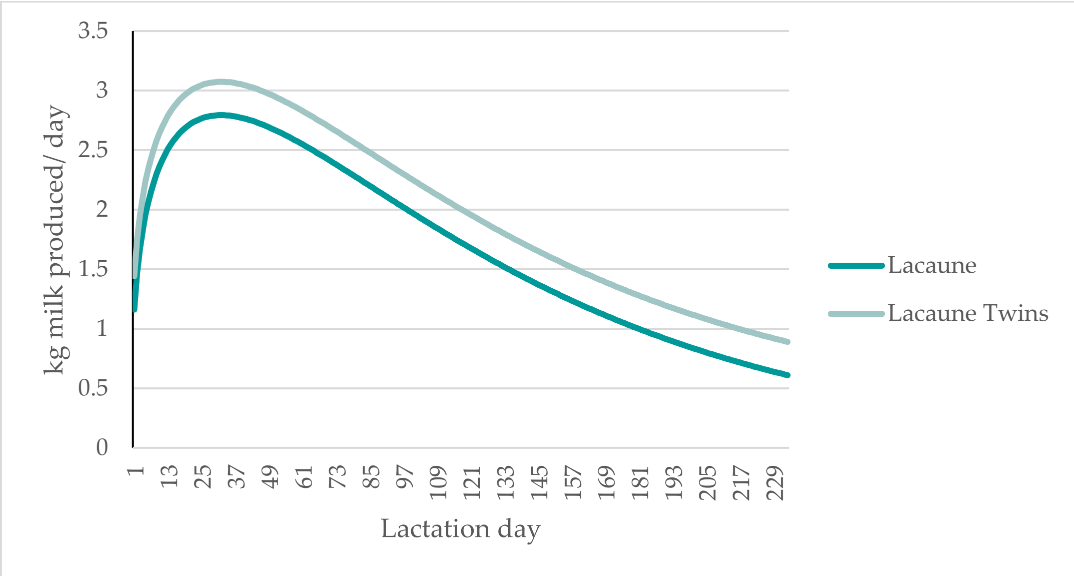


Figure 7. Lactation curve Wood function for Lacaune

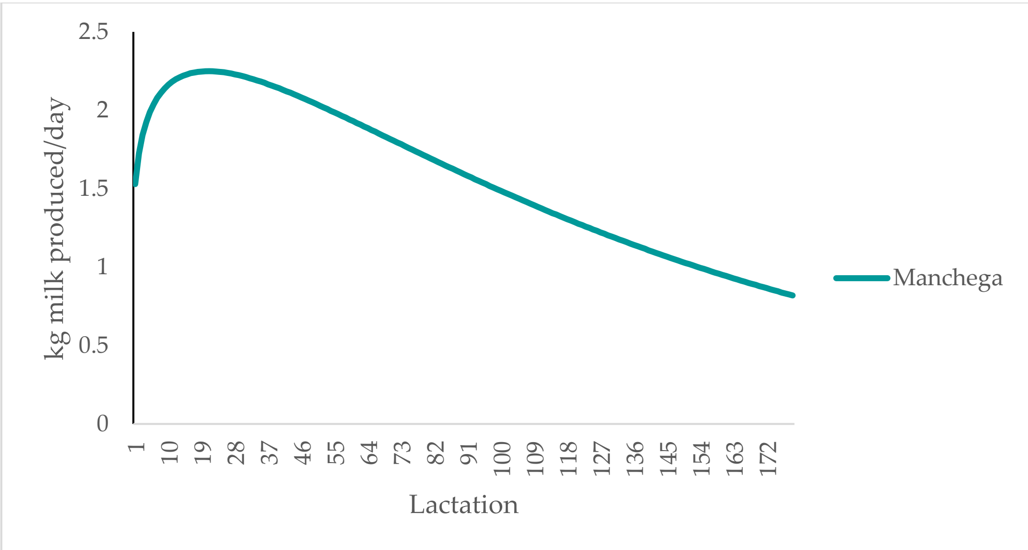


Figure 8. Lactation curve Wood function for Manchega

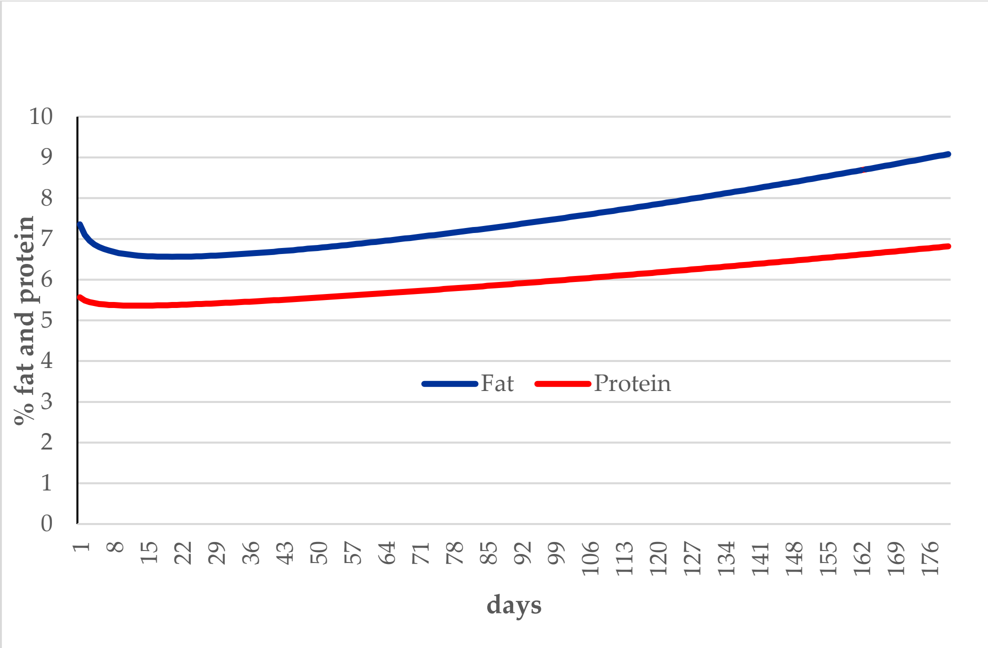


Figure 9. Fat and Protein Curve for Manchega breed using Wood factors.

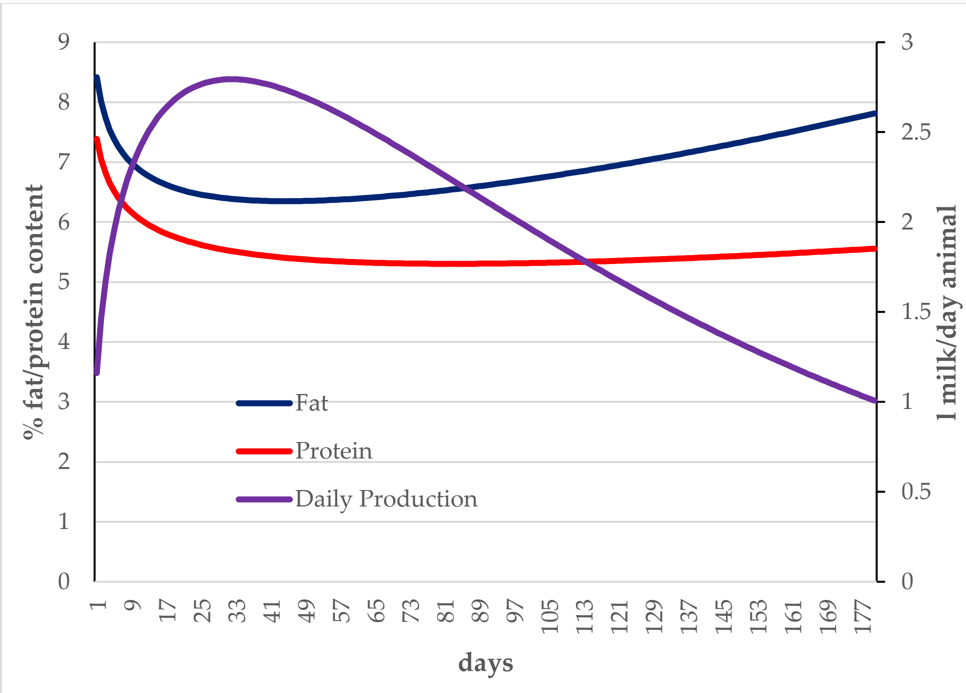


Figure 10. Milk yield, fat and protein curves for Manchega breed.

Table 8. Estimated parameters for Wood function in different goat breeds

Breed	Function	a	b	c	Milking days	Notes	Reference
Murciano-Granadina	Wood	0.8594	0.2005	-0.00368	240	1st milking	Leon et al. (2007)
		1.1124	0.1647	-0.00338	240	2nd milking	
		1.1532	0.173	-0.00367	240	3rd milking	
Alpine	Wood	2.316	0.23	-0.005	310		Sauvant et al. (2012)
Saanen	Wood	2.316	0.23	-0.005	310		Sauvant et al. (2012)

Table 9. Estimated parameters for French breeds using INRA model.

Breed	Function	
France	TMP*(-0,0030e(-0,0303t)+0,0070e(-0,0042t))	
Alpina	2nd lactation	+0,27kg/day
Saanen	twins	+0,28kg/day
	+3 kids/birth	+0,39 kg/day

TMP: Total milk production. Source: *Sauvant et al. (2012)*

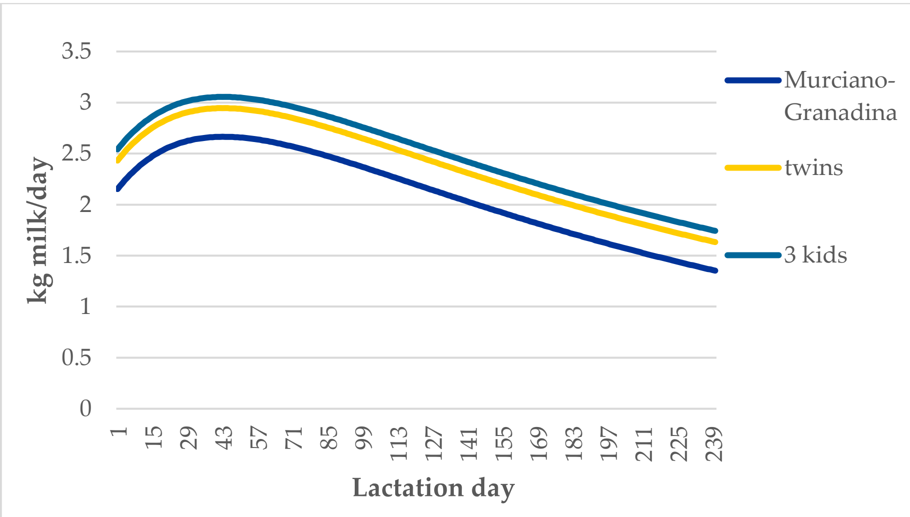


Figure 11. Lactation curve using Wood function for Murciano-Granadina breed.

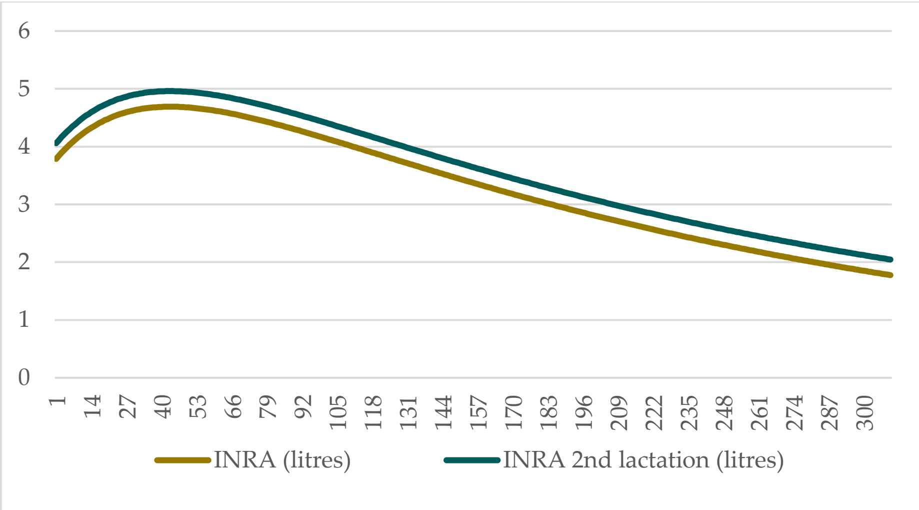


Figure 12. Lactation curve for Alpine Goat Breed for 1st and 2nd lactation (INRA model)

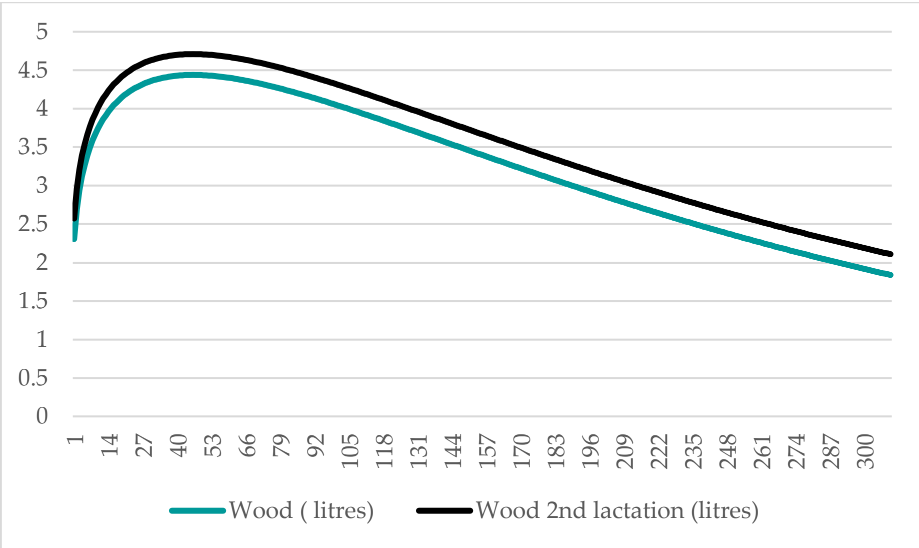


Figure 13. Lactation curve for Alpine Goat Breed for 1st and 2nd lactation (Wood parameters)

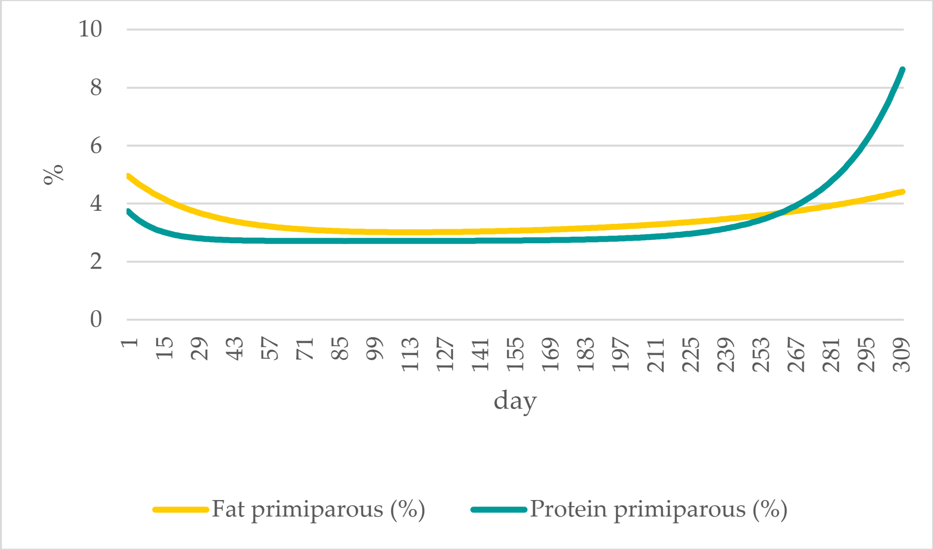


Figure 14. Protein and Fat curves for Alpine Goat Breed in France (INRA model)

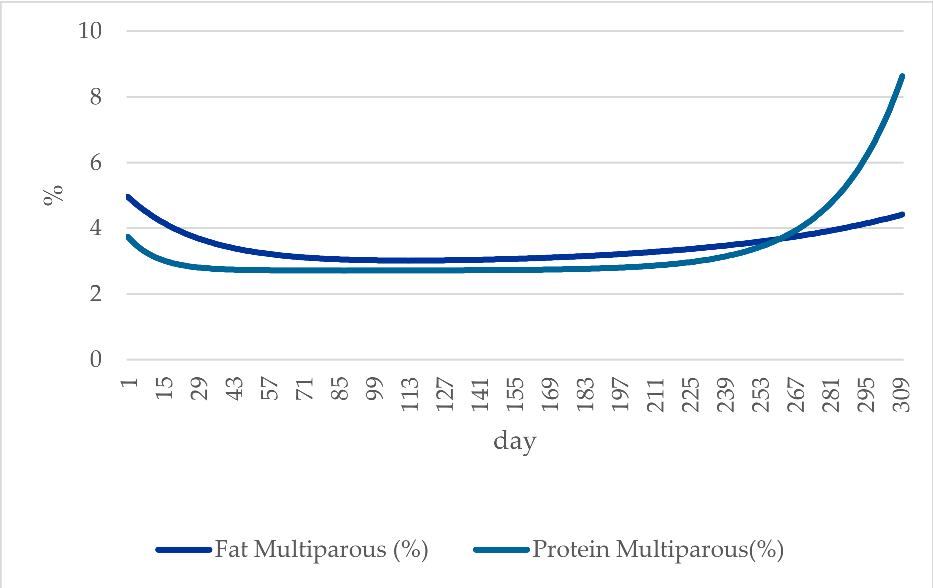


Figure 15. Protein and Fat curves for Alpine Goat Breed in France (INRA model)

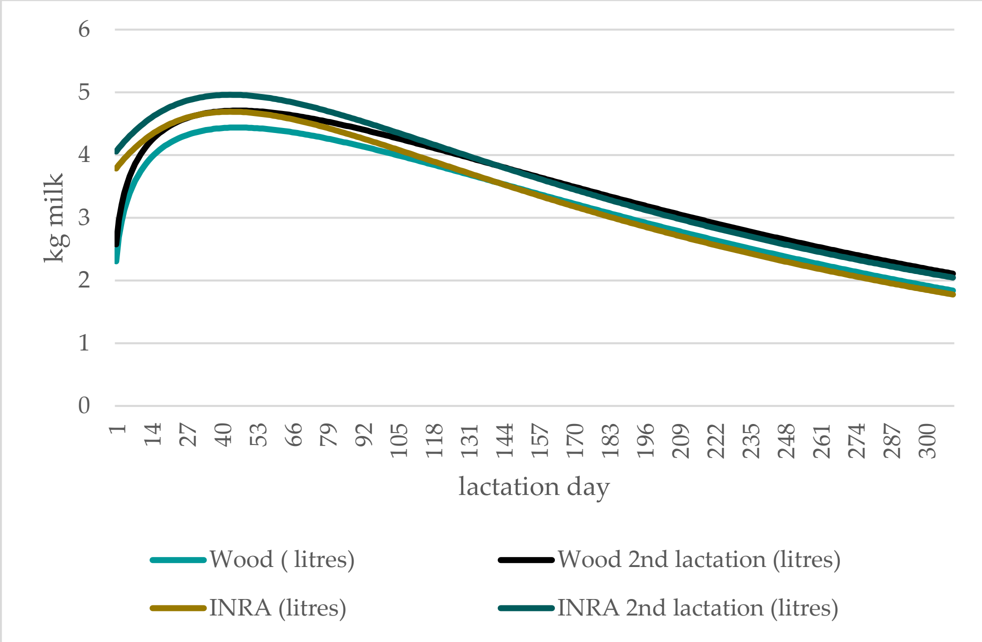


Figure 16. Comparison of lactation curves for Alpine Goat Breed in France using Wood parameters (INRA equations)

.3.3.1.3 *Feed allocation*

A feed allocation scheme is used to represent a producer's approach to making the best use of home-grown feeds. Feeds are represented in a generic way in order to be able to use the model in many different circumstances and contexts. Generically, feed is composed by:

- Grazed forage: Grassland (lowland, upland, Mediterranean, highlands/mountain), grazed fallow, grazed crop residues
- Home-grown forage: Grassland (silage/hay from lowland), forage maize, forage legume
- Purchased forage: Any generic type
- Grazed whole crops
- Home-grown grains
- Purchased concentrates

Feed home-grown availability is determined by the number of hectares and yield for the different months of the year. For harvested or conserved feed, $SIMS_{SR}$ assumes in its default mode that feed is stocked and available from 15 days to 1 month after cut or harvest in the year. This value depends on the type of crop/pasture.

For each breed, context and stage of the animal (for adult female) the model specifies an average and, minimum and maximum forage: concentrates ratio.

Some of these values come from consultation to the iSAGE industry partners. Table 10 shows some breeds' default values as an example. These values will be updated for as many breeds that we can have access of this type of data, and can be changed to explore the implications of making such change on the different sustainability variables of the farm.

Table 10. Forage: concentrates ratio for different animal types

BREED	FORRAGE: CONCENTRATES
Assaf	40:60
Churra	70:30
Lacaune	40:60
Latxa	70:30
Manchega	50:50
Frizarta	55:45
Chios	50:50 (I)/70:30 (SI)
Lacaune	82:18
Manech Red Face	84:16
Awassi	70:30:00
Merino	80:20
Rasa aragonesa	70:30/50:50 (pregnancy and milking)
North Country Mule	90:10
Scotish Blackface	90:10
Welsh Mountain	90:10
Swaledale	90:10
Lleyn	90:10
Texel	90:10
Merino (Fr)	89:11
Vendeens	80:20
Romane	75:25
BMC	85:12
Murciano-Granadina	30:70/50:50
Florida	60:40
Saanen	60:40
Alpine	70:30
Damascus	70:30:00
Hair Goat(Anatolian Black)	70:30

The user has also an input about whether the farmer allows/or not "grazing activity" for each of the day of the year and for each type of animal. Also, the farmer allows a particular generic land to be grazed from the previous list of grazed land. The amount of grazed feed will be determined by the availability of enough plant production on a particular day and by the aforementioned decision of the farmer (whether the animals can or not graze on that particular day). Grazing DM intake for each type of animal is estimated by calculating the potential DM intake per hectare in on-farm or leased grazing areas and adjusting for each grazing day how many animals and how much DM they can ingest. Should DM available be insufficient to satisfy maximum grazing potential for all animals the model prioritise grazing activity in the following sequence: young, male animals, dry ewes/does, pregnant ewes/does and finally, lactating ewes/does.

If for example, pasture is not available to meet the needs of the grazing animal groups, each group is supplemented with at least one other forage up to the estimated forage quantity taken in. Forage stocks, as previously mentioned will be stocked and offered in the year to the herd until stock is depleted. If home-grown feed is insufficient to reach this forage intake estimate, the farmer is assumed to buy a forage or mix of forages. The user specifies the quality of this purchased forage. If grain is harvested on-farm this will be used as one of the ingredients to satisfy the concentrates ratio fed.

3.3.2 Net energy (NE), protein (P) requirements and Dry matter (DM) intake estimation

The model is energy-driven and animal intake is a function of the nutrient requirements of each animal group and the nutrient constituents of the diet fed. The model simulates basic animal metabolic processes in order to quantify how different feeding strategies and animal types may affect animal productivity (i.e. economic sustainability) and excreta as well as C and N emissions. The animal at a particular condition, lactation stage or production level consumes the available feed to meet their energy requirement. However, the amount consumed cannot exceed the amount of fibre the animal can digest. Diets must also meet the animals' protein requirements.

Modelling of grazing/browsing involves the simulation of the direct interactions between the animal, the plant and the animal excreta. The model has flexibility to simulate pasture, fallow, crop residues and whole crops grazing/browsing with different sub-models that vary in complexity (section 3.3.6). The actual amount consumed is limited to the potential intake or the pasture available, whichever is less. Remaining pasture not consumed will be carried over to the next month.

Flows of DM, energy, N and P at the animal and herd level are mainly simulated through calculations of feed requirements and supply (DM, energy, and N). In this version of the model, default requirement calculations are based on AFRC (1993, 1998) for sheep and goats, respectively. There are other different potential methodologies that are also widely used (e.g. INRA, CSIRO…) and that may have been proved to work better for specific country and system specific context (Cannas et al., 2008). There is, however, not a fit-for-all-situations perfect one and the AFCR is widely used in international guidelines for small ruminants (e.g. IPCC, 2006, 2019). We envisage to gradually incorporate requirement calculations based on other systems (e.g. INRA) in order to improve the precision of the model to the particular simulated system.

Nutrients contents of each feedstuff come from various sources. Whereas some feed's (e.g. lowland pastures) nutrient content (e.g. protein) is simulated as a function of management and edapho-climatic conditions, other feed's nutrient contents (e.g. any nutritional value of soybean cake) is derived from literature tables (e.g. Feedipedia: https://www.feedipedia.org/) or can be imported as an input value.

The order of calculations can be summarised in X steps:

- prediction of total voluntary intake
- Predictions of animal net energy (NE) animal requirements.
- Predictions of metabolizable protein (MP) requirements
- Matching predictions of NE and MP requirements with feed supply

.3.3.2.1 Prediction of total voluntary DM intake:

There are many equations in the literature that have been derived from different animal types, breeds and agro-climatic conditions. In the context of ISAGE we have evaluated the main ones in the literature and our final selection was carried out through a consultation with ISAGE industry and scientist partners and the main criteria was simplicity, availability of input variables and proof that the equation had been successfully used for specific breeds and production systems. We have done a sensitivity analysis of some models of prediction of dry matter intake (DMI) in sheep and goat systems.

The following tables (Tables 11-14) show different prediction models of dry matter intake for sheep and goat systems as an example. The whole analysis is found in Annex 6.1.1.

Table 11. Dry Matter Intake prediction models for sheep.

Animal		Function	Unit	Reference
Sheep	Growing sheep Grass (no silage)	104.7ME/GE +0.307W-15	$kg^{0.75}$/day	ARC (1980)
Sheep	Growing sheep Silage	0.046 g/kg $W^{0.75}$	kg DM/day	AFRC(1993)
Sheep	Milking ewe	0.024W+0.9FPCM	kg DM/day	INRA(2007)
Sheep	Dry ewe or early pregnant ewe	$IW^{0.75}$ I=0.075 si bc 4-4.5 I=0.081 si bc 3-3.5 I=0.089 si bc 2-2.5	kg DM/day	INRA(2007)
Sheep	Milking ewe	$(-0.545+0.095W^{0.75}+0.65PLS+0.0025\Delta W)$ PLS(6.5%)	kg DM/day	Pulina et al.(1996) en FEDNA
Sheep	Dry ewe	$(-0.545+0.095W^{0.75}+0.005\Delta W)$ K	kg DM/day	Pulina et al.(1996) en FEDNA
Sheep	Milking ewe	0.0255W+0.75FPCM	kg DM/day	Caja et al (2002)
Sheep	Pregnant ewes	0.304-0.004N-0.049PN+0.027W	kg DM/day	Caja et al (2002)
Sheep	General	0.04W((actual W/W(1.7- (actual W/W))	kg DM/ day	NRC(2007)
Sheep	Milking ewes	0.0214W+0.319(kg milk/day*(0.25+0.085F+0.035P))+0.0373CP(%)	Kg DM/day	Serra (1998)
Sheep	Grazing systems (5-6 h) >16% CP	997.1+73.9HM -27.4PH +20.4HDM+0.16FPCM(g/day)-1.24SCPI	g DM/day	Avondo (2005)
Sheep	Grazing systems (5-6 h) 16-10% CP	420.4+95.9HM+0.33FPCM-1.24SCPI	g DM/day	Avondo (2005)
Sheep	Grazing systems (5-6 h) <10% CP	118.38+165.8HM+0.243FPCM	g DM/day	Avondo (2005)
Sheep	Grazing systems (unrestricted access)	1268+14.45PH	g DM/day	Molle et al (2004)
Sheep	Extensive systems	0.025W	kg DM/day	

ME Metabolized energy; GE Gross Energy; W; Liveweight ;Bc body condition; PL Milk production (kg/day); PLS (Standard milk production 6.5%); N number of lamb; PN total lamb weight at birth ;CP Crude Protein in diet (%);HM herbage mass (t DM/ha); PH pasture height (cm); HDM herbage dry matter content 8%); SCPI crude protein intake from supplements (g/day); MY(3.5fatl)

FPCM (0.0071G+0.0043P+0.2244); PLS (6.5%) 0.098G+0.36; MY kg/day (3.5% fat) (1+(0.0055 (Fat g/L -35) +0.0033(Protein g/L -31))/0.4) based INRA (2007)

Table 12. Dry Matter Intake prediction models for goats.

Animal		Function	Unit	Reference
Goat	Lactating goats	$0.024W^{0.75}$+0.4ΔW+0.42PL (3.5fat)+0.7%Forage	kg DM/day	AFRC (1995,1998) Based on INRA
Goat	Milking ewe	$164.7+368.6PL+34.8W^{0.75}$	kg DM/day	Sauvant et al (1991) en FEDNA
Goat	Milking ewe week >8	507.4+303.8PL+12.8ΔW 533+305.2PL+13.3W	kg DM/day	Sauvant et al (1991) in FEDNA
Goat	Replacement goats	$0.08P^{0.75}$	kg DM/day	Hadjipana et al (1991) in FEDNA
Goat		$(0.111W^{0.75})*(1-e^{-0.8t})$	kg DM/day	Fernandez et al (2003) in FEDNA
Goat	Lactation beginning	$164.7+368.6PL+34.8W^{0.75}$	g DM/day	Sauvant et al (1991)
Goat	Lactation	533+305.2PL+13.3W	g DM/day	Sauvant et al (1991)
Goat	Reposition	$0.080W^{0.75}$	kg DM/day	Sauvant et al (1991)

ME Metabolized energy; GE Gross Energy; W; Liveweight ;Bc body condition; PL Milk production (kg/day); PLS (Standar milk production 6.5%); N number of lamb; PN total lamb weight at birth ;CP Crude Protein in diet (%);HM herbage mass (t DM/ha); PH pasture height (cm); HDM herbage dry matter content 8%); SCPI crude protein intake from supplements (g/day); MY(3.5fatl)

Example of how estimations of DM voluntary DM intake may arise from using these different equations for dairy sheep (Figs 17-18), goats (Table 13) and growing lambs (Table 14) are shown below

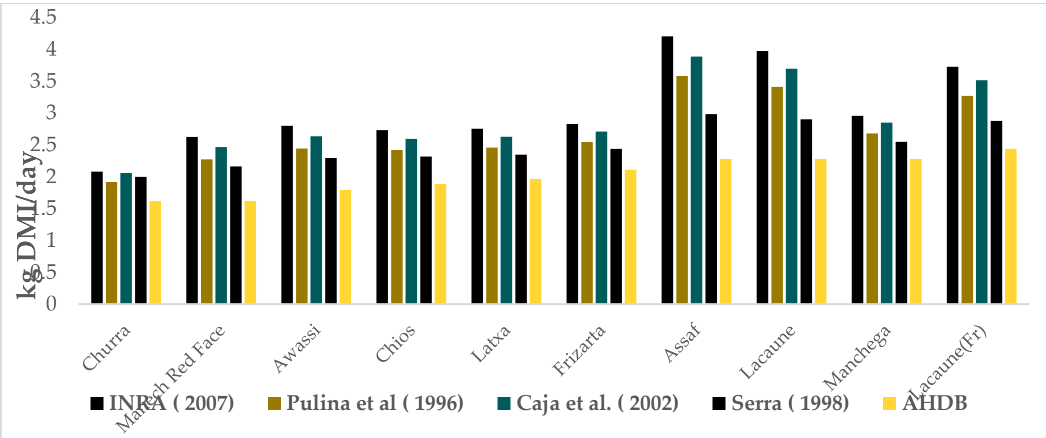


Figure 17. DMI prediction with different models for different dairy sheep breeds during milking period.

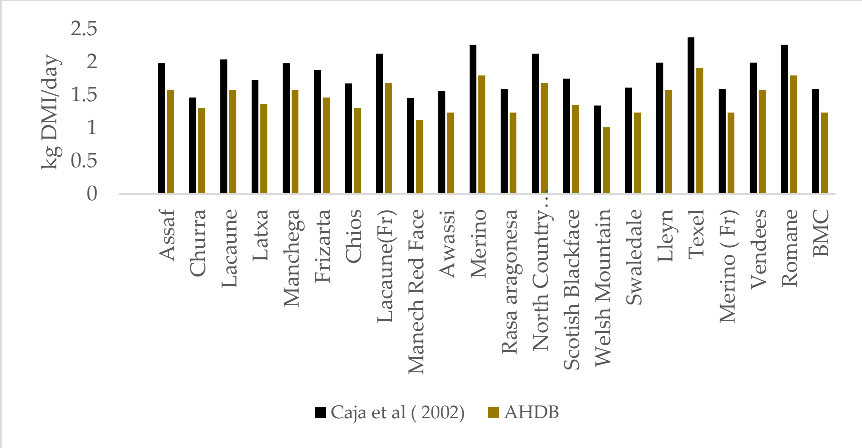


Figure 18. DMI prediction with different models for different dairy sheep breeds during last month of pregnancy

Table 13. Intake predictions with different models for milking goats.

				kg DMI/day				
Breed	**Liveweight**	**Forage diet**	**Milk production**	**AFRC (1995,1998)**	**Kearl (1982)**	**INRA (2007)**	**Sauvant et al.(1991)**	**Sauvant et al.(1991)**
	Kg	**(0-1)**	**kg/day**				**Starting**	**Decreasing**
Murciano-Granadina	50	0.25	2.192	1.851	2.249	1.840	1.62	1.867
Florida	60	0.6	2.407	2.154	2.578	1.995	1.80	2.066
Saanen	75	0.6	3.171	2.693	3.048	2.489	2.220	2.498
Alpine	65	0.6	2.413	2.077	2.738	2.013	1.850	2.134
Damascus	60	0.7	2	1.926	2.578	1.825	1.652	1.941
Hair Goat(Anatolian Black)	65	0.7	0.536	1.311	2.738	1.535	1.159	1.561

Table 14. Intake predictions with different models for growing lambs.

				kg DMI/day			
Breed	Born liveweight	Day weaning	Sacrificie liveweight	Pulina et al (1996)	AFRC (1983) Growing	NRC (2007)	UPM
	(kg)	g	kg	House	Grazing	General	Extensive
Assaf	4.2	38	15	0.142	1.05	0.410	0.105
Churra	3.75	275	10.5	0.480	0.75	0.302	0.094
Lacaune	3		12	0.038	1.05	0.346	0.075
Latxa	4.25	250	11	0.461	0.9075	0.317	0.106
Manchega	4.25	290	11.5	0.521	1.05	0.331	0.106
Frizarta	3.5	225	12	0.395	0.975	0.346	0.088
Chios	3.8	225	14.5	0.407	0.870	0.418	0.095
Lacaune(Fr)	4	300	13	0.527	1.125	0.374	0.100
Manech Red Face	4	200	11	0.377	0.750	0.317	0.100
Awassi	4.5	320	35	0.576	0.825	1.008	0.113
Merino	4	300	24.5	0.527	1.200	0.706	0.100
Rasa aragonesa	4	230	23	0.422	0.825	0.648	0.100
North Country Mule	4	250	38	0.452	1.125	1.094	0.100
Scotish Blackface	3.5	200	36	0.358	0.9	1.037	0.088
Welsh Mountain	3.5	180	36	0.328	0.675	1.037	0.088
Swaledale	3.5	180	36	0.328	0.825	1.037	0.088
Lleyn	4	250	38	0.452	1.05	1.094	0.100
Texel	4.5	320	40	0.576	1.275	1.152	0.113
Merino (Fr)	4	245	33	0.445	0.825	0.950	0.100
Vendees	4	400	40	0.677	1.05	1.152	0.100
Romane	4	330	37	0.572	1.2	1.066	0.100
BMC	4	280	36	0.497	0.825	1.037	0.100

.3.3.2.2 Predictions of net energy (NE) animal requirements.

The model estimates the amount of net energy (MJ/day) the animals need for maintenance and for such as activity, growth, lactation wool production and pregnancy. The equations below are used to derive this estimate:

Net energy for maintenance: (*NE_m*) $NE_m=Cf_i\ (Weight)^{0.75}$ ***Eq 4***

Net energy for activity: (NE_a) $NE_a=C_a\ (Weight)$ ***Eq 5***

Net energy for growth: (NE_g) $NE_g=WG_{lamb/kids}\ (a+0.5b(BW_i+BW_f))/365$ ***Eq 6***

Net Energy for lactation: (NE_L) $NE_L=Milk\ EV_{milk}$ ***Eq 7***

Net energy for wool production: (NE_{wool}) $NE_{wool}=(EVwool\ Production_{wool}/365)$ ***Eq 8***

Net energy for pregnancy: ($NE_{pregnancy}$)

$E_t=10^{(3.322-4.979\ e\text{^}-0.00643t)}$ ***Eq 9***

$NE_{pregnancy}=0.25\ W_0\ (E_t\ 0.07372\ e^{0.00643t})$ ***Eq 10***

Total net energy required: (NE_{TOTAL}) $NE_m+NE_a+NE_g+NE_L+NE_{wool}+NE_{pregnancy}$ ***Eq 11***

Constants and functions to derive some of these parameters are included in the Annex 6.1.2.

.3.3.2.3 Predictions of metabolizable protein (MP) requirements

The calculation of the metabolizable protein requirements is carried out using the AFRC (1993) method. The total estimate is made by calculating each of the following requirements:

MP requirements for maintenance (MP_m):

sheep (ewes): $MP_m=2.1875(Weight)^{0.7}+20.4$ ***Eq 12***

sheep (lambs): $MP_m=2.1874(Weight)^{0.7}$ ***Eq 13***

goats: $MP_m=2.30(Weight)^{0.7}$ ***Eq 14***

MP requirements for lactation (MP_l):

sheep: $MP_m=71.9\ Milk$ ***Eq 15***

goats: MP_m=47.7 Milk ***Eq 16***

MP requirements for liveweight gain (MP_f):

Sheep (males): MP_f=1.695 ΔWeight(160.4-1.22Weight+0.0105Weight^2) ***Eq 17***

Sheep (females): MP_f=1.695 ΔWeight(156.1-1.94Weight+0.0173Weight^2) ***Eq 18***

goats: MP_f= ΔWeight (266-1.18 Weight) ***Eq 19***

MP requirements for pregnancy (MP_c):

$TP_t = 10^{(4.928-4.873\ e^{\wedge}-0.00601t)}$ ***Eq 20***

$MP_c = 0.25\ W_c\ (0.079\ TP_t\ e^{-0.00601t})$ ***Eq 21***

MP for liveweight change in lactating animals (MP_g):

sheep: *MPg= 119* ΔWeight (loss) ***Eq 22***

sheep: *MPg= 140* ΔWeight (gain) ***Eq 23***

goats: MP_g=-30 (first month of lactation) ***Eq 24***

.3.3.2.4 *Matching predictions of NE and MP requirements with feed supply*

For matching a good match between requirements, supply and maximum DM intake capacity. Energy is the first limiting factor upon the level of animal production achieved by feeding the diet (AFCR, 1993). NE requirements are sequentially checked with ME supply (forage-grazed, forage-non-grazed and on-farm grown cereals) accounting for the efficiency of utilisation of ME for each feed as follows:

Efficiency for maintenance (k_m):

k_m=0.35 q_m +0.503 ***Eq 25***

Where q_m is the metabolisability of the GE of the feed at maintenance level:

q_m=ME/GE ***Eq 26***

Efficiency for lactation (k_l):

K_l=0.35 q_m +0.42 ***Eq 27***

Efficiency for growth (k_f, k_g):

Growing ruminants $k_f = 0.78\ q_m + 0.006$ ***Eq 28***

Lactating ruminants $k_g = 0.95 k_l$ ***Eq 29***

Efficiency for growth of the concepta (k_c):

$k_c = 0.133$ ***Eq 30***

Efficiency for utilisation of mobilised body tissue for lactation (k_t):

$k_t = 0.84$ ***Eq 31***

The type of purchased concentrate required in terms of ME is estimated from the energy requirements that have not been satisfied by the forage and on-farm cereals by assuming an average GE content of 18.5 MJ/kg DM. Total DM intake estimated cannot exceed the prediction of DM voluntary intake.

For a particular feeding level, the $ERPD_{intake}/FME_{intake}$ ratio (Effective rumen degradable protein: Fermentable ME) must be at least the MCP yield (MCP_{yield}) value. The following equations are used according to AFRC (1993).

$r = -0.024 + 0.179\ (1 - e(^{-0.278LEVEL}))$ ***Eq 32***

SDP (g/kg DM) = ((b c)/(c+r)[CP] ***Eq 33***

QDP (g/kg/DM) = a [CP] ***Eq 34***

ERDP (g/kg DM(= 0.8 [QDP] +[SDP)] ***Eq 35***

$ERDP_{intake}$ (g/day) $= W_1$ (ERDP1)$+W_2$ (ERDP2)… ***Eq 36***

MCP_{yield} (g MCP/MJ FME) = 7 +6 (1-e(-0.35^{LEVEL})) ***Eq 37***

The adequacy of the ERDP supply is considered next in order to maximise MCP synthesis by rumen microbes, before considering whether the MP supply meets requirements. The MP supply adequacy is checked as a final step. More details can be found in AFRC (1993).

$MP_{supply} = 0.6375\ MCP_{yield} + DUP_{supply}$ ***Eq 38***

From these calculations and considering that requirements must match supply, the model estimates the protein characteristics of the purchased concentrates in terms of ERDP content, DUP content and crude protein (CP) content. Should any of these values be out of standard values, the model assumes a minimum (if values are too low) or maximum (if values are too high) value and prompts a warning message.

For crude protein content of the concentrate the model estimates a potential value as a function of the DUP content of the concentrate (Figure 19). This relationship has been developed using a collection of standard values of DUP and CP content (AFRC, 1993 tables) from selected typical ingredients of a concentrate.

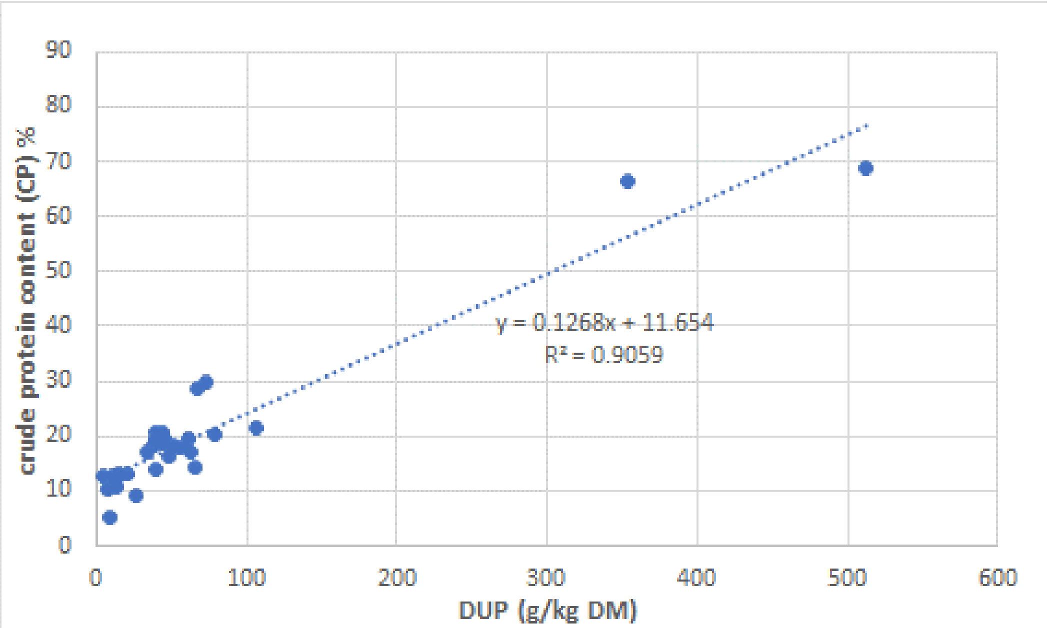


Figure 19. Relationship between crude protein content and DUP content of the concentrate. Dots represents values from typical ingredients.

The next Figures (Figs 20-21) illustrate an example simulating energy requirements (Fig 20) and dry matter intake from different sources (Fig 21) from a dairy sheep flock.

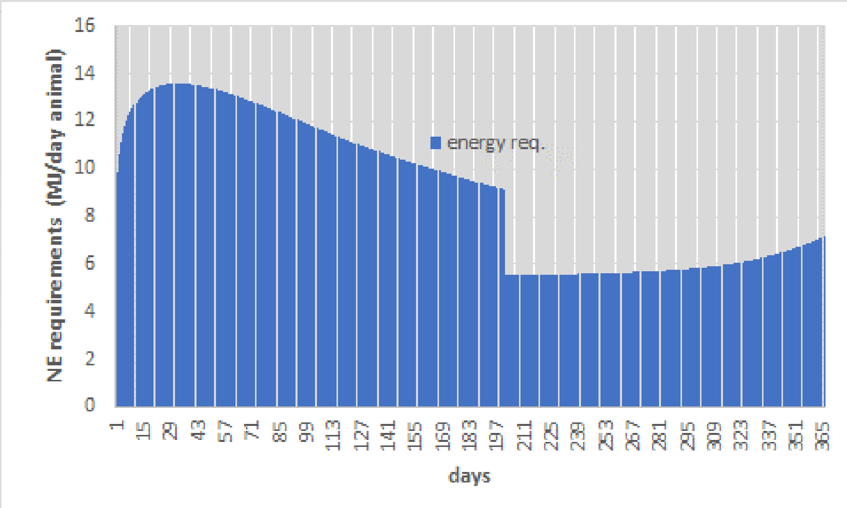


Figure 20. Example of daily simulated energy requirements for a dairy sheep flock (Chios breed) lambing in January.

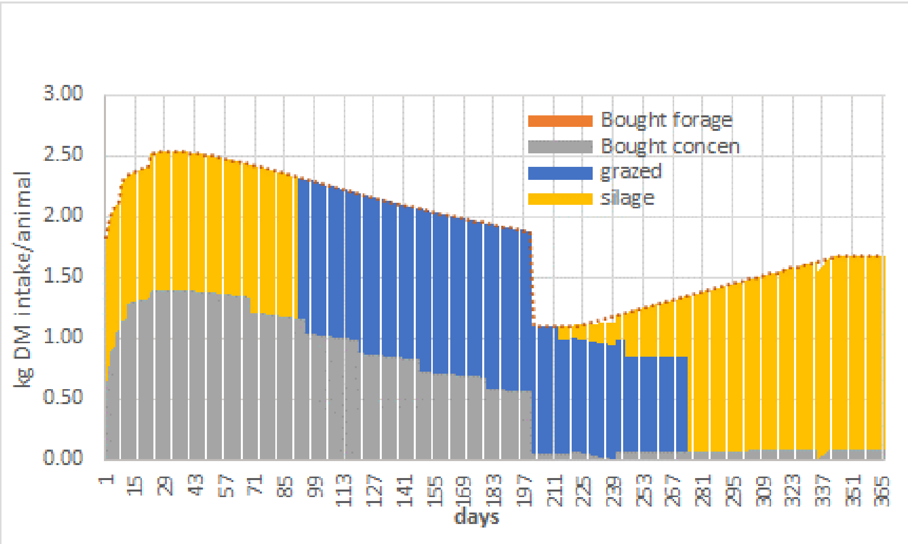


Figure 21. Example of daily simulated dry matter intake for different feeds for a dairy sheep flock (Chios breed) lambing in January.

3.3.3 Calculation of enteric methane output

For methodological comparison purposes, methane emissions from animal enteric fermentation are simulated using different methods:

- the TIER2 approach from IPCC (2006) and assuming default IPCC (2006) Y_m (% CH_4 from gross energy intake)
- the TIER2 approach from IPCC (2006) and estimating Y_m (% CH_4 from gross energy intake) as a function of GE digestibility of feed (Cambra-Lopez et al., 2008; FAO, 2010)
- the TIER2 approach from IPCC (2019) and assuming default IPCC (2019) Y_m (% CH_4 from gross energy intake)
- an empirical equation that relates animal DM intake and CH_4 output (for goats, see annex 6.1.4)

$Y_m=0.0038DE^2+0.4178DE-4.3133$ (Cambra-Lopez et al., 2008) ***Eq 39***

$Y_m = 9.75 - 0.005\ DMD$ (FAO, 2010) ***Eq 40***

Where DE and DMD are % digestibility for the energy and dry matter, respectively.

For all of the approaches it is key to both estimate gross energy intake and digestibility of feed. Highly digestible diets, such as those rich in starch, are in general associated with higher digestibility of the excreted VS thereby higher CH_4 losses in subsequent CH4 emissions (at the manure level) (Hindrichsen et al., 2006).

Reducing N fertilization rates in pastures have been found to result in grass with lower degradable crude protein, lower digestibility, lower hemicellulose, more cellulose and larger particle size leading to lower fermentation rate in the rumen and therefore, lower VFA, H_2 and CH_4 production (Beukes et al., 2011). $SIMS_{SR}$ will have limitations to model this effect.

Next figure shows an example simulating CH_4 enteric losses from a dairy sheep flock.

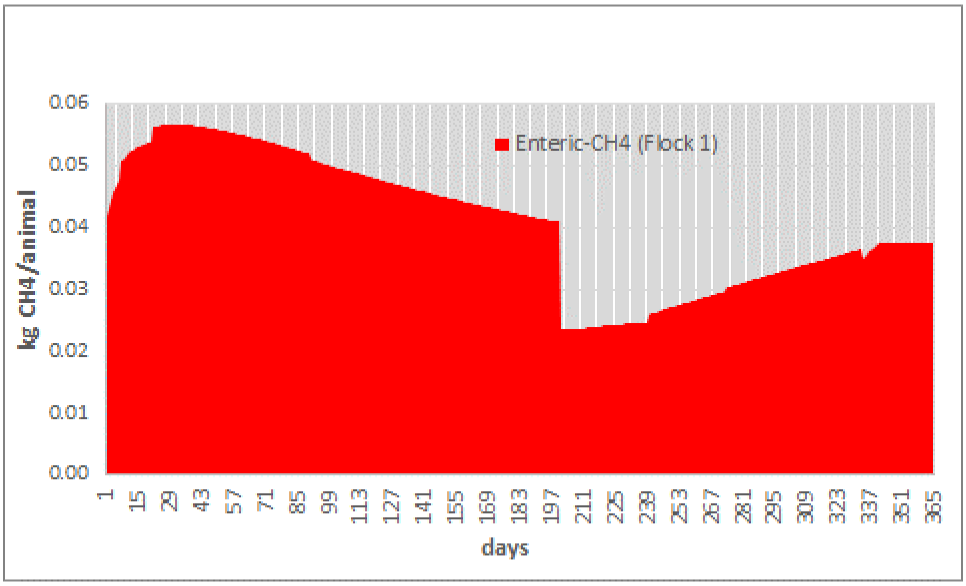


Figure 22. Example of daily simulated CH_4 emissions associated to a sheep flock (Chios breed) lambing in January.

3.3.4 Animal excreta and manure calculations

Animal excreta is simulated on a daily basis for the different animal categories and adult female groups. Nitrogen, phosphorus (P), carbon (C) and volatile solids (VS) are calculated for the animals whilst they are grazing or housed.

The model differentiates two excretion pathways: (i) excreted on the soil whilst grazing and (ii) excretion in the house, which will lead to manure formation.

Phosphorus and nitrogen excretion are calculated at the animal and herd level by subtracting N and P in milk and net body change from those N and P ingested by the animals. The model further partitions excreted matter/energy into two pools of different chemical composition: urine and faeces. For partitioning excreted N we used a fixed value for sheep faeces and new empirical equations relating diet composition and the urine: dung ratio for goats (Figure 23). These equations have been developed as part of A. Del Prado contribution on creation of specific factors for the new IPCC Methodology Report titled "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories" (to be approved in May 2019) (see annex 6.1.4).

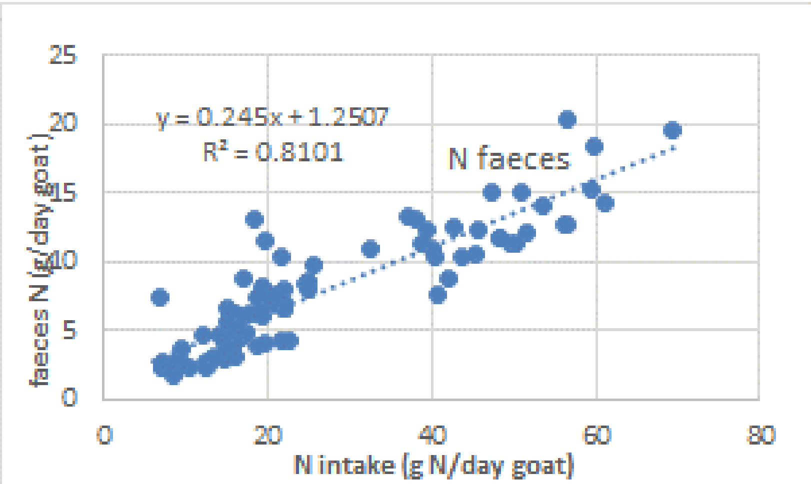


Figure 23. Daily N excretion as faeces output per animal expressed in relation to daily N intake.

Nitrogen excreted in faeces is reported to be rather constant in proportion to DM intake, about 8 g kg^{-1} DM ingested according to Peyraud et al. (1995). Urinary N excretion, on the other hand, appears to be more variable. Increases in dietary protein or N intake generally lead to substantial increases in urinary loss (Van Soest 1994) with almost all N ingested in excess of animal requirement excreted in urine Peyraud et al. (1995).

An example of the partition of N intake into N in milk and excreted N (as urine and faeces) is provided below (Figure 24).

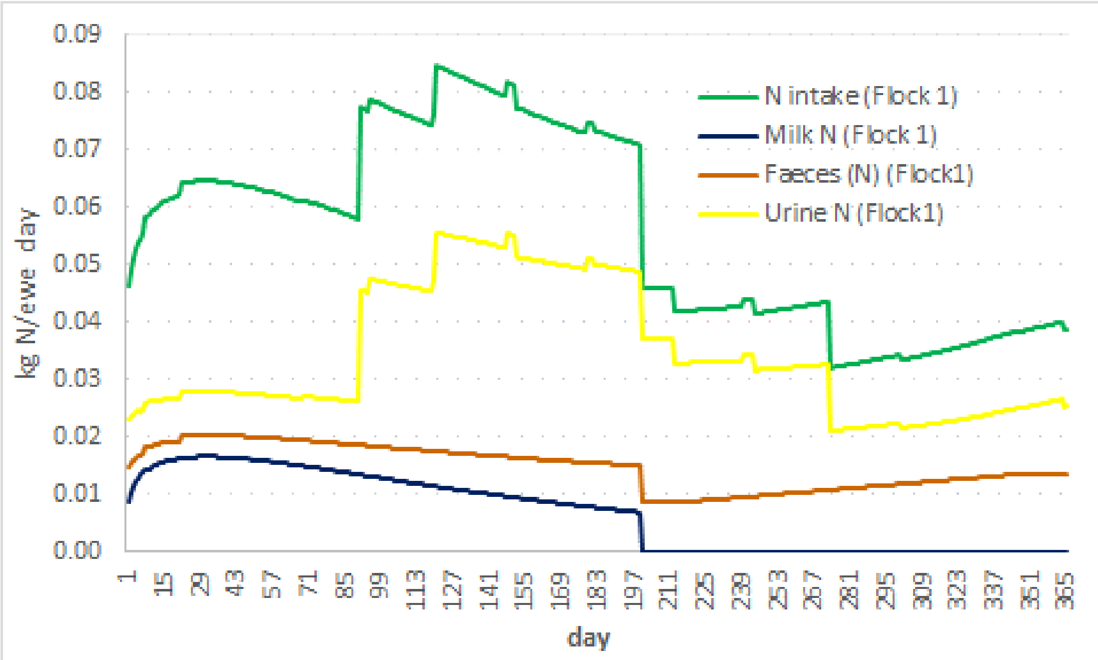


Figure 24. Example of daily simulated N balance for a dairy sheep flock (Chios breed) lambing in January.

It is assumed that most of the urine N is mineralized within a few hours and that 22 % of the dung N is readily mineralisable and will contribute to the TAN pool in the excreted N pool and to NH_3 volatilization.

Manure is formed in the house by mixing excreta, feed losses and bedding material. A small percentage of the DM offered in the house is considered to remain on the floor of the housing facilities and is simulated to be mixed with the bedding material and the animal excreta. The model simulates the DM, N, P and C manure flows and losses along the different stages of manure management prior to soil application: production and storage. The application of manure is subsequently simulated within the soil-based sub-models.

Nitrogen and C flows for each of these pools are calculated using the input values of CP (for N) and the C contents of feed: 0.4 kg C/kg DM for forages and 0.4 or 0.45 C/kg DM for protein-poor and protein-rich concentrates, respectively.

Volatile solids (VS) are the organic material in livestock manure and consist of both biodegradable and non-biodegradable fractions (IPCC, 2006). The VS content of manure equals the fraction of the diet consumed that is not digested and thus excreted as faecal material which, when combined with urinary excretions, constitutes manure (IPCC, 2006). For volatile solids (VS) excretion rates we used the IPCC (2006) approach by which total VS in excreta is derived from the DM intake and feed composition (%DE, ash content) as follows:

$$VS_{LOAD} = (GE\ (1-DE/100) + (UE\ GE)((1-ASH)) \qquad \textbf{\textit{Eq 41}}$$

Where:

(UE GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine).

An example with the daily VS load and emptying from a farm yard manure (FYM) – based system is shown in Figure 25 below.

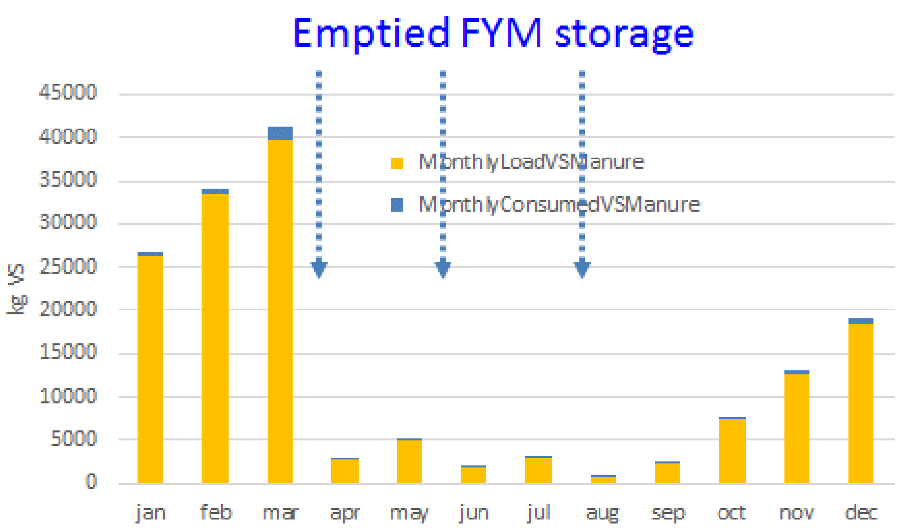


Figure 25. Example of monthly simulated VS manure storage load and emptying for a dairy sheep farm of 300 ewes (Chios breed) lambing in January.

For manure deposited by grazing animals onto pasture, ranges and paddocks, a single emission factor per unit of volatile solid excretion is used.

An example of how the model functions for nitrogen load and emptying from the manure storage system is shown below (Figure 26).

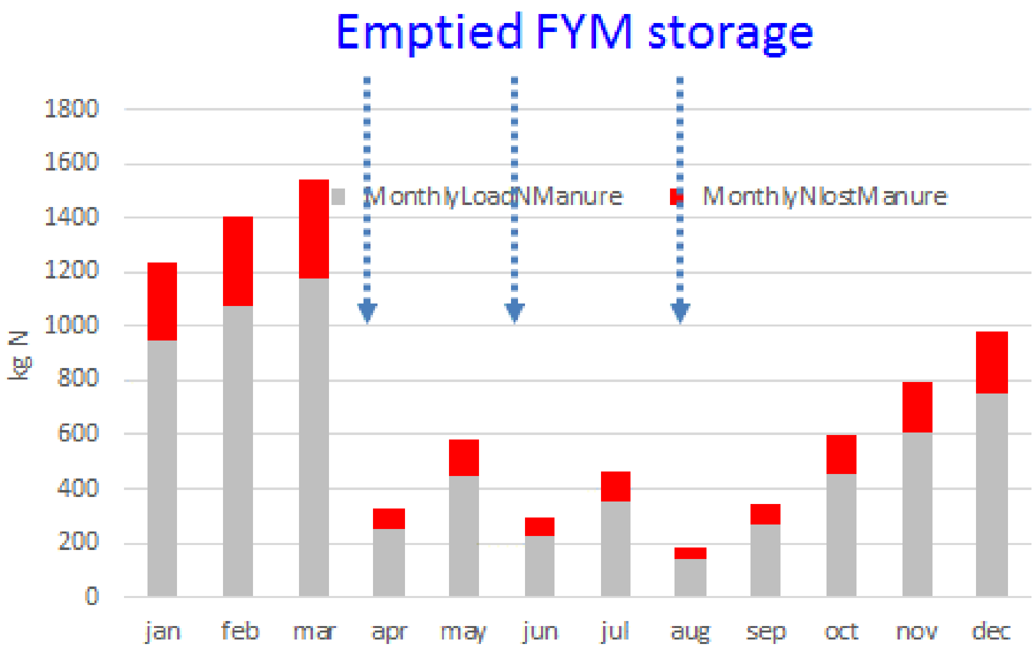


Figure 26. Example of monthly simulated manure storage N load and emptying for a dairy sheep farm of 300 ewes (Chios breed) lambing in January.

Methane emissions from manure storage are simulated using Tier 2 methodology from IPCC (2006) as a function of manure volatile solids (VS) and mean air temperature:

$$\text{kg } CH_4\text{/day (manure storage)} = VS_{LOAD}\ B_0\ \ 0.67\ \text{KMCF\_Factor} \qquad \textbf{\textit{Eq 42}}$$

Where B_0 is the maximum CH_4 producing capacity (m^3/kg VS) for manure produced (m^3/kg VS) and the KMCF_Factor is the CH_4 emission potential of liquid manure. Emissions from liquid systems increase exponentially with increasing temperatures. The maximum methane-producing capacity of the manure (Bo) varies by species and diet. The model uses as default B_0 values of 0.19 and 0.18 for sheep and goats, respectively.

The amount of methane generated by a specific manure management system is affected by the extent of anaerobic conditions present, the temperature of the system, and the retention time of organic material in the system.

KMCF_Factor values are determined for a specific manure management system and range from 0 to 100 % and indicate the potential CH_4 output based on their readily biodegradable organic matter present in the manure. A higher KMCF result in higher CH_4 potential emissions. KMCF values for liquid manures are highly temperature dependent and are calculated using the following equations based on the van´t Hoff-Arrhenius equation. This approach is consistent with the IPCC Guideline (IPCC, 2006).

AFACtorSlurry=15175 ((Temp+273.15)-303.15) ***Eq 43***

BFACtorSlurry=1.987 (Temp+273.16) 303.16 ***Eq 44***

KMCF_Factor=EXP(AFACtorSlurry/BFACtorSlurry) 0.39/0.13 ***Eq 45***

Where Temp is the temperature in the house/storage pit (in ºC). Subsequently, the annual emission is calculated from the estimated total amount of days of manure in storage. The model simulates that the manure pit is emptied a number of times per year (user input data) and that the manure storage volume changes dynamically as it daily accumulates until emptied.

For solid manures the model takes manure emission factors based on Pardo et al. (2015).

An example of how manure CH_4 losses from manure storage may compare with those from enteric CH_4 is shown below (Figure 27).

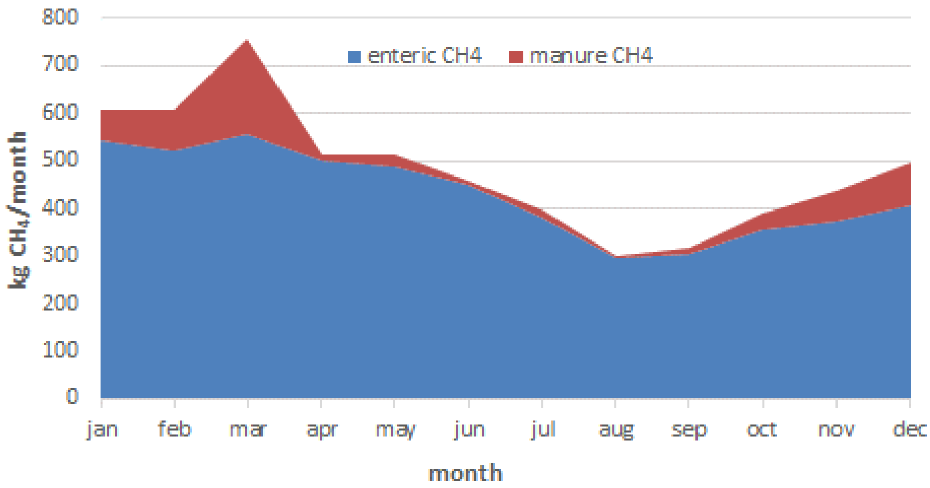


Figure 27. Example of monthly simulated total enteric CH_4 losses with those resulting from manure storage of a dairy sheep farm of 300 ewes (Chios breed) lambing in January.

The total initial ammonium N (TAN) in manure is calculated to be related to the urine, dung, bedding and feed loss in the manure. Ammonia, N_2O, NO_x and N_2 emissions are calculated from the pool of TAN in manure N according to different emission factors (EFs) for different manure management stages before application (housing and storage). Manure N losses are simulated following the principles of a mass-balance approach from Webb and Misselbrook (2004), by which NH_3, N_2O, NO_x and N_2 emissions are calculated from the pool of total ammonium nitrogen (TAN) in manure N according to different emission factors (EFs) for different manure management stages before application (housing and storage).

An example of simulated manure N losses is shown below (Figure 28).

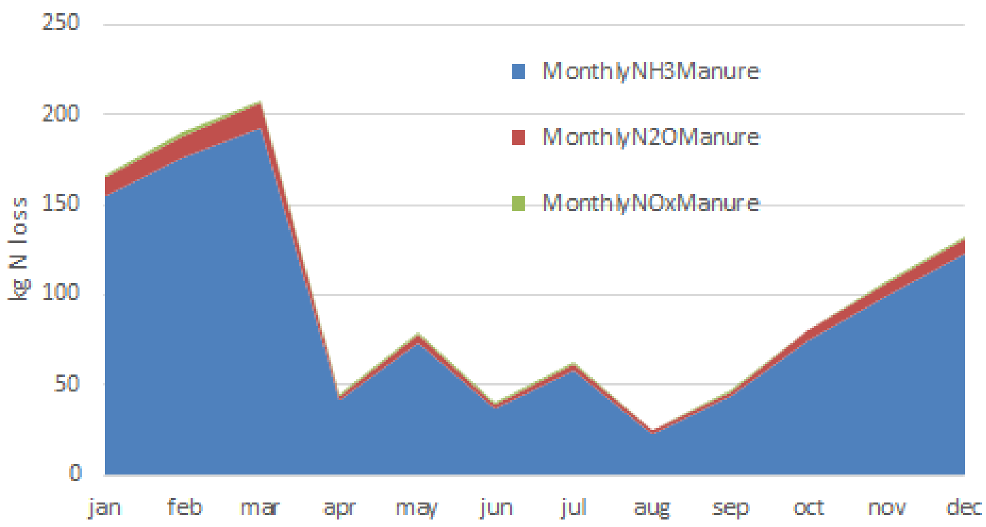


Figure 28. Example of monthly simulated total N losses in different forms of N resulting from manure storage of a dairy sheep farm of 300 ewes (Chios breed) lambing in January.

The N and P contents of manure produced during manure storage and housing are simulated to be fully applied to the different farm fields unless otherwise stated (i.e. exported).

Although we know that some NH_3 emissions (Misselbrook et al., 2001; 2006) and substantial run-off incidents (Edwards et al., 2008) may come from the hard standings area –for simplicity we choose not to include hardstanding areas in the model, as there are too many unknown factors which we cannot include (e.g. area of concrete, frequency of use, frequency of scraping etc.).

After subtraction of ammonia volatilization from the N deposited, the remaining N and VS is available for plant uptake, losses or storage after application to soils (or exported).

3.3.5 Simulation of the effect of heat stress on milk productivity, weight gain, energy requirements and dry matter intake

The approach is thoroughly explained in WP3 (D3.2). Two different approaches (semi-mechanistic and empirical) have been developed to capture the influence of heat stress on sheep and goats productivity, both using the temperature and humidity index (THI) as the indicator of thermal stress severity.

The semi-mechanistic model developed follows an energy balance perspective. The decline on productivity induced by heat stress is attributed to two main causes: a) a reduction on feed intake and b) an increase in energy maintenance requirements.

Heat-stressed animals decrease feed intake in an attempt to create less metabolic heat, since feeding is a source of heat production of significant importance in ruminant animals (Kadzere et al., 2002). Based on NRC (1981) and a review conducted for sheep and goats, a relationship was developed to capture the gradual reduction on feed intake under hot conditions (Figure 29).

Under heat stress conditions energy requirements for maintenance are expected to be significantly increased (by 7-30% (NRC, 2001) mainly due to a rise in body temperature and respiration rate (Sevi et al., 2012). A meta-model is developed to correct the magnitude of the increase in energy requirements depending on the severity of heat stress (Figure 30).

Finally, an energy balance is applied to account for the implications that these two mechanisms have on the energy available for production, and ultimately in the animal efficiency and productivity (Figure 31).

The empirical approach is based on regression models. In contrast to semi-mechanistic approach, its simplicity allows it to be implemented directly into the last step of the farm modelling framework to account for the effect of environmental conditions on the productivity (Figure 32).

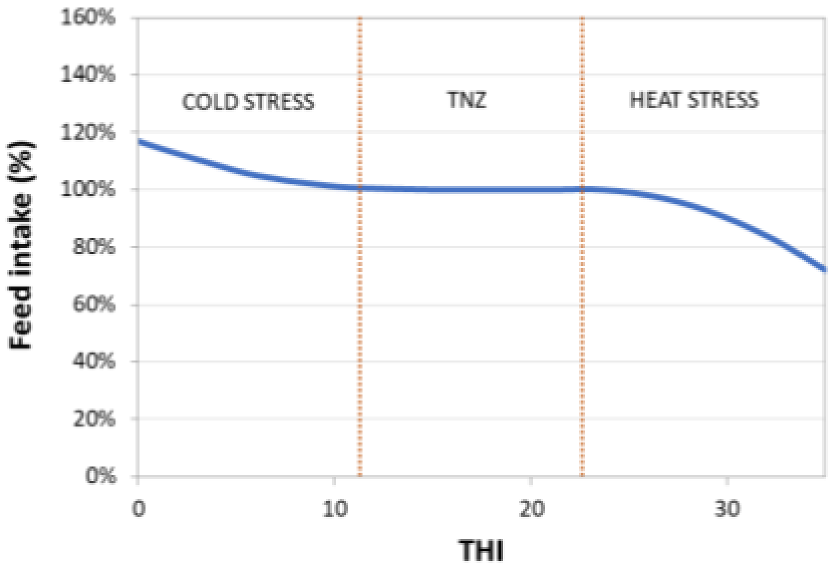


Figure 29. Effect of thermal stress conditions (THI) on feed intake of lactating small ruminants. (THI_{CS} threshold = 11.5; THI_{HS} threshold = 22.2).

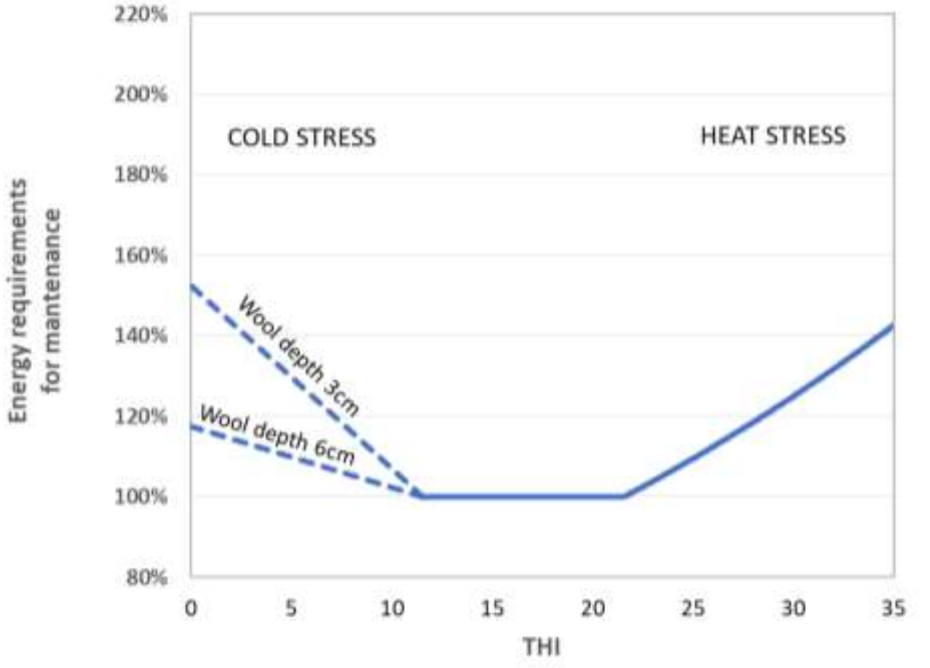


Figure 30. Estimation of increase on energy requirements for maintenance under cold stress (THI_{CS} threshold = 11.5) and heat stress conditions (THI_{HS} threshold = 22.2).

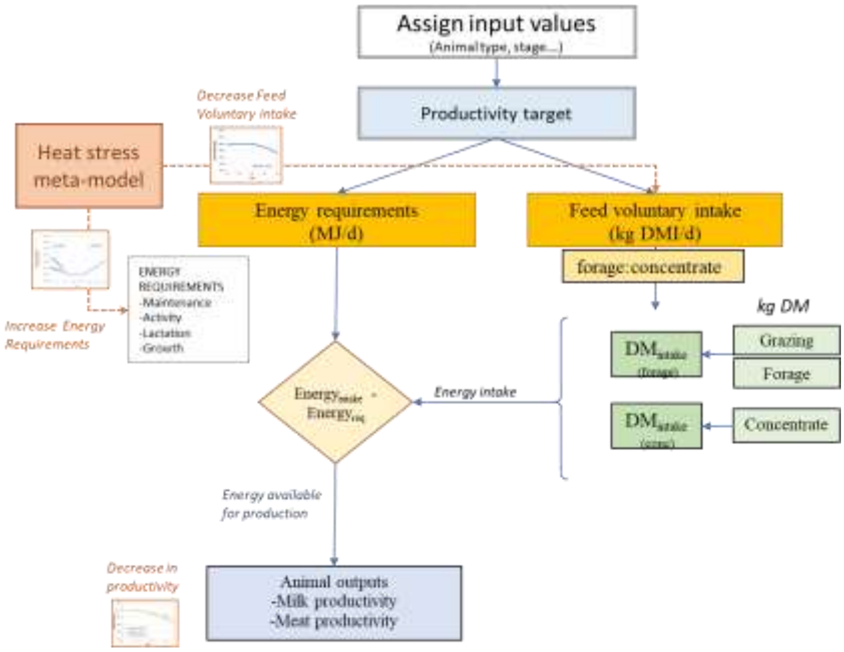


Figure 31. Integration of the heat stress meta-model (approach 1) into the farm modelling framework (SIMSSR) to account for potential reduction in productivity

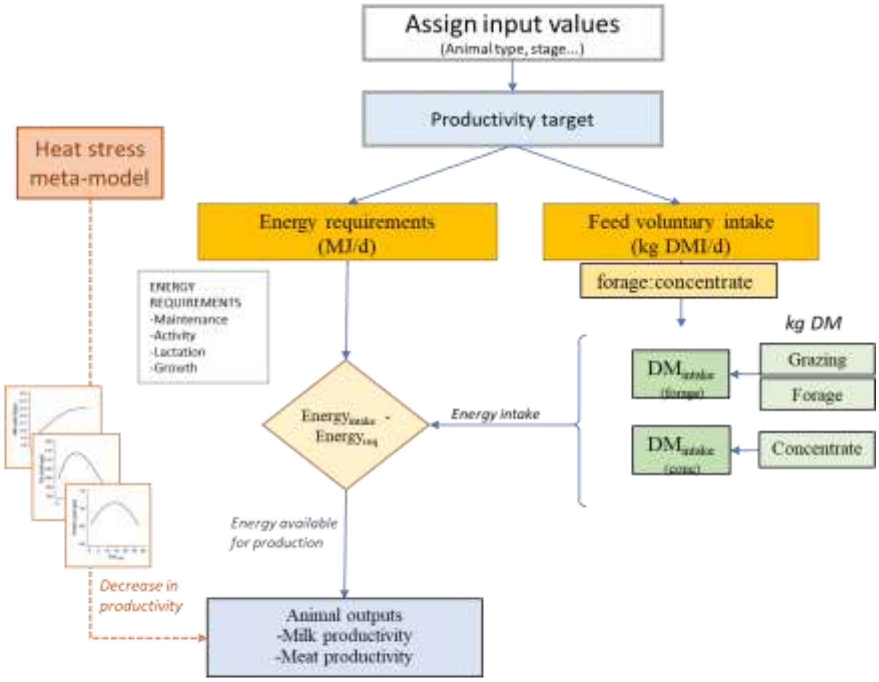


Figure 32. Integration of the heat stress meta-model (approach 2) into the farm modelling framework (SIMSSR) to account for potential reduction in productivity.

3.3.6 Land use management, productivity and emissions

SIMSSR calculates the effect of herd management, soil type and weather/climate conditions on land productivity and nutrient emissions (gaseous and diffuse pollution to waters). For simplicity purposes and considering the large diversity of land types that small ruminant farming systems may occupy in Europe, the model defines the following generic land uses associated to feeds classes as follows (Table 15).

Table 15. Generic land uses associated to feeds classes

Land use/feedstuff class	Where is it produced?	costing
Grazing		
Grazed Grassland-Lowland	on-farm	labour for shepherding and land management
Grazed Grassland-upland	temporarily leased	labour for shepherding
Grazed Grassland-Mediterranean	temporarily leased	labour for shepherding
Grazed Grassland-highlands	temporarily leased	labour for shepherding
Grazed Fallow	temporarily leased	labour for shepherding
Grazed Crop Residues	temporarily leased	labour for shepherding
Grazed whole Crops	on-farm	labour for shepherding and land management
Conserved/cut/fed in the house		
Silage/hay Grassland Lowland	on-farm	labour for land management
Silage Maize	on-farm	labour for land management
Silage/hay Forage Legume	on-farm	labour for land management
Grains cropland	on-farm	labour for land management
Bought/fed in the house		
Bought Concentrate*	market	depending on ingredients
Bought Forages*	market	depending on forage bought

*The model incorporates a small calculation of impacts associated to the production of purchased feed (including land use and emissions)

The simulated farm scenario has to define a number of hectares of each type of land use that animals will get feed from.

For the farm scenario to run, the user must also specify on a daily basis and for each herd group/flock the potential access to feed from each of this land uses. For grazed feed this potential is realised if enough plant material is available on that date and assuming certain rules/assumptions where young, male and dry animals are prioritised on the access to this feed resource and land. For non-grazed feed (housed) this potential is realised if the feed stocks are available on the date. This feed stocks are created or topped-up on the dates after harvesting/mowing of fields.

For the potential use of each on-farm/leased area feed/land the model has defined different variables that take a 0-1 value depending on whether no potential access is assumed to a specific land/feed (0) or full access is allowed (1). Table 16 and 17 show the variable name and briefing of what the variable refers to for indoors and grazing, respectively.

Table 16. Variable name within the model code and briefing of what the variable refers to for housing

VARIABLE NAME	WHAT IT REFERS?
TRUE_GrassSilage	Silage/hay of grass
TRUE_MaizeSilage	Silage of Maize
TRUE_Straw	Cereal straw, mainly from crop residue of cereals
TRUE_CropGrainFeed	Cereal grains produced in the farm by the farmer
TRUE_CropLegumesFeed	Legumes or other crop produced and harvested for the flock (e.g. lupins, alfalfa…)
TRUE_CropRFeed	Crop Residue Feed. Any crop residue except cereal residue (straw). Rapeseed cake, vineyard residue, etc…

Table 17. Variable name within the model code and briefing of what the variable refers to for grazing

VARIABLE NAME	WHAT IT REFERS?
TRUE_ GrazCropR	Grazing crop residues
TRUE_ GrazFallow	Grazing fallow lands
TRUE_ GrazMont	Grazing on mountain lands
TRUE_PoorGraz	Grazing poor quality pastures
TRUE_ GrazUp	Grazing uplands, specially UK
TRUE_ GrazLow	Grazing atlantic grassland, valleys High quality

Due to the diversity of land uses covered by the model, $SIMS_{SR,}$ in its current version has incorporated and modified different existing crop/pasture models (e.g. NGAUGE (Brown et al., 2005), $SIMS_{NIC}$ (Gallejones et al., 2016), NFIXCYLE (Scholefield et al., 1995) that have been validated in the past and used for specific agro-climatic and conditions and crop types (e.g. NGAUGE: Atlantic pastures, $NGAUGE_{MAIZE}$: Atlantic forage maize, $SIMS_{NIC}$: Mediterranean cropping). Also, based on Gallejones et al. (2016) a water balance submodel has been incorporated in order to simulate the water that is lost bellow the rooting zone. For some land uses (e.g. grazing on mountain lands) the model has incorporated simple approaches which rely on the availability of existing case-by-case data to estimate plant material productivity, grazing potential and effect of weather/climate on plant material productivity. This approach is, in a way, similar to that already used by other models, e.g. in Olesen et al., (2006), where gross yield and crop N demand are defined for the farm as an input.

Moreover, $SIMS_{SR}$ has flexibility to incorporate specific existing approaches to improve the simulation of specific land uses under different regions but this is beyond the potential scope for $SIMS_{SR}$ current version.

.3.3.6.1 Water balance sub-model

The main principles of the model are explained in Gallejones et al. (2016). For the current version of $SIMS_{SR}$ we have the possibility to run the water balance model daily or monthly. The choice will be decided upon the temporal resolution of weather/climate input data.

The water balance submodel is based on Allen et al. (1998). The model requires the soil texture and climatic parameters to estimate the daily/monthly drainage. The main assumption for the soil structure is that the soil profile has a single and homogeneous layer with a depth equal to the rooting depth and with negligible lateral movement. The water requirement by the crop is calculated from the reference crop evapotranspiration (ETo). The potential evapotranspiration (ETc) is calculated multiplying the ETo by a crop factor (Kc) which depends on the developmental stage.

The downward movement of water is based on the excess of field capacity. The available water (TAW) in the rooting zone is initially calculated through the difference between the volumetric water content at field capacity (VFC) and at wilting point (VWP) for each soil type.

If rainfall is enough to meet crop needs (ETc), actual evapotranspiration (AET) will be equal to ETc. The rain excess that has not been used for crop needs is stored in the soil until exceeding the water soil capacity (TAW), when the excess of water is drained bellow the rooting zone. When ETc is higher than the rainfall rate, there is a water deficit which could be offset by taking some of the water stored in the soil. When the soil water content is bellow a threshold, the water is more difficult to be removed by the crop and a soil plant water stress occurs. The portion of available water that a crop is able to uptake without having a water stress is defined as easily removable water. This value is calculated depending on the daily previously estimated ETc and the “p” parameter (Allen et al. 1998), which represents the fraction of TAW that can be depleted before water stress occur.

.3.3.6.2 Grassland sub-model

Grass silage/hay from grasslands is simulated using the main principles from NGAUGE (Brown et al., 2005), NFIXCYLE (Scholefield et al., 1995) and NCYCLE (Scholefield et al., 1991). These models have been originally developed for a UK context. In the last 20 years and throughout varied number of studies these models have been used for cattle (dairy and beef) and sheep (meat) contexts and have been adjusted to countries in Europe other than UK (e.g. GREENDAIRY EU INTERREG project covering the Atlantic region in Europe).

Prediction of DM yields, grazing and N flows are simulated for grassland swards or mixed grass & clover swards. Yield response is sensitive to inorganic N flows in the soil, soil water availability and temperature. The model uses the main functions from NGAUGE (Brown et al., 2005) but it has been calibrated to account for CO_2 fertilisation and to improve sensitivity to temperature and soil water content using the information from D3.3 (pastures meta-models). From D3.3 we incorporated for each of the 5 agro-climatic regions parameters to account for changes in productivity in long term vs. temporary grasslands. These parameters account for the effects of elevated atmospheric CO2 concentration, elevated temperature and changes in soil water availability. Some specific variables account for the effect of: rainfall in April and May or average temperature in June, July and August, the number of harvests per year, percentage of nitrogen-fixing plants (e.g. white clover). From the 3 approaches used in D3.3. we selected to use the results from the linear regression models. The sub-model within $SIMS_{SR}$ simulates with a monthly resolution grass and clover response so it cannot capture extreme weather events that may occur on a daily basis.

Grass DM response in mixed grass and clover swards is predicted by the proportion of sward clover in equilibrium and normalised by the existing factors which have an effect on grass and (ii) mineral N fluxes in the soil regulate the inhibitory effect of NO_3 on the N_2 fixation activity of established clover root nodules and hence, the ratio of Fixed N: uptaken N in the clover plant (Nesheim and Boller, 1991).

$SIMS_{SR}$'s assumption is that grassland fields in the farm can be simplified as either a field for only cut/mown for silage/hay or a field area where there is a grazing and potentially some additional cuts. The submodel assumes an optimal utilisation by the animals depending on the availability of pasture. The amount of pasture consumed each month is limited by that available as predicted by the model. The amount consumed is also limited by the forage requirement of all animal groups grazed. The model does not allow for pasture forage to be carried over from a given month to the next; therefore, forage grown during a given month must be used during that period.

Predicting the nutritive content of grazed forage is very difficult since animals are selective in what they consume. Grazing animals tend to eat the plants and the plant parts that are highest in nutritive value. For simplicity, the nutritive contents of pasture are assigned with different values during the various months of the grazing season. Crude protein of the swards is simulated monthly using empirical relationships relating soil N availability and crude protein for different periods of the year. Digestibility is simulated to change during the season according to empirical relationships accounting for NDF content of the sward.

Pasture is allocated along with other available feeds to meet the nutrient needs of each animal group in the herd while making best use of the available pasture. This is done by developing a balance diet that best compliments the quantity and nutrient content of the pasture consumed. The pasture consumed by a given animal group is limited by either that available or the maximum amount of pasture forage that can be consumed by that animal.

Allocation is done each month to make best use of the pasture available that month, and stored feed inventories are modified to prepare for the allocation next month.

The goal in the allocation each month is to use as much of the available pasture as possible, and to use stored forages at an appropriate rate.

The calculations can be summarised in 10 steps:

(1) The simulated water balance provides variables of monthly hydrologically effective rainfall (HER) and soil water content as %WFPS that can be used as inputs by this sub-model as parameters for calibration of the effect of soil water content on grassland productivity and to calculate NO_3 leaching losses per hectare and concentration in the leachate (based on Brown et al. 2005).

(2) The N manure pools that have been already calculated in the herd and subsequently manure sub-models are applied to the soil (unless exported) at field rates given by user input. Mineral fertiliser application rates and timing for each field type areas are user-input values. All the harvested grass will be simulated to undergo silage or hay making and will be stocked from each harvested month and potentially offered to the animals until depletion or a certain rule to stock and carry over (i.e. for sale or store instead of self-consumption).

(3) Flows of N losses (N_2O, NO_x, N_2) and products (milk N and N, and DM plant yields) are simulated on a per hectare basis within the submodule (based on Brown et al. 2005). The approach goes beyond an IPCC-based TIER2 approach and directly accounts for factors such as soil water content, CO_2 respiration and soil inorganic N flows, and indirectly to factors such as temperature.

(4) Ammonia emissions from manure application to the soil are calculated as described in Brown *et al.* (2005). The original EFs were modified to improve sensitivity of NH_3 losses to changes in manure management factors using equations from the decision support system, MANNER (Chambers *et al.*, 1999). New EFs for NH_3 volatilisation from slurry were used for application on grassland and maize land according to: (i) properties of the slurry (% DM), (ii) application date (for soil moisture content), (iii) incorporation timing after application, (iv) method of application and (v) method of incorporation. Ammonia volatilisation from FYM application accounted for factors such as

incorporation delay and technique.

(5) As in the model SIMS$_{DAIRY}$ (Del Prado et al., 2011) SIMS$_{SR}$ also includes the possibility to use certain potential innovations at the level of nitrification inhibitors (del Prado et al., 2010) or new grass genetic traits (Del Prado & Scholefield, 2008).

(6) As in the model SIMS$_{DAIRY}$ (Del Prado et al., 2011) SIMS$_{SR}$ also includes a simple estimation of silage making losses.

An example of the effect of change in monthly rainfall on DM herbage production is shown in the figure below (Figure 33).

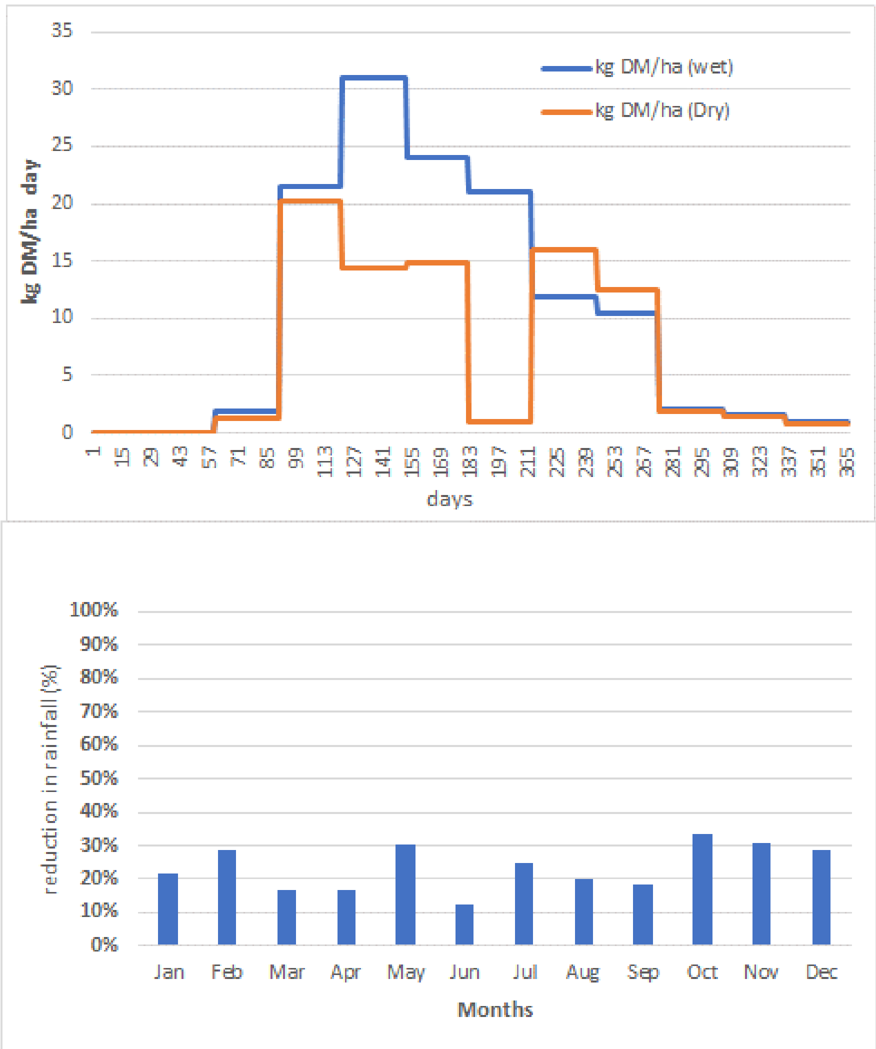


Figure 33. Comparison between herbage productivity in a wet compared with a dry year.

.3.3.6.3 Cropping sub-model

$SIMS_{SR}$ uses the basis of the existing $SIMS_{NIC}$ (Simulation of Nitrogen in Cropping systems) model (Gallejones et al., 2016). This model calculates N cycling, DM yield for the different parts of the plant, N losses and the main processes involved through the different components of the soil-plant system following a mass-balance approach.

The model partitions the plant into 3 (grain, shoot and roots) parts. It simulates on a monthly basis the N flows and losses per hectare of a 3-year crop rotation. $SIMS_{NIC}$ has been parameterized for rainfed wheat and rapeseed cropping systems. As data becomes available, we expect to be able to rotations involving other different crops and climatic conditions. For different crops new empirical curves for plant simulation will be developed while assuming that the simulation of soil processes follows the same principles as shown here.

Crop N and dry matter (DM) for the different plant parts (grain, shoot and roots) are estimated as a function of the annual inorganic N flows (sum of all the N inputs to the system) and weather conditions. Calculations are carried out through several iterations until annual mineralised N reaches a steady state. Then, the model recalculates the soil water balance and simulates N flows in the soil-plant system using a monthly time-step. For each month of the 3-year rotation and the extra initial year, N flows are monthly simulated at the plant level (using the annual values and a function relating relative plant N uptake over the total N uptake and developmental stage of the crop) and the soil level (N mineralisation and N losses) (details are provided in Gallejones et al., 2016). The inorganic N that is not lost nor taken up by the plant is simulated to be carried over to the subsequent month. Calculations are carried out for several iterations until annual mineralised N reaches a new steady state.

The main inputs to the model are: (i) daily or monthly climatic variables (maximum and minimum temperature and rainfall), (ii) soil type (texture), (iii) fertilisation management (fertiliser type, monthly rate, manure application and its incorporation technique, and timing) and (iv) cropping management (seeding date, harvest date, tillage strategy, management of plant residues and use of nitrification inhibitors). The outputs of the model are monthly N flows (e.g. plant, mineralisation) and losses (N_2O, N_2, NO_x, NO_3^- leaching and NH_3), and DM yield.

Eight developmental growth stages (sowing, tillering, jointing, booting, heading, anthesis, grain filling and harvest) were considered to make a cumulative N uptake curve Temperature is considered the main factor affecting crop development, thus the accumulation of daily mean temperature above a base temperature, expressed as growing degree days, is used to predict each developmental stage.

As an example, Figure 34 shows % of N taken up by the plant for each development stage of the plant (rapeseed) as a function of cumulative growing degree days (GDD)

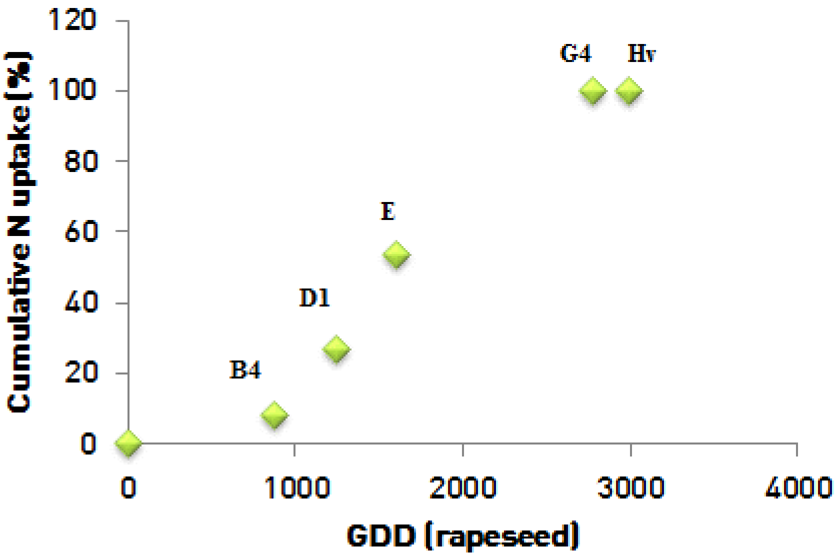


Figure 34. N taken up by the plant for each development stage of the plant (rapeseed) as a function of cumulative growing degree days (GDD)

.3.3.6.4 Forage maize submodel

For forage maize DM yield and N flows and losses are predicted using empirical equations (after Van de Ven 1996), which relates the amount of annual inorganic N flux in the soil to the amount of N and dry matter (DM) in the harvestable part of the plant. The parameters have to be adjusted for the expected dry matter yields of a particular European region.

Details of the management of the maize fields are shown in Table 18.

Some results of DM yield, N in yield, leached N (total load, peak N and average N concentration in the leachate), NH_3, N_2O, N_2 are shown below for an Atlantic French situation

Table 18. Results per hectare of DM and N yield, leached N (total load, peak N and average N concentration in the leachate), NH_3, N_2O, N_2 in maize fields.

Maize		**Den**	**NH_3**	**Leached N**	**NO3-N**		**N_2**	**N_2O**	**NO**	**N_2O nit**
kg N/ha	kgDM/ha	Kg N//ha			mg N/L		Kg N/ha			
123	12100	24.7	26.5	31.9	12.9	7.1	20	4.7	0	0.7
122	12007	25.9	24.8	33.4	13.5	7.4	20.9	5	0	0.7
142	13379	26.3	44.2	31.2	12.6	6.9	21.4	4.9	0.1	0.7

.3.3.6.5 Simulation of SOC changes based on RothC model

$SIMS_{SR}$ has incorporated the existing RotchC model. The Rothamsted carbon (RothC) model (Coleman and Jenkinson, 1996) is one of the most widely used models to simulate SOC dynamics. RothC has been evaluated in a variety of ecosystems such as croplands, grasslands and forests and under different soil types and climatic conditions, including semi-arid environments.

A detailed description of the model is given by Coleman and Jenkinson (1996). RothC's simulation runs are based on relatively few parameters and input data that are readily available (Smith et al., 1997): soil type, temperature, moisture content and plant cover. Soil organic carbon is split into four active fractions and one small inert organic matter (IOM) fraction. The active fractions are: decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO), and humified organic matter (HUM). Each fraction decomposes by a first-order process with its own characteristic rate, while the IOM fraction is considered to be resistant to decomposition. For the $SIMS_{SR}$ we have modified the RothC model in order to incorporate the grazing activity and manure amendments. Pasture yield responses and SOC accumulation may also be altered by poaching and compaction by the animals. This effect has been introduced in the RothC model (Figure 35). Soil compaction and yield decline may occur in seasons such as moist summer or autumn periods, particularly in temperate climates.

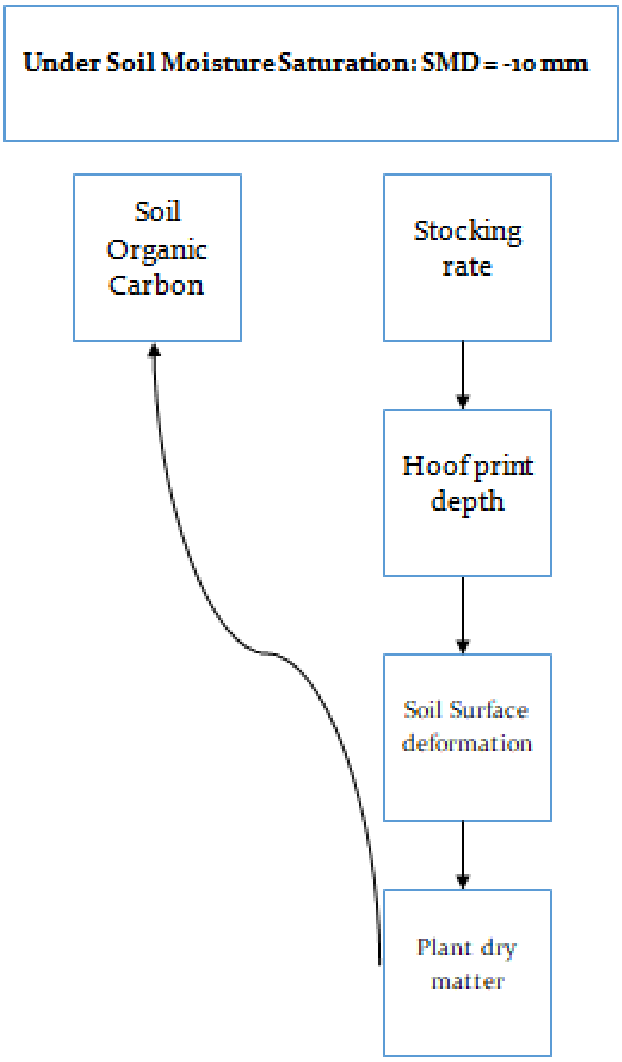


Figure 35. Model of poaching effect on SOC sequestration

Outputs from the grassland model are used as inputs to RothC through default C/N ratios conversion factors.

Dead grass/crop residues quality simulation is variable and depends on several factors. The RothC version integrated in $SIMS_{SR}$ simulates the fact that forage quality declines with advancing maturity. Forage quality also is influenced by climate variables via the negative effects of high temperatures accelerating tissue ageing at the seasonal scale and moisture stress.

In order to take into account the variability of forage quality and its effect on SOC accumulation, we incorporated equations that empirically predict neutron detergent content (NDF) of forage. This NDF content modulates the amount of the different C quality (degradability) from plant residues.

For assessing the ratio between roots and shoots we also incorporated new functions that account for N fertilisation on this ratio.

.3.3.6.6 Simulation of other land uses

For other land uses in different countries we are currently incorporating information about typical yields and quality of forages (e.g. Mediterranean grasslands: Papachristou et al.,1994; 2005; Hadjigeorgiou, 2011). This is an ongoing task that will be fulfilled as the different scenarios are simulated within the scenario testing task.

3.3.7 Carbon and nitrogen balances in the farm

Figure 36 illustrates a diagram of the main components, inputs, outputs and N and C (Figure 36) flows and emissions (e.g. C and N) from a small ruminant livestock system based on Del Prado et al. (2013). Depending on the farm typology, the farm comprises land for home-grown feed purposes and thus, a soil-plant component whereby crops or forage are subsequently fed to the housed animals or grazed. Animal excreta are recycled within farm fields whilst grazing or on the farm via collection, storage and subsequent application of manure to the soils (or exported to another farm). The C and N cycle through the different farm components; their flows and losses are affected by management and weather conditions. Carbon dioxide (CO_2) exchange is regulated by processes which fix C in the system and those linked with respiration processes or direct energy use. Methane is primarily produced in the rumen and in anaerobic storages of organic matter such as manure and silage. Atmospheric N is fixed by leguminous species and N_2O emissions are generated by both denitrification and nitrification processes in manure storages and soils and indirectly from N lost from the farm in ammonia (NH_3) volatilization and nitrate (NO_3) leaching.

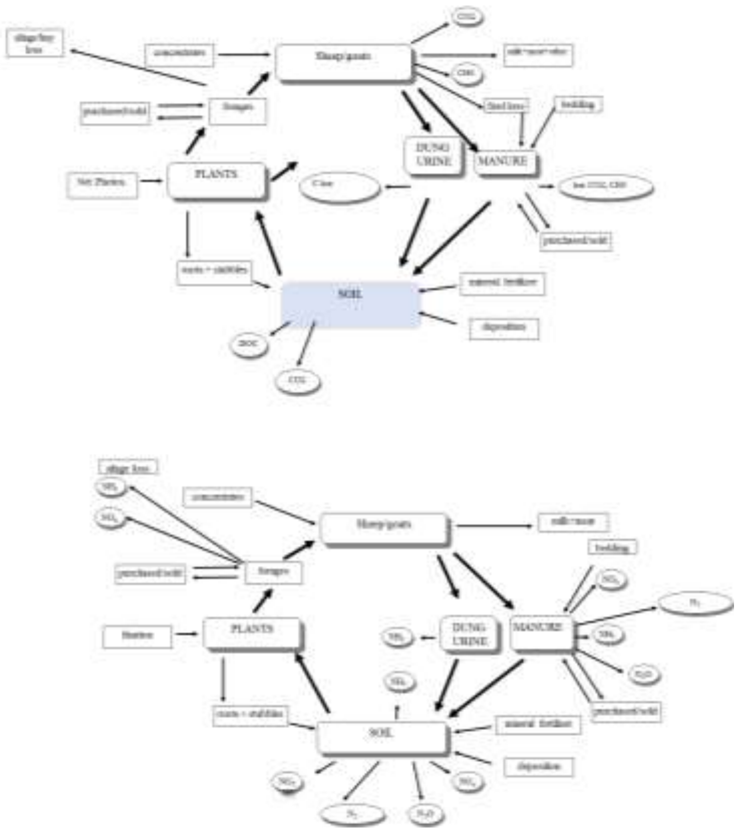


Figure 36. Diagram of flows of C and N simulated in the SIMS$_{SR}$ model

The water, C and N cycles are tightly coupled and very much influenced by farm management and the environment. $SIMS_{SR}$ is able to test measures that may increase N use efficiency, reduce N and C emissions and promote greater productivity. The measures that operate at one farm component may however affect C and N flows in other components. $SIMS_{SR}$ model is able to simulate some of these interactions.

3.3.8 Economic SIMS$_{SR}$ sub-model

The SIMS$_{SR}$ model makes a simple calculation of the revenue and costs attributed to sheep or goat farming in a European context. There are a series of econometric relationships that replicate the underlying production and cost structures of small ruminants' management farm. Considering the diversity of systems in Europe, the model currently has the basic structure to make a calculation of a simple net farm margin but it requires specific economic data regarding the typology and context under study.

The farm incomes which are expected to account the most are milk and meat mainly (wool could be representative in some systems); but in the context of the European Union and under a Common Agricultural Policy, subsidies are necessary to take into account under different scenarios and due to its importance in the economy of many farm systems. In the case of farm costs feed purchases are expected to suffer the most variability, not only in the case of concentrate prices, but also the cost of grazing and fodder. For milk pricing, the user may use fixed prices or try a pricing scheme where milk price depends on fat and protein content, seasonality of production and pattern/volume of milk supply. As it was proposed for dairy cattle systems in the existing model SIMS$_{DAIRY}$ Del Prado et al., 2011) a base milk price (€ Lmilk-1) can be modified accordingly with these factors. For meat pricing, the user may use fixed prices too or try a pricing scheme being the seasonality of production and the carcass weight the most important variables.

To approach with farm economic profitability we can consider many economic aspects for the model, but we can focus on that ones that can be modified with the model. Specially those relative to feed availability and milk and meat production. For the assessment of the prices' volatility and the capacity of the farmer to have a quick answer with a set of strategies we are contemplating to incorporate some of the following indicators:

- Feed self-reliance, as the capacity of the farmer to obtain his own feed of the total feed requirements of the flock.
- Concentrates expenses/ total expenses, the importance in economic terms of feed expenses in total farm costs.

- Feed expenses/total expenses, measuring the weight of total feed expenses in the global costs of the farms.
- Feed expenses= fodder + concentrates + grazing expenses
- Feed expenses /litre milk
- Feed expenses/reproductive ewe or goat.
- Incomes
- Milk income/ litre sold
- Milk income/reproductive ewe or goat.
- Meat income/lamb or kid sold
- Meat income/ reproductive ewe or goat
- Milk income / feed expenses
- Meat income / lambs or kid sold
- Feed expenses / litre of milk sold
- Feed expenses / kg lamb or kid sold
- % Human-edible feed of total feed
- Stability of Net Margin; variation of net margin along some years.
- % Subsidies / Total incomes; importance of subsidies in the total incomes of the farm.

This list is still under construction and will depend on the scenario testing exercises.

3.3.9 Qualitative attributes of sustainability

The $SIMS_{SR}$ model replicates the scoring system already in place for the $SIMS_{DAIRY}$ model for dairy cattle (Del Prado et al., 2011).

Attributes of biodiversity, milk quality, soil quality and animal welfare can be scored through indices in relation to their contribution to farm sustainability. Some inputs may come from outputs from the previous calculations in the model.

The scoring system for sheep and goat farming systems within the $SIMS_{SR}$ was expected to be fed with specific information from WP1 (sustainability assessments and relationships between management variables and sustainability attributes) but this analysis is still under way.

For animal welfare, the information from WP3 is expected to be helpful to qualitatively assert the incidence of heat stress on general animal welfare. In anticipation, we can summarise some of the variables that were incorporated for dairy cattle systems and potentially could also be relevant for sheep and goat systems. The following variables could be interesting:

- Diet profile effect on the concentration beneficial milk fatty acids (FAs) (e.g. OMEGA-3 FA and CLA) {MILK QUALITY}.
- Grazing pressure {BIODIVERSITY}
- fertiliser rate {BIODIVERSITY}
- cutting management {BIODIVERSITY}
- reseeding management {BIODIVERSITY}
- soil quality {BIODIVERSITY}
- the inclusion of patches for biodiversity (margins, hedges and buffer-strips). {BIODIVERSITY}
- grazing time per year and per day {ANIMAL WELFARE}
- livestock density {ANIMAL WELFARE}
- milk productivity per animal {ANIMAL WELFARE}
- amount of bedding {ANIMAL WELFARE}
- soil quality (poaching and compaction risk in the grazing areas) {ANIMAL WELFARE}

- soil texture, drainage class and soil water content {SOIL QUALITY}
- sward age {SOIL QUALITY}
- stock and manure managements {SOIL QUALITY}

3.3.10 Inputs and outputs in the model

Inputs to the model are:

For the herd are breed and those for production and reproduction performances in Tables 1-6. Also, number of adult ewe/does, expected grazing calendar for each land use type, hectares of each land use type, characteristics of these fields. The main user inputs include those related to land and crop management. These are mainly defined by typical inputs in crop/grassland model used. For example, including for example, mineral fertiliser management, type of soil (texture and drainage status), sward age and history past management. Other input variables that may affect nutrient cycling are related to site conditions (climatic conditions) or genetic traits for plant varieties.

Other inputs to the $SIMS_{SR}$ are: (i) monthly climatic variables (maximum and minimum temperature and rainfall), (ii) soil type (texture), (iii) fertilisation management (fertiliser type, monthly rate, manure application and its incorporation technique, and timing) and (iv) cropping management (seeding date, harvest date, tillage strategy, management of plant residues and use of nitrification inhibitors).

Typical user inputs for the manure management in the model are:

- Type of manure system: slurry-based or straw-based farm yard manure (FYM). Slurry-based and FYM systems operate using cubicle (slatted floor) and loose housing, respectively.
- Storage type: different slurry tanks and lagoons (slurry) and heaps (FYM)
- Application method: broadcast, injection (shallow and deep) and band-spread trailing (hose and shoe).
- incorporation time and technique of incorporation.
- Timing of application and rate (defined as the proportion of total annual manure applied in a period of time) and manure dry matter (DM) content.
- Spatial distribution of manure applied: defined as the proportion of total annual manure applied on each field type.

A summary of the most important outputs from the model are:

Environmental losses:

- Methane (CH_4) from animals (daily)
- Methane (CH_4) and N losses (e.g. N_2, N_2O, NH_3, NO_x) from manure management at different levels (monthly)
- Emissions from farm energy use
- Emissions from pre-farm gate inputs to the farm (e.g. concentrates or synthetic fertilisers) (monthly)
- soil N losses (N_2O, N_2, NO_x, NO_3^- leaching and NH_3) (monthly)
- Soil organic Carbon (SOC) sequestration (monthly)
- C footprint
- Hectares used

Nutrient cycling:

- monthly N and C flows and transformations (e.g. plant, mineralisation)

Productivity

- milk and meat sold (monthly)
- DM yield and quality (CP) (monthly)

Sustainability (socio- economics dimension)

- Milk quality, animal welfare, biodiversity and soil quality qualitative assessment (annual)
- Simplified Economic and social performance (annual)

Other

- soil water status and hydrologically effective rainfall (HER)

3.3.11 Testing the model

An example test of a farm model simulation is carried out under this report and shown below to be used as an illustration to show the potential utility of the $SIMS_{SR}$ model. Some of the sub-models comprising $SIMS_{SR}$ have been partially validated (e.g. grasslands: Brown et al., 2005, cereals: Gallejones et al., 2016, manures: Pardo et al., 2017) or are currently under the latest stages of being formally validated (RothC for grazed pastures: Jebari et al. *in prep*). Further testing with future data from any of the components and processes of the plant-soil-animal system will contribute to improve predictability and robustness of the model. As experimental data becomes available, future versions could incorporate more comprehensive sub-models to improve the simulation of the effect of the interactions between animal, soil, management and climatic conditions to encompass the diversity of European small ruminants' sector.

A more comprehensive $SIMS_{SR}$ model evaluation is part of the next phase in the iSAGE project, where the whole-farm model together with the LP-model are utilised under varied site and systems conditions to run scenarios under current and future climate change conditions and using different innovations. Results from different scenarios involving a varied selection of combinations of systems, breeds and locations will be co-analysed with relevant iSAGE industry partners. Moreover, the presentation of model results as part of a process may also be seen as a form of expert validation (Rivington et al., 2007; Andrieu et al., 2012).

Amongst foreseen innovations to run in next phase, genetic changes in plant and animals, as shown in Del Prado and Scholefield (2008) and Del Prado et al. (2010) for dairy cattle systems, may be instrumental for providing effective methods to increase sustainability (Del Prado and Scholefield, 2008) and decrease GHG emissions (Del Prado et al. 2010).

For the example to run $SIMS_{SR}$ we chose a meat sheep farming system located in north-eastern Spain, at the catchment basin of the Ebro River. We selected a specific weather year (2008). Daily temperature and rainfall is shown for this location in Figure 37.

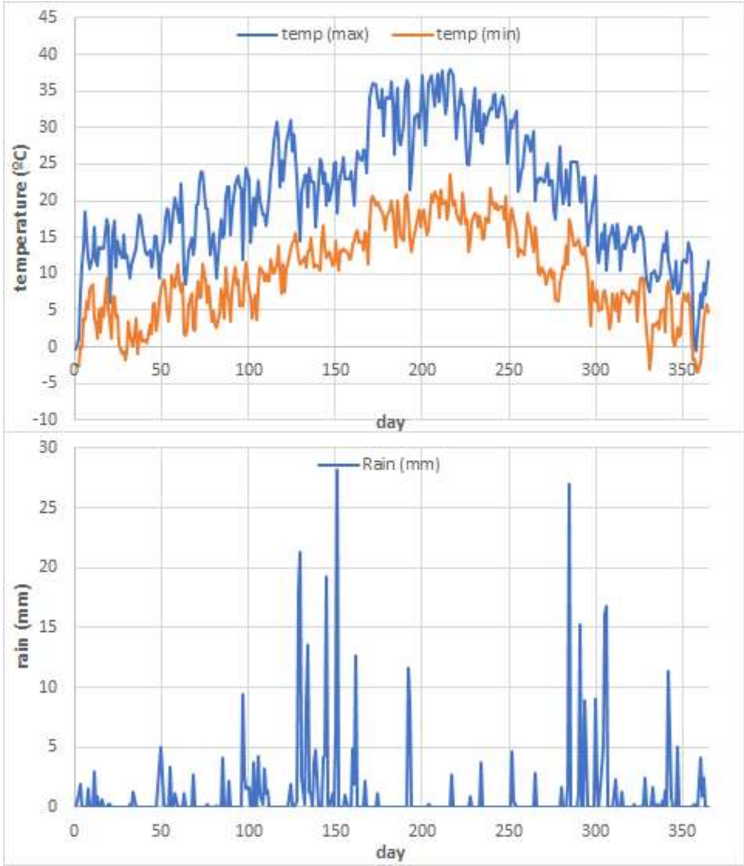


Figure 37. Daily temperature (maximum and minimum) and rainfall rate for the scenario simulated.

We defined a baseline meat sheep farm system (Table 19), similar to one of those studied by Ripoll-Bosch et al. (2013) (mixed-sheep cereal system) with rasa-aragonesa breed (Figure 38). This virtual farm relies on on-farm forage (cut and grazed rainfed alfalfa), semi-arid grasslands grazing and purchased concentrates and forage for sustaining livestock. Non-lamb sheep graze for ca. 7-8 months and remain housed during the rest of the year. Lambs are fully housed and fed with concentrates, forage and milk. Some assumptions were made in order to simplify the simulations in terms of young cattle characteristics and the grassland area for grazing and cutting management. For example, any non-lamb sheep other than adult (young animals) were simulated with the assumption that it would be represented by an average animal with a bodyweight of the average between the lamb and the adult weight and no body-weight change was assumed during the year.

The reproductive management is mid-intensive with three lambing per ewe every two years. We assumed 2 homogeneous groups of ewes with the same grazing and reproductive calendar (Batch 1 and Batch2). For this simulation, in order to simplify the scenario, we chose not to include any cereal cropping.

For the basic economics assessment we used values from existing literature and current Spanish market prices. For sales costing we assumed: 3€/kg live-weight lamb, 30€/culled ewe-ram and 350 €/tonne wool. For costs we assumed 220€/ha of on-farm alfalfa cropping, 60€/tonne of forage maize, 150 €/tonne of alfalfa and concentrates prices according to Table 20. Manure was assumed to be fully applied on farm land. For simplicity purposes, we did not include subsidies in our simple economic budgeting.

Figure 38. Picture of rasa-aragonesa breed animals grazing pastures.

Table 19. Basic farm inputs to run the farm simulation

System	meat sheep (semi-extensive)					
Region	Aragon (Spain)					
Mean annual precipitation (mm)	535 mm					
Vegetation	Semi-arid grassland (grazed) , alfalfa (rainfed) (cut-grazed)					
Total on-farm arable	50			ha		
Communal off-farm land	500			ha		
soil type	loam					
Herd details						
Breed	Rasa aragonesa					
average number of ewes	550					
reproductive management	3 lambing: 2 years					
Number of Adult Males	39					
Lambs management						
Days until weaned	45	days				
Days until slaughtered	90	days				
Feed (other than milk) until weaned	concentrates					
Feed from weaned to slaughtered	concentrates+ forage maize					
Born weight	4	kg				
Weight gain	220	g/day				
slaughtered weight	22	kg				
Reproduction calendar	%	**Lambing**	**Tupped/mated**	%single	%twins	% triplets
ewes (Batch1)	50%	Jan, Sep	Apr, Dec	90%	8%	2%
ewes (Batch2)	50%	May	Aug	90%	8%	2%
Grazing calendar						
	semi-arid grassland		alfalfa			
ewes (Batch1)	Mar-Apr/Nov-Dec		Apr-Jun			
ewes (Batch2)	Jan-Apr/Oct-Dec		Jul-Aug			
Young animals	Jan-Apr/Sep-Dec					
Male	Jan-Apr/Sep-Dec					

Table 20. Price of concentrates assumed in the scenario-based simulation

CONCENTRATES	
lamb (1-45 days)	€ 301.88
lamb (45- days)	€ 283.23
ewes (maintenance)	€ 247.00
young/rams	€ 276.00
ewes (producing)	€ 274.00

Source: https://www.feriasymercados.net/

Feed allocation results

Figure 39 and Table 21 show the main simulated aggregated results for feed allocation for each type of animal groups and type of feeding in terms of DM intake. Purchased forage and concentrates DM represented about 42% and 34% of the total DM in the diet, respectively. $SIMS_{SR}$ estimated an annual on-farm alfalfa yield of about 2.5 t DM/ha and the model assumed 2 cuts (2 t DM/ha, 0.5 t DM/ha) (*data not shown*). When stocks of alfalfa were depleted and forage grazed is insufficient for minimum forage in the diet the model simulates that forage must be purchased. Annual stocks of on-farm alfalfa were depleted and hence, resulted in no forage stocks for the oncoming year.

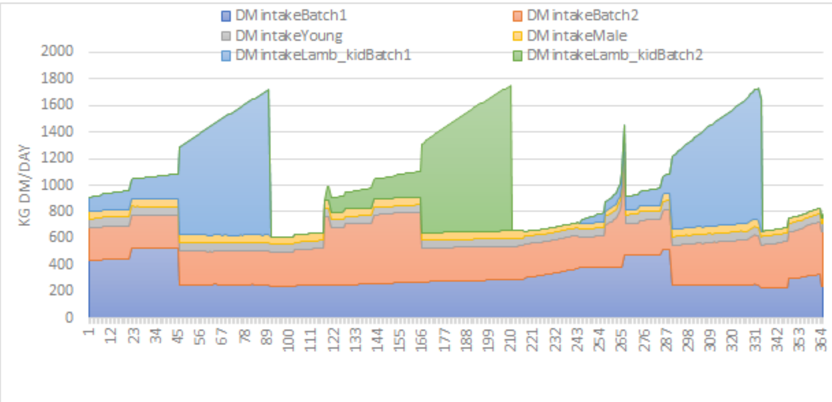


Figure 39. Aggregated simulated DM intake per day for each type of animal group.

Table 21. Annual aggregated simulated DM (kg) intake for each type of animal groups and type of feeding.

	forage (bought)	conc (bought)	grazed[a] (home)	alfalfa silage (home)	TOTAL
Ewes (batch1)	41920	24029	24157	24775	114882
Ewes (batch2)	47186	26418	19873	18749	112226
Young animals	13792	2111	1384	5205	22492
Rams	13526	2698	628	2360	19213
Lambs (batch1)	33323	52541	0	0	85864
Lambs (batch2)	19092	28089	0	0	47181
TOTAL	168840	135886	46043	51088	401857

[a]Grazed forage values aggregates both alfalfa and semi-arid pastures grazing together

Environmental results

Figure 40 and Table 22 show the main aggregated annual and monthly results for the environmental N and C losses in the farm and for some pre-farm gate embedded emissions (i.e. purchased feed and manufactured fertiliser). Emissions from on-farm energy use were excluded in the analysis.

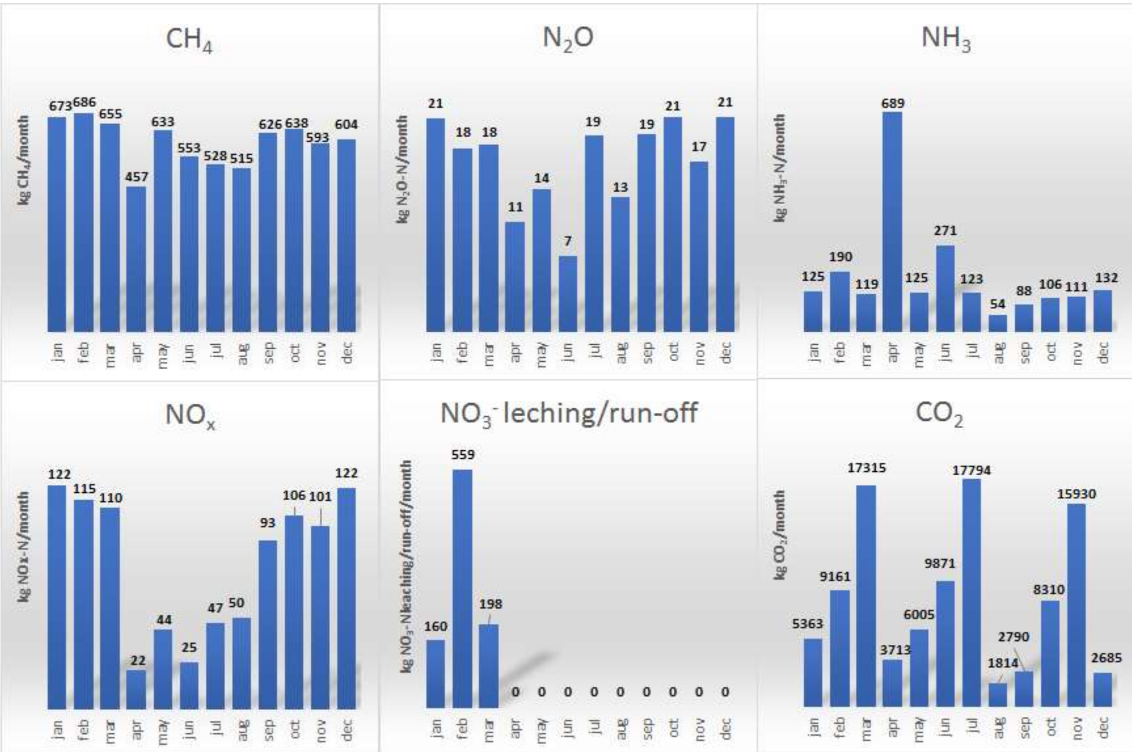


Figure 40. Monthly total aggregated simulated N and C losses. CO2 only includes the net CO_2 emissions comprising off-farm CO_2-e from purchased feed and fertilisers and potential on-farm soil organic C sequestration

Table 22. Aggregated annual simulated environmental C and N losses from different sources expressed as total, per ha (on-farm, on-farm+ communal land), per ewe, per lamb sold and per kg lamb sold.

	Total	per ha (on-farm)	per ha (on-farm+communal land)	per ewe	per lamb sold	per kg (liveweight) lamb sold
on-farm						
enteric CH_4 (kg CH_4/yr)	5959	119.18	10.83	10.8	6.6	0.30
manure CH_4 (kg CH_4/yr)	1126	22.52	2.05	2.0	1.2	0.06
Manure N_2O (kg N/yr)	131	2.61	0.24	0.2	0.1	0.01
Manure NH_3+NOx (storage/yr) (kg N/yr)	1829	36.58	3.33	3.3	2.0	0.09
soil N_2O (kg N/yr)	49	0.98	0.09	0.1	0.1	0.00
soil NO_x (kg N/yr)	43	0.86	0.08	0.1	0.0	0.00
NO_3^- leaching/run-off (kg N/yr)	918	18.35	1.67	1.7	1.0	0.05
NH_3 (fertiliser/yr) (kg N/yr)	284	5.68	0.52	0.5	0.3	0.01
NH_3 (manure application/yr) (kg N/yr)	823	16.46	1.50	1.5	0.9	0.04
NH_3 (grazing/yr) (kg N/yr)	111	2.22	0.20	0.2	0.1	0.01
CH_4 from soil (kg CH_4/yr)	75	1.50	0.14	0.1	0.1	0.004
CO_2 seq (kg CO_2/yr) (on-farm)	-12500	-250.00	-22.73	-22.7	-13.9	-0.63
CO_2 seq (kg CO_2/yr) (communal land)	-42500	-850.00	-77.27	-77.3	-47.1	-2.14
off-farm						
CO_2 from manufacturing fertiliser	3990	79.80	7.25	7.3	4.4	0.20
CH_4 from manufacturing fertiliser	3	0.05	0.00	0.0	0.0	0.0001
N_2O from manufacturing fertiliser	20	0.40	0.04	0.0	0.0	0.0010
CO_2-e purchased feed (kg CO_2/yr)	109262	2185.24	198.66	198.7	121.1	5.51

Total GHG emissions were 366.4 t CO_2-eq yr^{-1} (*data not shown*). This will equate to about 18.5 kg CO_2/kg lamb live weight. A large proportion of total GHG emissions was associated with enteric CH_4 output (46%) and purchased feed (30%) (*data not shown*) (Figure 41). Total on-farm N_2O losses (direct N_2O and indirect emission from NH_3, NO_x and NO_3) and manure storage emissions represented the third and fourth source of GHG emissions.

The contribution of NH_3 volatilisation and NO_3 leaching (as indirect N_2O emissions) to the total on-farm N_2O emission losses was also large. Soil organic carbon sequestration was simulated to be about 250 kg C/ha yr. This value is subject to large uncertainty and depends on assumptions of initial C stocks and previous land history.

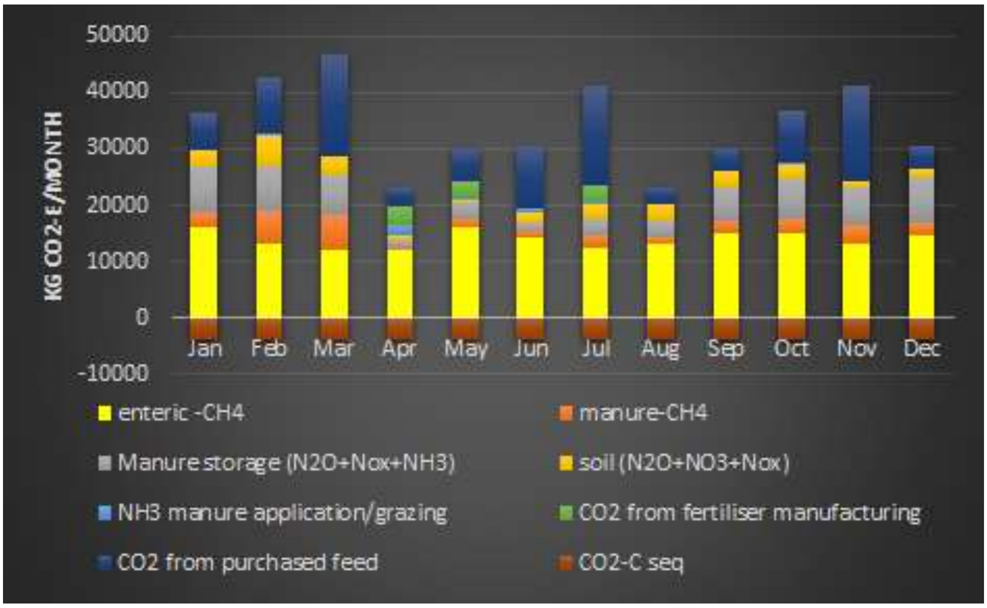


Figure 41. Contribution of the different sources to the total monthly C footprint

Selecting the right unit of reference (functional unit) to measure GHG emissions is instrumental as results will be significantly different when assessed per unit of land or production for example. Most systems that reduce GHG emissions per kg of product through increasing the N use efficiency of the farm and thereby, requiring less forage area to produce the same amount of total product, increasing GHG emissions per unit of ha (Del Prado et al. 2010).

Socio-economic results

Table 23 shows basic economic results for the whole farm scenario. This information will only be relevant for those future scenarios where the iSAGE LP model is not utilized in order to provide a basic comparative assessment between simulated scenarios.

Table 23. Basic economic budgeting of the farm

INCOME					
sales					
Milk	NA				
Lambs	€	59,532			
culling livestock	€	2,475			
Wool	€	387			
manure	NA				
Subsidies					
CAP	not included				
COSTS					
	cost		DM (tonnes)	ME (MJ/kg DM)	CP (kg/kg DM)
purchased concentrates	€	38,057	136	11.5 (10-13.2)	23
forage purchased	€	10,130	169	11	6
forage stocked	NA		0	NA	NA
land costs	€	11,000			

3.4 Description of linear programming model for economic optimisation (iSAGE LP model)

Linear Programming is a mathematical procedure for optimum resource allocation. Linear Programming maximizes or minimizes a linear function of variables (objective function) that are subject to linear inequalities (constraints) and must assume non-negative levels (Sultan, 1993; Rardin, 1998; Matouek and Gartner, 2006; Bazaraa et al., 2010).

The algebraic expression of a Linear Programming problem is:

max (min) $$(1)\ \sum_{j=1}^{M} c_j x_j = Z$$

$$(2)\ \sum_{j=1}^{M} a_{ij} x_j \leq A_i$$

$$(3)\ x_j \geq 0$$

Where:

xj the activities, in this case the number of units (hectare) of the farm type j,

cj the contribution of each activity xj to the objective function (gross margin),

Z the objective function,

αij represents the requirements per unit (hectare) of farm type j for input i, where its available resource is A.

The solution produces an optimum combination of activities in terms of cost minimization or output maximization. The mathematical expression of the parametric programming model is the same, however, the available resources (Ai) of an input or the gross margin cj, vary within an acceptable price range, yielding a set of alternative optimal plans.

The method has been applied in the livestock sector for numerous research purposes. Sintori et al. (2013) used a mathematical programming model to simultaneously assess the socio-economic and environmental performance of sheep farms in Greece. In the dairy cow sector, Theodoridis et al. (2008) used a mathematical programming model to assess the impact of farm policies. In the sheep sector, recent applications of the method include the work of Almeida et al. (2017), who studied the optimal structure of sheep production relative to the use of pastures and of Wall et al. (2018), who used a linear programming model to assess the effects of innovations in reproduction management in sheep flocks. Olaizola et al. (2015) used a mixed programming approach to assess the adaptation strategies for sheep-crop mixed systems in Spain. In Greece, relevant examples include the papers by Sintori et al. (2016).

3.4.1 The iSAGE LP model

The iSAGE LP model simulates the main interactions between the animal, management, prices and local conditions at the farm level and can assess the overall sustainability of farm types (production systems) under various scenarios. The basic idea behind the iSAGE model is to simulate the actual operation of a sheep and goat farm through the maximization of its economic performance. As the model integrates all aspects of the operation of a sheep and goat farm, it allows to predict the impact of changes in one component on the others. With this design, the model allows to examine a wide variety of scenarios/challenges relevant to sheep and goat production, for instance

- Impacts of turbulances in the economic environment
- Shocks in the availability of labor (generational renewal in farms, increased hired labor)
- Climate change impacts on extensive grass-fed systems
- Impacts of changes in the marketing of products (e.g. on-farm cheese production)
- Decision-making regarding the choice of the production system
  Required interventions in the operation of specific production systems to make them more profitable

3.4.2 The optimization part of the iSAGE LP model

The optimization part of the model, which is explained in what follows, involves the optimization of the economic performance (gross margin) subject to a set of constraints.

Therefore the model will be able to assess the sustainability of farms (production systems) under various scenarios, like the ones described above.

Data requirements for the model include

- Product prices and yields
- Availability of land by type
- Availability of labor and labor requirements per ewe (dam)
- Requirements in variable capital (physical and economic units)

The mathematical programming model used in this application aims at the maximization of the total economic result (gross margin) in the objective function, under a set of physical and economic constraints. The gross margin is calculated as **gross revenues minus variable costs**.

In this exemplary generic model, the farm is a semi-extensive dairy farm rearing Chios sheep and has the alternative to graze them from April to October. Especially in summer, the farm has more rangeland acreage available. In addition to grazing, the farm can also cultivate land for feedstuff. Irrigated land can be cultivated with maize and/or clover and non-irrigated can be cultivated with wheat and/or barley. Available labor involves the two adult members of the farm family (the farmer and his wife), who can additionally resort to hired labor and recruit three more persons. The main product of the farm is milk, which can be either sold in markets (dairy industries) or part of it can be transformed to cheese on-farm and sold directly to consumers.

The gross margin in the objective function is expressed analytically and all its components are expressed separately. These are

- **Revenues.** Milk (yield*price); Meat (yield*price); Cheese (sales*price/kg); Wool (quantity*price). Each type of product can include more sources e.g. lamb meat and/or culled animals meat etc.
- **Prices.** For each product, prices are included separately (in a separate column) and are linked to constraint expressing product yields. Milk and cheese prices are

expressed per month (each month a separate column) – since milk production varies between months -, while meat prices are expressed in an annual basis.

- **Variable costs.** The unit costs of all forms of variable capital are included (e.g. prices of purchased feedstuff, variable production costs of home-grown feed etc). Veterinary expenses per animal, other variable expenses as well as costs for additional feedstuff (e.g. additives)

Constraints refer to:

- **Land**

The model accommodates the different types of land typically available to European sheep farms. Therefore, in this application relevant constraints in the model account for the availability of cropland (crop production mainly for feed) and of grasslands. The average yields of each crop are included in the model. For grazing, the available land is linked to activities (objective function) by including the grazing capacities (monthly production of grazing material) in the model.

The model design allows for flexibility when connecting land uses to the dietary needs of animals. In fact, farmers have three options: to let animals graze (natural or cultivated grazing land), to produce feedstuff on-farm or to buy feedstuff from markets. The importance of these three sources may vary and this is reflected in the constraints of the model.

- **Labor**

Labor constraints constitute a significant part of the model. Labor requirements are included in the model expressed in h/ewe/year required to perform all tasks related to farm management (including grazing). In other words, the generic specification of the model requires only to input the total labor requirements. The RHS of the model requires that the available labor is included. Here, the available family labor is included (hours/year) without additional costs (i.e. the implicit costs of family labor are not included). Farms have the option to resort to hired labor, but at a cost and can only hire up to three persons.

- **Variable capital requirements**

These include purchased feedstuff (forage (silage, clover, straw) and concentrates (maize, barley, wheat, flakes, cotton pie), veterinary expenses (drugs and other treatments), crop production expenses for feedstuff (clover, maize, wheat, barley) etc. They are all included as separate constraints in the model. In some of these constraints, the RHS may vary by country, breed, production system, scenario etc. An additional constraint sums up the individual elements of variable costs and expresses the overall capital requirements of the farm. The RHS in this constraint is allowed to vary, corresponding to different levels of capital availability, examining scenarios of intensification of the production system.

- **Animal and flock-related constraints**

The model includes separate constraints for the monthly energy and protein requirements of animals (ME (MJ/ewe/month); ERDP/ewe/month; DUP/ewe/month). In addition, separate constraints account for the nutritional content of feedstuff consumed in farms and also for grazing material (ME, DUP, ERDP), based on the profile of a typical Mediterranean grassland of average quality. Additional constraints involve the minimum and maximum percentages of certain feeds (e.g. concentrates should be between 20% and 50% of all feed consumed; flakes, cotton pie and maize cannot exceed 15%, 12% and 45% of total concentrates respectively).

- **Market-related constraints**

The solution of the model will indicate the appropriate /optimal structure of the farm and consequently the required adjustments in the farming system in order to valorize fully the existing production technology. The comparison between the structural and economic characteristics of the current situation with those of the optimal scenario will indicate the necessary improvements in the farm structure and consequently will reveal efficient management and production practices.

The following Table presents the results of the model based on real farm-level data (collected on-farm) and on bibliographical data provided to AUTH by BC3.

Table 19. Basic results of the model – Optimal organization of a semi-extensive Chios sheep farm

SHEEP	625
LAND	
Irrigated land (ha)	
Clover	0
Maize	4,74
Non-irrigated land (ha)	
Barley	0
Wheat	0
Rangeland (ha)	**63,6**
LABOR (h/year)	
Family	4200
Hired	6300
VARIABLE INPUTS	
Purchased feedstuff (kg/year)	
Straw	34360,35
Silage	153287,41
Clover	0
Wheat	44266,92
Barley	0
Cotton Pie	11513,48
Flakes	0
Maize	0
PRODUCTS	
Milk (kg/year)	121505,78
Cheese (kg/year)	14878,26
Lamb meat (kg/year)	12187,09
Ewe meat (kg/year)	3124,89
ECONOMIC INDICATORS	
Gross revenues	
Total (€)	288603,6
Per ewe (€/ewe)	461,77
Variable capital	
Total (€)	54220,25
Per ewe (€/ewe)	86,8
Gross margin	
Total (€)	234383,38
Per ewe (€/ewe)	375,0

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5 Annex

5.1 NE, protein requirements and DM intake estimation according to different methods

5.1.1 DM intake estimation

There are in literature some mathematical models to estimate dry matter intake (DMI). The objective of this study has been to compare the results obtained using these different models to take a decision of which use in the model proposed.

We have done a sensitivity analysis of some models of prediction of DMI in sheep and goat systems.

The following tables show different prediction models of dry matter intake for sheep and goat systems.

Table 20. Dry Matter Intake prediction models for sheep.

Animal		Function	Unit	Reference
Sheep	Growing sheep Grass (no silage)	104.7ME/GE +0.307W-15	$kg^{0.75}$/day	AFRC (1980)
Sheep	Growing sheep Silage	0.046 g/kg $W^{0.75}$	kg DM/day	AFRC(1993
Sheep	Milking ewe	0.024W+0.9FPCM	kg DM/day	INRA(2007)
Sheep	Dry ewe or early pregnant ewe	$IW^{0.75}$ I=0.075 si bc 4-4.5 I=0.081 si bc 3-3.5 I=0.089 si bc 2-2.5	kg DM/day	INRA(2007)
Sheep	Milking ewe	(-0.545+0.095$W^{0.75}$+0.65PLS+0.0025ΔW) PLS(6.5%)	kg DM/day	Pulina et al.(1996) en FEDNA
Sheep	Dry ewe	(-0.545+0.095$W^{0.75}$+0.005ΔW) K	kg DM/day	Pulina et al.(1996) en FEDNA
Sheep	Milking ewe	0.0255W+0.75FPCM	kg DM/day	Caja et al (2002)
Sheep	Pregnant ewes	0.304-0.004N-0.049PN+0.027W	kg DM/day	Caja et al (2002)
Sheep	General	0.04W((actual W/W(1.7- (actual W/W))	kg DM/ day	NRC(2007)
Sheep	Milking ewes	0.0214W+0.319(kg milk/day*(0.25+0.085F+0.035P))+0.0373CP(%)	Kg DM/day	Serra (1998)
Sheep	Grazing systems (5-6 h) >16% CP	997.1+73.9HM -27.4PH +20.4HDM+0.16FPCM(g/day)-1.24SCPI	g DM/day	Avondo (2005)
Sheep	Grazing systems (5-6 h) 16-10% CP	420.4+95.9HM+0.33FPCM-1.24SCPI	g DM/day	Avondo (2005)
Sheep	Grazing systems (5-6 h) <10% CP	118.38+165.8HM+0.243FPCM	g DM/day	Avondo (2005)
Sheep	Grazing systems (unrestricted acces)	1268+14.45PH	g DM/day	Molle et al (2004)
Sheep	Extensive systems	0.025W	kg DM/day	Apuntes UPM

ME Metabolized energy; GE Gross Energy; W; Liveweight ;Bc body condition; PL Milk production (kg/day); PLS (Standar milk production 6.5%); N number of lamb; PN total lamb weight at birth ;CP Crude Protein in diet (%);HM herbage mass (t DM/ha); PH pasture height (cm); HDM herbage dry matter content 8%); SCPI crude protein intake from supplements (g/day); MY(3.5fatl)

FPCM (0.0071G+0.0043P+0.2244); PLS (6.5%) 0.098G+0.36; MY kg/day (3.5% fat) (1+(0.0055 (Fat g/L -35) +0.0033(Protein g/L -31))/0.4) based INRA (2007)

Table 21. Dry Matter Intake prediction models for goats.

Animal		Function	Unit	Reference
Goat	Lactating goats	$0.024W^{0.75}+0.4\Delta W+0.42PL$ (3.5fat)+0.7%Forage	kg DM/day	AFRC (1995,1998) Based on INRA
Goat	Milking ewe	$164.7+368.6PL+34.8W^{0.75}$	kg DM/day	Sauvant et al (1991) en FEDNA
Goat	Milking ewe week >8	$507.4+303.8PL+12.8\Delta W$ $533+305.2PL+13.3W$	kg DM/day	Sauvant et al (1991) in FEDNA
Goat	Replacement goats	$0.08P^{0.75}$	kg DM/day	Hadjipana et al (1991) in FEDNA
Goat		$(0.111W^{0.75})*(1-e^{-0.8t})$	kg DM/day	Fernandez et al (2003) in FEDNA
Goat	Lactation beginning	$164.7+368.6PL+34.8W^{0.75}$	g DM/day	Sauvant et al (1991)
Goat	Lactation	$533+305.2PL+13.3W$	g DM/day	Sauvant et al (1991)
Goat	Reposition	$0.080W^{0.75}$	kg DM/day	Sauvant et al (1991)

ME Metabolized energy; GE Gross Energy; W; Liveweight ;Bc body condition; PL Milk production (kg/day); PLS (Standar milk production 6.5%); N number of lamb; PN total lamb weight at birth ;CP Crude Protein in diet (%);HM herbage mass (t DM/ha); PH pasture height (cm); HDM herbage dry matter content 8%); SCPI crude protein intake from supplements (g/day); MY(3.5fatl)

Using these equations and the data from the breed databased we have collected for testing the model different prediction numbers have been obtained for different breed and goat production stages of its cycle.

SHEEP DRY MATTER INTAKE REQUIREMENTS

For sheep: Milking, dry period and last month of pregnancy.

For rams: No specific moment. General

For lambs: Growing requirements.

Table 22. Intake prediction with different model for lactating dairy sheep.

			kg DMI/day				
			Housed				UK system
Breed	Weight (kg)	Milk production (kg/ day)	INRA (2007)	Pulina et al (1996)	Caja et al. (2002)	Serra (1998)	AHDB
Assaf	70	2.763	4.204	3.577	3.888	2.980	2.275
Churra	50	1.01	2.081	1.917	2.055	1.999	1.625
Lacaune	70	2.417	3.971	3.408	3.694	2.899	2.275
Latxa	60.5	1.332	2.756	2.458	2.629	2.348	1.966
Manchega	70	1.295	2.958	2.677	2.850	2.547	2.275
Frizarta	65	1.418	2.824	2.543	2.711	2.436	2.113
Chios	58	1.647	2.731	2.419	2.595	2.316	1.885
Lacaune(Fr)	75	1.948	3.724	3.266	3.516	2.875	2.438
Manech Red Face	50	1.502	2.625	2.270	2.462	2.163	1.625
Awassi	55	1.500	2.798	2.441	2.634	2.293	1.788

PREGNANCY

Table 23. Intake prediction with different model for the last period of pregnancy in sheep.

			kg DMI/day	
Breed	Weight (kg)	Lamb bornweight (kg)	Caja et al (2002) 1 lamb	AHDB
Assaf	70	4.2	1.984	1.575
Churra	50	3.75	1.466	1.305
Lacaune	70	3	2.043	1.575
Latxa	60.5	4.25	1.725	1.36125
Manchega	70	4.25	1.982	1.575
Frizarta	65	3.5	1.884	1.463
Chios	58	3.8	1.680	1.305
Lacaune(Fr)	75	4	2.129	1.688
Manech Red Face	50	4	1.454	1.125
Awassi	55	4.5	1.565	1.238
Merino	80	4	2.264	1.800
Rasa aragonesa	55	4	1.589	1.238
North Country Mule	75	4	2.129	1.688
Scotish Blackface	60	3.5	1.749	1.35
Welsh Mountain	45	3.5	1.344	1.013
Swaledale	55	3.5	1.614	1.238
Lleyn	70	4	1.994	1.575
Texel	85	4.5	2.375	1.912
Merino (Fr)	55	4	1.589	1.238
Vendees	70	4	1.994	1.575
Romane	80	4	2.264	1.8
BMC	55	4	1.589	1.238

DRY SHEEPS

Table 24. Intake prediction with different model for dry sheep, general and other cases.

		kg DMI/day						
Breed	Weight (kg)	INRA (2007)	INRA (2007)	INRA (2007)	Pulina et al (1996)	AHDB	NRC (2007)	UPM notes
		BS (4-4.5)	BS(3-3.5)	BS (2-2.5)			General	Extensive
Assaf	70	1.815	1.960	2.154	1.754	1.05	2.016	1.750
Churra	50	1.410	1.523	1.673	1.241	0.75	1.44	1.250
Lacaune	70	1.815	1.960	2.154	1.754	1.05	2.016	1.750
Latxa	60.5	1.627	1.757	1.931	1.516	0.9075	1.7424	1.513
Manchega	70	1.815	1.960	2.154	1.754	1.05	2.016	1.750
Frizarta	65	1.717	1.854	2.037	1.630	0.975	2.016	1.625
Chios	58	1.576	1.702	1.871	1.452	0.870	1.872	1.450
Lacaune(Fr)	75	1.911	2.064	2.268	1.876	1.125	1.6704	1.875
Manech Red Face	50	1.410	1.523	1.673	1.241	0.750	2.16	1.250
Awassi	55	1.515	1.636	1.797	1.374	0.825	1.44	1.375
Merino	80	2.006	2.167	2.381	1.996	1.200	2.304	2.000
Rasa aragonesa	55	1.515	1.636	1.797	1.374	0.825	1.584	1.375
North Country Mule	75	1.911	2.064	2.268	1.876	1.125	2.16	1.875
Scotish Blackface	60	1.617	1.746	1.919	1.503	0.9	1.728	1.500
Welsh Mountain	45	1.303	1.407	1.546	1.106	0.675	1.296	1.125
Swaledale	55	1.515	1.636	1.797	1.374	0.825	1.584	1.375
Lleyn	70	1.815	1.960	2.154	1.754	1.05	2.016	1.750
Texel	85	2.100	2.268	2.491	2.114	1.275	2.448	2.125
Merino (Fr)	55	1.515	1.636	1.797	1.374	0.825	1.584	1.375
Vendees	70	1.815	1.960	2.154	1.754	1.05	2.016	1.750
Romane	80	2.006	2.167	2.381	1.996	1.2	2.304	2.000
BMC	55	1.515	1.636	1.797	1.374	0.825	1.584	1.375

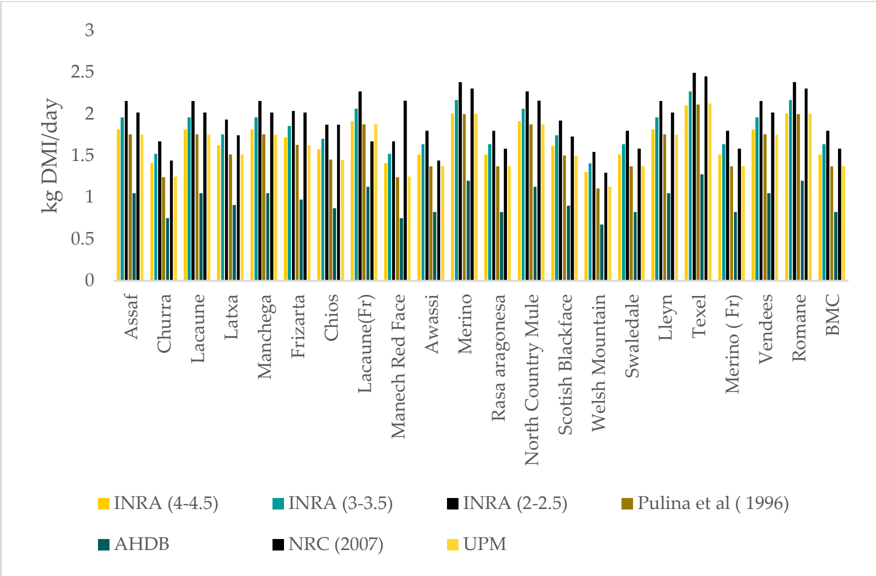

Figure 37. DMI prediction with different models for different breeds during dry period.

Table 25. Intake prediction with different models for rams.

		kg DMI/day		
Breed	Rams weight (kg)	Pulina et al. (1996)	UPM Notes	NRC (2007)
Assaf	105	2.132	2.625	3.024
Churra	70	1.573	1.750	2.016
Lacaune	95	1.978	2.375	2.736
Latxa	65	1.488	1.625	1.872
Manchega	90	1.899	2.250	2.592
Frizarta	87.5	1.860	2.188	2.52
Chios	78	1.706	1.950	2.246
Lacaune(Fr)	100	2.055	2.500	2.88
Manech Red Face	65	1.488	1.625	1.872
Awassi	75	1.657	1.875	2.16
Merino	100	2.055	2.500	2.88
Rasa aragonesa	80	1.739	2.000	2.304
North Country Mule	93.75	1.958	2.344	2.7
Scotish Blackface	75	1.657	1.875	2.16
Welsh Mountain	56.25	1.335	1.406	1.62
Swaledale	68.75	1.552	1.719	1.98
Lleyn	87.5	1.860	2.188	2.52
gTexel	106.25	2.151	2.656	3.06
Merino (Fr)	80	1.739	2.000	2.304
Vendees	80	1.739	2.000	2.304
Romane	140	2.646	3.500	4.032
BMC	80	1.739	2.000	2.304

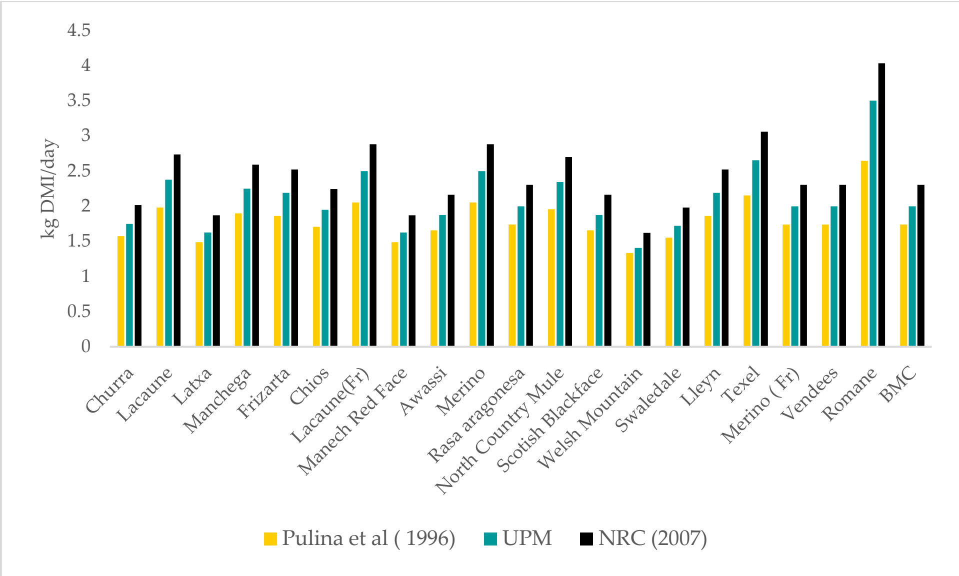

Figure 38. DMI prediction with different models for different breeds for rams.

Table 26. Intake predictions with different models for growing lambs.

				kg DMI/day			
Breed	Born liveweight	Day weaning	Sacrificie liveweight	Pulina et al (1996)	AFRC (1983) Growing	NRC (2007)	UPM
	(kg)	g	kg	House	Grazing	General	Extensive
Assaf	4.2	38	15	0.142	1.05	0.410	0.105
Churra	3.75	275	10.5	0.480	0.75	0.302	0.094
Lacaune	3		12	0.038	1.05	0.346	0.075
Latxa	4.25	250	11	0.461	0.9075	0.317	0.106
Manchega	4.25	290	11.5	0.521	1.05	0.331	0.106
Frizarta	3.5	225	12	0.395	0.975	0.346	0.088
Chios	3.8	225	14.5	0.407	0.870	0.418	0.095
Lacaune(Fr)	4	300	13	0.527	1.125	0.374	0.100
Manech Red Face	4	200	11	0.377	0.750	0.317	0.100
Awassi	4.5	320	35	0.576	0.825	1.008	0.113
Merino	4	300	24.5	0.527	1.200	0.706	0.100
Rasa aragonesa	4	230	23	0.422	0.825	0.648	0.100
North Country Mule	4	250	38	0.452	1.125	1.094	0.100
Scotish Blackface	3.5	200	36	0.358	0.9	1.037	0.088
Welsh Mountain	3.5	180	36	0.328	0.675	1.037	0.088
Swaledale	3.5	180	36	0.328	0.825	1.037	0.088
Lleyn	4	250	38	0.452	1.05	1.094	0.100
Texel	4.5	320	40	0.576	1.275	1.152	0.113
Merino (Fr)	4	245	33	0.445	0.825	0.950	0.100
Vendees	4	400	40	0.677	1.05	1.152	0.100
Romane	4	330	37	0.572	1.2	1.066	0.100
BMC	4	280	36	0.497	0.825	1.037	0.100

GOAT DRY MATTER INTAKE REQUIREMENTS

For goats: Milking, dry period and last month of pregnancy.

For males: No specific moment. General dry matter requirements

For kids: Growing requirements.

Table 27. Intake predictions with different models for milking goats.

				kg DMI/day				
Breed	**Liveweight**	**Forage diet**	**Milk production**	**AFRC (1995,1998)**	**Kearl (1982)**	**INRA (2007)**	**Sauvant et al.(1991)**	**Sauvant et al.(1991)**
	Kg	**(0-1)**	**kg/day**				**Starting**	**Decreasing**
Murciano-Granadina	50	0.25	2.192	1.851	2.249	1.840	1.62	1.867
Florida	60	0.6	2.407	2.154	2.578	1.995	1.80	2.066
Saanen	75	0.6	3.171	2.693	3.048	2.489	2.220	2.498
Alpine	65	0.6	2.413	2.077	2.738	2.013	1.850	2.134
Damascus	60	0.7	2	1.926	2.578	1.825	1.652	1.941
Hair Goat(Anatolian Black)	65	0.7	0.536	1.311	2.738	1.535	1.159	1.561

Table 28. Intake prediction with different model for pregnant goats.

			kg DMI/day		
Breed	**Liveweight**	**AFRC (1995,1998)**	**AFRC (1995,1998)**	**Kearl (1982)**	**INRA (2007)**
	Kg		**Last month**		
Murciano-Granadina	50	1.197	1.077	1.435	1.126
Florida	60	1.332	1.199	1.645	1.273
Saanen	75	1.535	1.381	1.945	1.493
Alpine	65	1.400	1.260	1.747	1.346
Damascus	60	1.332	1.1988	1.645	1.273
Hair Goat(Anatolian Black)	65	1.3995	1.25955	1.747	1.346

5.1.2 NE estimation

Table 29. Coefficients for calculating net energy for maintenance (NE_m)

	Cfi
Sheep (lamb one year)	0.25
Sheep (older than one year)	0.23
goats	0.315

Table 30. Coefficients corresponding to animal's feeding situation (C_a)

	C_a
Housed ewes	0.0096
Grazing flat pasture	0.0107
Grazing hilly pasture	0.024
Housed fattening lambs	0.0067
Pregnant ewes	0.0054
Lowland goats	0.019
Hill/mountain goats	0.0240

Table 31. Constants for use in calculating NE_g for sheep and goats

	a (MJ/kg)	b (MJ/kg^2)
intact males (Sheep)	2.5	0.35
castrates (Sheep)	4.4	0.32
females (Sheep)	2.1	0.45
goats (all)	4.972	0.3274

EV_{milk} value (net energy required to produce 1 kg of milk): Different sources allows estimation of this parameter. For example IPCC (2019) indicates a default EV_{milk} value of 4.6 MJ/kg (sheep) (AFRC 1993; AFRC 1995) and 3 MJ/kg (goats) (AFRC 1998), which corresponds to a milk fat content of 7% and 3.8% by weight for sheep and goats, respectively. In ISAGE model we use the following equations to estimate this value:

For lactating sheep:

EV_{milk}=0.0328 BF_{milk} +0.0025 $days_{lact}$ +2.2033 ***Eq 46***

For lactating goats (INRA, 2007):

EV_{milk}=(((0.4+0.0075)(BF_{milk}10)-35))1700/4.184)/1000 ***Eq 47***

EV_{wool} value (net energy value of each kg of wool produced weighed after drying but before scouring): A default value of 24 MJ kg^{-1} can be used for sheep estimate. For goats we only consider this parameter if we simulate a fibre-producing goat breed. For fibre-producing sheep NE_{wool} can be estimated that 0.25 MJ day^{-1} is retained in the fibre (AFRC 1993; AFRC 1995). For fibre-producing goats 0.25 and 0.08 MJ day^{-1} for angora and cashmere breeds (AFRC 1993; AFRC 1995), respectively.

The following tables show the comparison between different systems for energy requirements.

Table 32. Maintenance and Activity Energy Requirements of small ruminants

	Maintenance Requirements				Units	References
Sheep	(F + A) /k_m				MJ/day	AFRC
	F Fasting metabolism	< 1 year female	$1 \cdot 0.25 \cdot \left(\frac{W}{1.08}\right)^{0.75}$			(41)
		< 1 year entire ram lamb	$1.15 \cdot 0.25 \cdot \left(\frac{W}{1.08}\right)^{0.75}$			(41)
		> 1 year female	$1 \cdot 0.23 \cdot \left(\frac{W}{1.08}\right)^{0.75}$			(42)
		< 1 year entire ram lamb	$1.15 \cdot 0.23 \cdot \left(\frac{W}{1.08}\right)^{0.75}$			(42)
	A Activity allowance	Lactating ewes, housed	0,0096W			(46)
		Pregnant ewes, housed	0,0054W			(47)
		Lowland ewe	0,0107W			(48)
		Hill grazing ewe	0,024W			(49)
		Fattering lambs	0,0067W			(50)
		All	$0.27W^{0.75}$	/(Eficacia 0.72)	MJ/day	FEDNA Aguilera et al (1986)
		All	$0.235W^{0.75}$		MJ /day	INRA (2007)
	Maintenance	< 1 year female	$0.236W^{0.75}$		MJ/day	IPCC (draft 2019)
		> 1 year female	$0.217W^{0.75}$			(eq 10.3, T 10.4)
	Activity	House ewes	0.0096W			(eq 10.5,T 10.5)
		Grazing flat pasture	0.0107W			
		Grazing hilly pasture	0.024W			
		House fattering lambs	0.0067W			
Goat	(F + A) /km				MJ/day	AFRC
	F Fasting metabolism	All	$0.438W^{0.75}$			(Table 5.3 yellow book)
	A Activity allowance	low land	0,019W			(51)
		hill grazing	0,024W			(52)
		Lactating goats	$0.401W^{0.75}$	Eficiencia 67%	MJ/day	FEDNA Aguilera et al. (1990)
		Growing goats	$0.421W^{0.75}$	Eficiencia 76%		FEDNA Aguilera et al. (1991)
		Castrate	$0.443W^{0.75}$	Eficiencia 73 %		FEDNA Prieto et al. (1990)
	Maintenance	All	$0.315W^{0.75}$		MJ/day	IPCC (draft 2019) (eq 10.3,T 10.4)
	Activity	Low land goats	0.019W		MJ/day	(eq 10.5,T 10.5)
		Hill and mountain goat	0.024W			

Table 33. Lactation Energy Requirements of Small Ruminants

	Milking Requirements								Units	References
Sheep		0.0328F+0.0025d+2.2033							MJ/kg	AFRC (57) Brett et al. (1972)
		0.46F+1.71 1.71MJ/litre of milk		Standardise 6.5% fat			0.098G+0.36		MJ/litre of milk Kg/day	FEDNA Molina et al. (1991)
		(0.00588F + 0.265)*1.7								INRA (en Pulina, 2004)
		ΔW/day		150	250	350	450	550	MJ	INRA (2007)
		0-3 weeks	Lambs milk consumption	0.9	1.4	1.9	2.6	3		
			MJ	4.27	6.40	8.53	11.73	13.86		
		4-6 weeks	Lambs milk consumption	0.75	1.15	1.6	2.25	2.6		
			MJ	3.56	4.98	7.11	9.95	11.38		
		7-10 weeks	Lambs milk consumption	0.5	0.8	1.05	1.45	1.65		
			MJ	2.49	3.91	5.33	7.11	8.18		
		11-14 weeks	Lambs milk consumption	0.3	0.4	0.6	0.8	0.9		
			MJ	1.42	2.13	3.20	4.27	4.98		
		EV(7% fat)=4.6 MJ/kg milk			NE=4.6*kg milk /day				MJ/day	IPCC (draft 2019) (Eq 10.9)
Goat		¿?								AFRC
	ENL	38F+24.44GP+16.45L		L(45)			Effectiveness 66.7%		KJ/kg	FEDNA
		EV (3.8% fat)=3 MJ/kg Milk		NEl= 3*kg milk /day					MJ/day	INRA(2007) (Eq 10.9)

F: Fat content; GP: Gross Protein ;d: days of lactation; L: lactose; EV: Energy value

Table 34. Pregnancy Energy Requirements of Small Ruminants

	Pregnancy Requirements							Units	References
Sheep	Energy content at time t	E_t			$Log_{10}(E_t)=3.322-4.979e^{-0.00643t}$			MJ	AFRC (73)
	Daily energy retetion	E_c			$0.25W_0(E_t 0.07372e^{-0.00643t})$			MJ/day	(74)
					$9.2438LWe^{-11.465}e^{-0.00643t-0.00643t}$			kcal/day	FEDNA
			Weight kg	Camada weight kg	-6/ 5 MJ/d	-4/3 MJ/d	-2/1 MJ/d	MJ	INRA (2007)
			55	4	5.2614	5.9724	7.0389		
				5	5.3325	6.3279	7.7499		
				7	5.4747	6.8967	8.8164		
			60	5	5.688	6.6123	8.0343		
				6	5.7591	6.8967	8.6031		
				7	5.8302	7.2522	9.243		
				8	5.9013	7.6077	9.8118		
			70	5	6.2568	7.2522	8.6742		
				7	6.399	7.7499	9.7407		
				9	6.6123	8.1054	10.665		
				11	6.6123	8.8164	11.5893		
	NE_m Maintenance Energy	Single births			$NEp= 0.077 NE_m$			MJ/day	IPPC(2019)
		Double births			$NEp=0.126 NE_m$			MJ/day	(Eq. 10.13, T 10.7)
		Triple births			$NEp=0.150 NE_m$			MJ/day	
Goat		Month 4th;W 50 kg	1.35					MJ/day	AFRC(1998)
		Month 5th; W 50 kg	2.59					MJ/day	AFRC (1998)
			Usa INRA + AFRC						FEDNA
	Pregnanºcy + Maintenance	Month 4th;40 kg	4.83					MJ/day	INRA
		Month 4th;50 kg	6.25						
		Month 5th; 40 kg	5.72						
		Month 5th;50 kg	6.34						
	NE_m Maintenance Energy	Single births			$NEp= 0.077 NE_m$			MJ/day	IPPC(2019)
		Double births			$NEp=0.126 NE_m$			MJ/day	(Eq. 10.13, T 10.7)
		Triple births			$NEp=0.150 NE_m$			MJ/day	

LW: Litter weight; t: time since mating

Table 35. Growth Energy Requirements of Small Ruminants

	Growth Requirements			Units	References
Sheep	Energy Retained in animal body	$\Delta W\ EV_g$		MJ/day	AFRC(62)
	Energy Value of liveweight gain	Non merino males	EV_g 2.5+0.35W	MJ/kg	(63)
	EV_g	Castrates	EV_g 4.4+032W		(64)
		Females	EV_g 2.1+0.45W		(65)
	NE_g	Intact male	(ΔW (2.5+0.5*0.35*(Ww+Ws))/days	MJ/day	IPCC (Draft 2019)
		Castrates	(ΔW (4.4+0.5*0.32*(Ww+Ws))/days	MJ/day	(Eq 10.7, T 10.6)
		Females	(ΔW (2.1+0.5*0.45*(Ww+Ws))/days	MJ/day	
Goat	Body Energy Content E_g	$4.972W + 0.1637W^2$	(62)	MJ	ARFC (66)
	EV_g	4.972+0.3274W		MJ/kg	(67)
	NE_g		(ΔW (4.972+0.5*0.3274*(Ww+Ws))/days		IPCC (Draft 2019) (Eq 10.7, T 10.6)

Table 36. Wool Energy Requirement of Small Ruminants

	Energy Requirements		Units	References
Sheep	EVw= 24 MJ/kg wool	NE_w= (24*kg wool)/365	MJ/day	IPCC (Draft 2019) (Eq 10.12)

5.1.3 Estimation of Default Emission Factor(s) for Goat Tier 2 parameters as part of A. Del Prado's work for the new IPCC Methodology Report titled "2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories" (to be approved in May 2019) (see annex). (Some of this text may appear in this IPCC document)

A database was compiled from peer-reviewed articles that studied in-vivo methane (CH_4) production from goat enteric fermentation and N excretion. These studies were identified through a comprehensive literature search performed in Goggle scholar and researchgate and from sources that carried out review work such as a recent study attempting to derive statistical models for prediction of enteric CH_4 from goats (Patra & Lalhriatpuii 2016) and a New Zealand technical report for CH_4 and N excretion rates for goats (Lassey 2012). Data were directly extracted from the individual studies identified. Authors were contacted in order to fill in gaps of information from the studies.

Overall, 63 publications were obtained from a varied sample of countries and 18 different goat breeds.

We analyzed the relationship between methane output and diet type (e.g. diet digestibility, % forage use) but there were not any clear statistical relationships between diet type and enteric methane output (*data not shown*).

Methane output per animal were positively correlated with dry matter and gross energy intake (Figures 37 and 38)

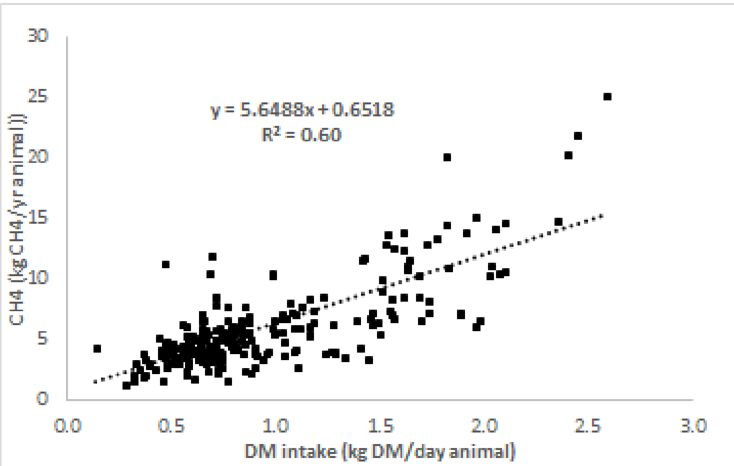

Figure 37. Annual enteric methane output per animal expressed in mass in relation to daily dry matter (DM) intake.

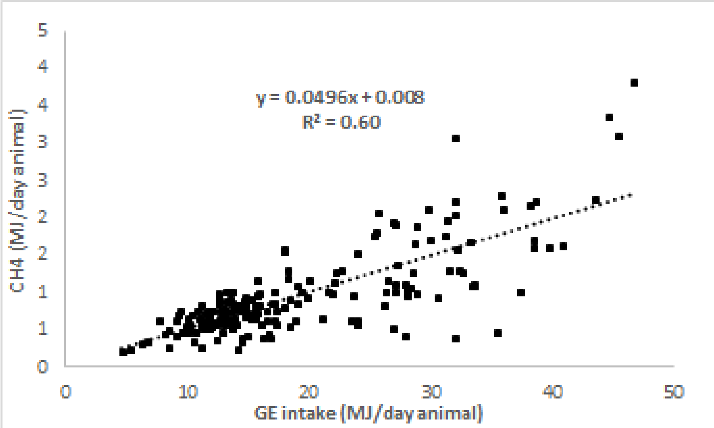

Figure 38. Daily enteric methane output per animal expressed in energy in relation to daily gross energy (GE) intake.

Daily N intake and animal weight were found to be correlated with daily N excretion (Figs 39 and 40)

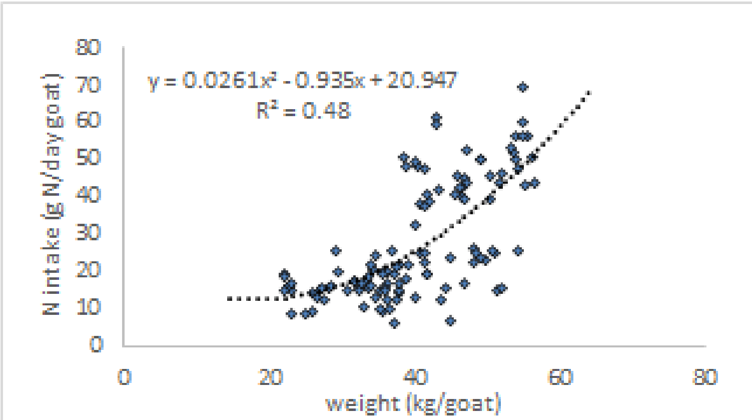

Figure 39. Daily N excretion output per animal expressed in relation to animal weight.

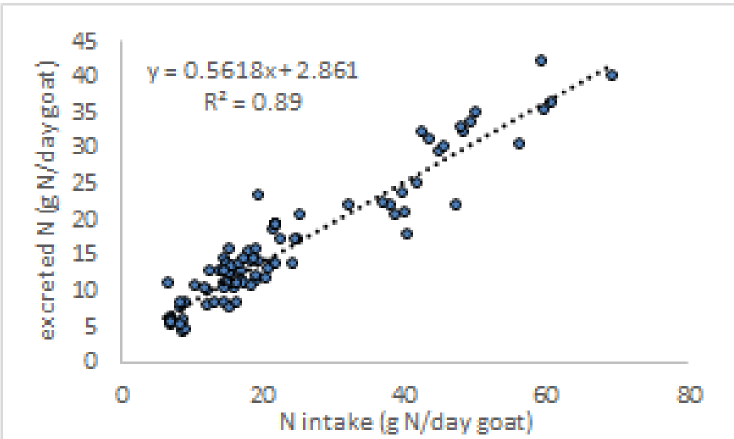

Figure 40. Daily N excretion output per animal expressed in relation to daily N intake.

For Partitioning excreted N into faces and urine the following relationship was derived from the database (Figure 41).

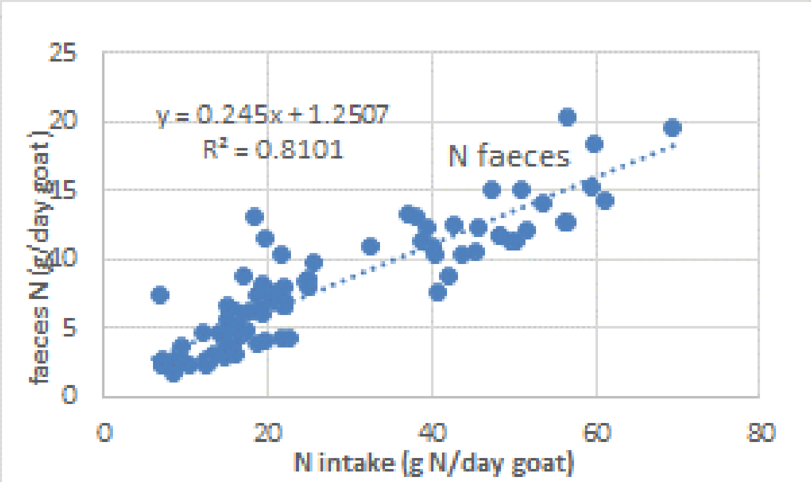

Figure 41. Daily N excretion as faeces output per animal expressed in relation to daily N intake.

5.2. Lactation curves

There are on literature different model to estimate lactation curves for sheep and goats. Wood function (Wood, 1967) is the most used in general. Nevertheless, other methods have been used. In the model, a predicted milk production, milk protein and fat % are calculated. The predicted milk yield for the entered days in milk, lactation number and herd average is computed as follows, based on Wood (1967) equation coefficients for lactation. The lactation curves allow us, to estimate milk yields along the lactation period, as well as protein and fat curves during the milking of the sheep/goat.

Wood function

Daily production day t(kg): = at^be^{-ct}

Parameters a,b,c databased (breed)

Also, curves of fat and protein milk content can be estimated with Wood functions.

Fat and protein milk content.

George equations (1984) for protein and fat curves. These equations are modelled to dairy cows.

Fat milk content

Daily fat content in milk day t (g/kg):= 1.01*%peak milk fat*$(((t+1)/7)^{-0.13})*e^{(0.02*((t+1)/7))})$;

Protein milk content

Daily protein content in milk day t (g/kg):= 1.14*%peak milk protein*$(((t+1)/7)^{-0.12})*e^{(0.01*((t+1)/7))})$;

SHEEPs

Table 32. Estimated parameters for Wood function in different sheep breeds.

Breed	Function	a	b	c	Milking days
Lacaune	Wood	1.173	0.352	0.011	234
Assaf	Wood	1.0159	0.2515	0.01	120
Manchega	Wood	1.544	0.185	-0.0089	180
	Fat	7.338	-0.056	0.0028	
	Protein	5.557	-0.023	0.0018	
Awassi	Wood	1.462	0.218	-0.062	164

Table 33. Estimated parameters for lactation curve for different function in different sheep breeds.

Breed	Function	a	b	c	d	Milking days	Notas
Latxa	Morant & Gnanasakthy					180	
	November	-0.234	0.801	-0.067	1.331		Month
	December	-0.018	0.758	0.134	0.859		
	January	0.0079	0.762	0.484	1.008		
	February	0.0623	0.836	0.517	0.614		
	March	0.0336	0.868	0.582	2.009		
	0 lamb	*0.0132*	*0.587*	*0.505*	*0.443*		Nº live lambs
	1 lamb	*-0.009*	*0.769*	*0.344*	*0.845*		
	2 lamb	*0.0745*	*0.94*	*0.406*	*1.087*		
	1st	0.0154	0.587	0.651	0.578		Parity
	2nd	0.0058	0.799	0.431	0.781		
	3rd-6th	0.0083	0.832	0.272	0.892		
	>7th	-0.0408	0.803	0.245	1.501		

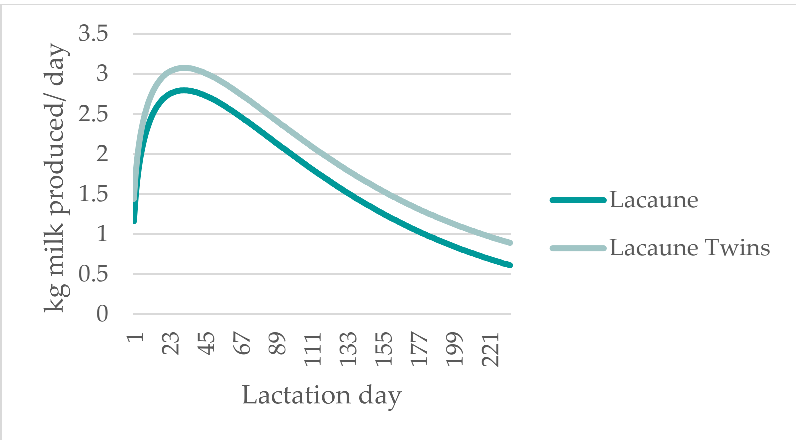

Figure 42. Lactation curve Wood function for Lacaune

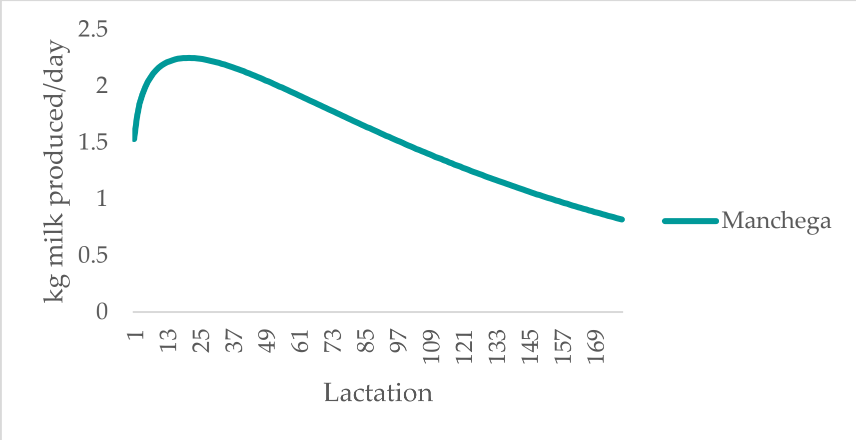

Figure 43. Lactation curve Wood function for Manchega

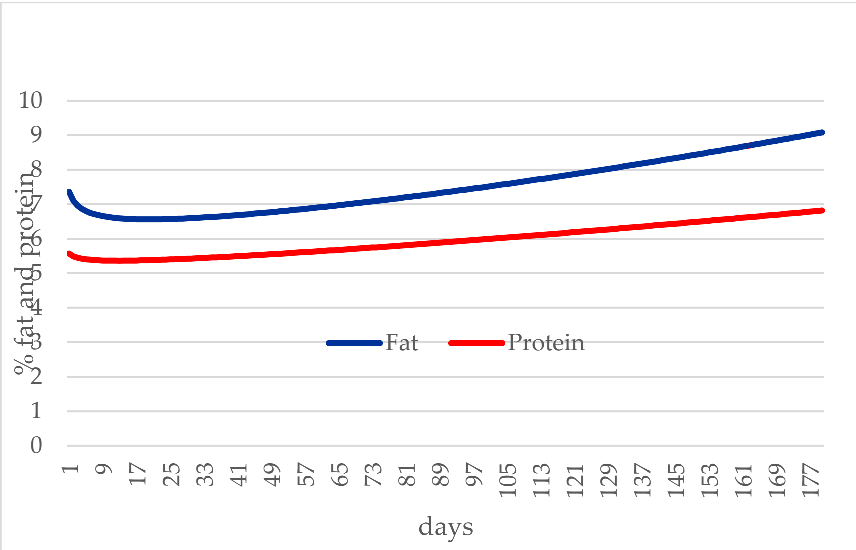

Figure 44. Fat and Protein Curve for Manchega breed using Wood factors.

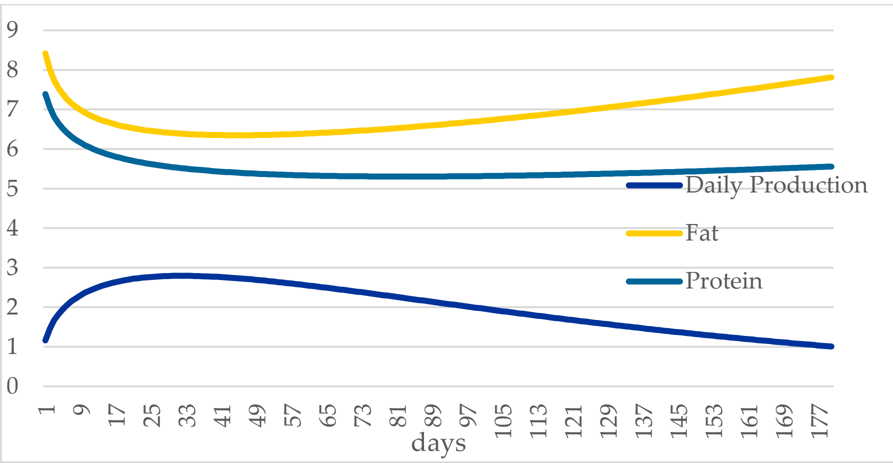

Figure 45. Milk yield, fat and protein curves for Manchega breed.

GOATs

Table 34. Estimated parameters for Wood function in different goat breeds

Breed	Function	a	b	c	Milking days	Notes
Murciano-Granadina	Wood	0.8594	0.2005	-0.00368	240	1st milking
		1.1124	0.1647	-0.00338	240	2nd milking
		1.1532	0.173	-0.00367	240	3rd milking
	Wood	2.287	0.129	-0.029		
Verata	Wood	1.29	0.207	-0.0052		
La Mancha	Wood	2.316	0.23	-0.005		
Alpine	Wood	2.316	0.23	-0.005	310	
Saanen	Wood	2.316	0.23	-0.005	310	

Table 35. Estimated parameters for French breeds using INRA model.

Breed	Function	
France	TMP*(-0,0030e(-0,0303t)+0,0070e(-0,0042t))	
Alpina	2nd lactation	+0,27kg/day
Saanen	twins	+0,28kg/day
	+3 kids/birth	+0,39 kg/day

TMP: Total milk production

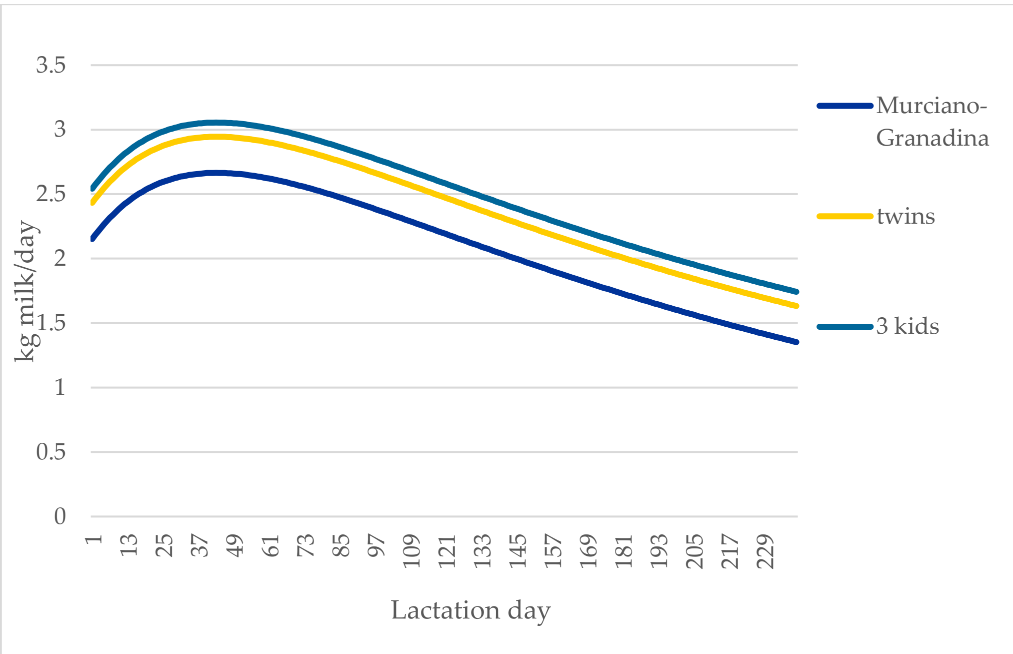

Figure 46. Lactation curve using Wood function for Murciano-Granadina breed.