Multicriteria Evaluation Tree

Task 2.2

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INTRODUCTION

Due to a growing world population and an endangered environment, we have to reduce the pressure exerted by humans on global resources. The quantity of food consumed and the way it is produced are key issues. This is a major challenge for societies, agriculture and more particularly livestock farming systems. Bender (1992) estimates that an average of 7 plant kcal is required to produce 1 kcal of animal products. Delaby et al (2014) estimate that 2.5 to 10 kg of vegetable protein is needed to produce 1 kg of animal protein. However, vegetable proteins consumed by livestock are not always edible by humans. Among livestock farming systems, ruminant-based systems have the advantage of using resources non edible by humans and converting these into high quality human food (Wilkinson, 2011).

The objective of SustainBeef is to identify production methods that reduce feed/food competition in beef production systems while estimating their impacts on the overall sustainability of the farm through bio-economic simulations.

Many methods for assessing the sustainability of agricultural farms already exist, such as the IDEA method (Vilain, 2008), TREE (Pervanchon, 2004) or DIAMOND (Litt et al., 2012). However, these are not adapted to the data from simulations and do not include indicators dealing with food safety or more particularly feed/food competition. There is indeed no consensus around this type of indicator, which is emerging in the literature and not yet widely applied (Laisse et al., 2019; Wilkinson, 2011). Thus, the main subject of this study is to establish a method for assessing the sustainability of European beef cattle systems based on different criteria, including feed/food competition, and adapted to the available data from bio-economic simulations.

2 Specification of the evaluation method

The first step in creating a new evaluation method is to explicit its specifications. It consists in i) setting the goal of the evaluation, ii) defining the system and scale, iii) discussing the strategy and the available data and iv) agreeing on the role of each partner. These points have been presented, discussed and validated with at least one representative of each partner on the 23rd of March 2018.

The purpose of the evaluation is to test the effectiveness of innovations in reducing feed/food competition while maintaining the sustainability of beef production systems. The aim is therefore to compare the sustainability of each farm-types **before and after innovation**. The concept of sustainable development was born in 1951 on both the economic and environmental pillars. It was in 1987 that the World Commission on Environment and Development (WCED) proposed a first definition of sustainable development as development that "must satisfy the needs of the present without compromising the ability of future generations to satisfy their own needs" (WCED, 1987). This definition was extended to the three pillars at the Rio Earth Summit in 1992, when development must be economically viable, socially equitable and environmentally friendly. Thus, we will define sustainability as: the sustainability of a model, its condition and its ability to persist over time on the three pillars: environmental, economic and social.

The method should be applicable to the farm types analyzed in SustainBeef. These farm types include: specialized breeders, specialized fatteners, fattening breeders, dairy systems with or without fattening of dairy calves, mixed dairy-suckler cow systems as well as mix crop-livestock systems in the socio-economic, soil and climatic contexts in the countries of the project partners. These innovations will be applied to the farm types before and after the implementation of innovations. The evaluation method must therefore be sensitive to a change in practice induced by the innovation tested.

The scale of the assessment chosen is the **farm** as a whole. However, this scale can be adjusted according to the indicators in order to remain relevant. Indeed, the farm's inputs and outputs are taken into consideration (Figure 1). However, for some indicators, it will be more relevant to work at beef meat production scale. In this specific case, all feed consumed by the animals will be taken into consideration, whether purchased or produced on the farm.

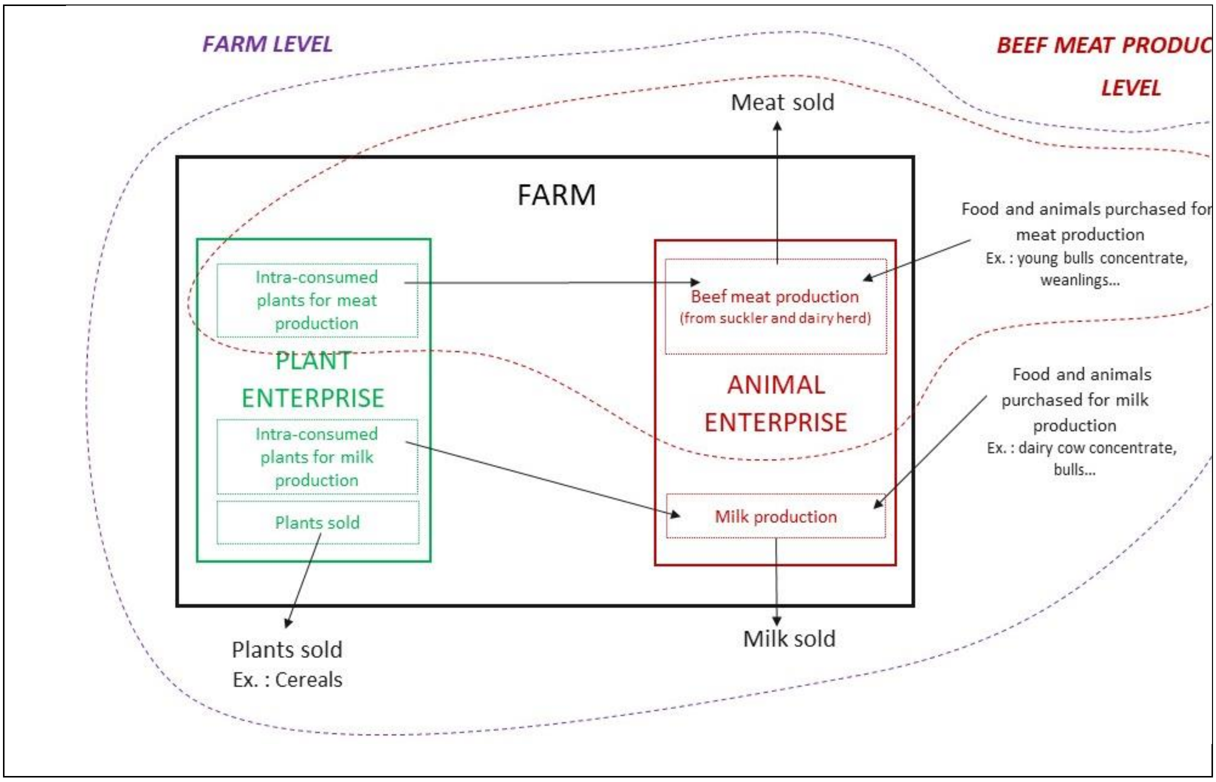


Figure 1: The different scales used for the multi-criteria evaluation method

: limit of the evaluation

By adapting different evaluation methods to our question, we'll build a model (or evaluation tree) to assess the sustainability of the selected farm-types. **The strategy** to build this evaluation tree is first to carry out bibliographic research. Existing methods are not always agreed upon (Barbier et al., 2010). Thus the evaluation method is based on different existing methods, including SAMAP (Terrier, 2009), SAFA (FAO, 2013b.), IBEA (IBEA, 2013), Sustainable Agriculture Network (Sustainable Agriculture Network, 2016), IDEA (Vilain, 2008), EcoAlim (Wilfart et al., 2016), and is adapted to the project by including the feed/food competition dimension.

The data used to calculate the indicators should be based on objective data and not on subjective data from expert's opinion, as could be the case when conducting field surveys on farms. Regarding the **role of each partner**, it was agreed that the creators of the method are the people involved in WP2 and the non-project experts consulted.

3 Building the evaluation tree

3.1 Organization of the evaluation tree.

The three main branches of the evaluation tree are the three **pillars** of sustainability (1st hierarchical level) environmental, economic and social (ENV, ECO and SOC respectively). Each pillar is divided into smaller branches called '**components**' (2nd level), themselves subdivided into smaller branches called '**criteria**' (3rd level) and '**sub-criteria'** (4th level) that define them. The calculated data at the end of a branch is called an '**indicator**' (5th and last level). An indicator is the synthesis or simplification of data deemed relevant to report the impacts of a practice. Causal indicators report on practices and effect indicators report on impacts.

The environmental, economic and social pillars are rated. Each component is named by a letter (e.g.: (X)), each criterion is named by the letter of its parent component followed by its own letter (e.g.: (X.Y)), each sub-criterion is named by the code of its parent criterion followed by its own letter (e.g.: (X.Y.Z)). And finally, each indicator is named by the code of its parent sub-criterion followed by a number (e. g. (X.Y.Z.1)). In the case where the parent of the indicator is a component, its code is reduced to one letter and one number (e. g.: (D.1)). Similarly, if the parent of the indicator is a criterion, its code is reduced to two letters and a number (e. g. (A.B.1)).

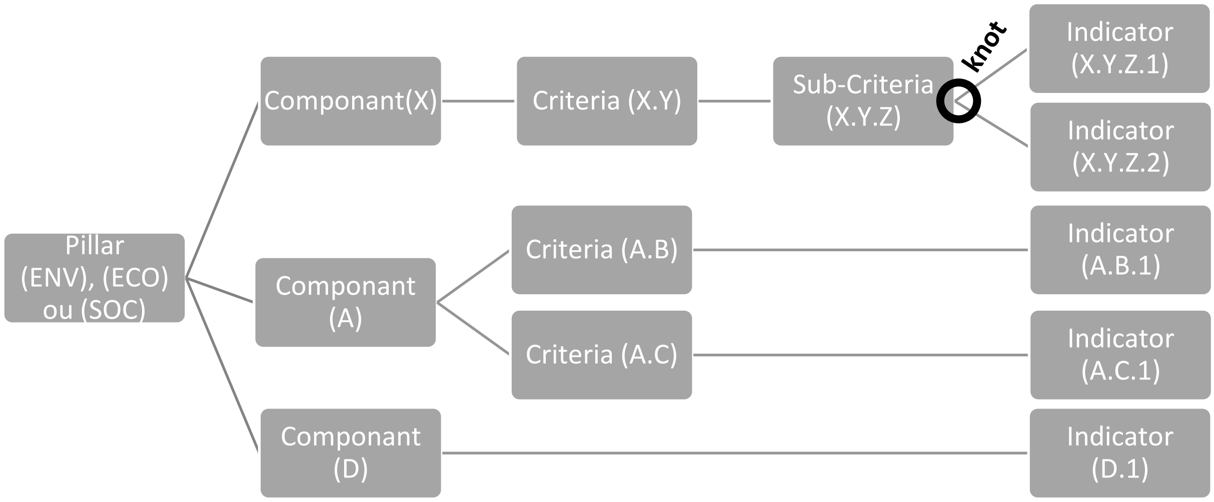


Figure 1 : Hiérarchie et nomenclature de l'arbre d'évaluation

3.2 Functional units

The functional unit is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related. The functional units should be precise and common to the different case studies to enable comparisons. Three functional units are considered: meat carcass, Human Edible protein (HEP) and Energy (HEE) produced at farm level and the utilized arable area.

3.2.1 Meat carcass

The main function of beef production studied in Sustainbeef is the provision of food. The first relevant functional unit is thus the **kg of beef carcass sold**.

The calculation of quantity of beef produced on the farm is as follows:

$$beef\_carcass\ (kg) = \sum_{i=1}^{n} \left(\left(AnimalSold_i - AnimalPurchased_i(head) \right) \times AnimalLiveweight_i(kg) \times carcass\ yield\ _i\ (\%) \right)$$

Where:

- **i** = the different type of animals taken into account (young bulls, culled cows, weanlings etc.)

For animals that are not sold to the slaughterhouse but to another farm where they will be fattened, the carcass yield is approximated. Appendix, table 3 provides carcass yield values for weanlings. Ideally, a joint analysis of the production of the two farms (breeding farm and fattening farm) should be performed.

3.3 Human Edible Protein (HEP) and Human Edible Energy (HEE) produced at farm level

The Sustainbeef project has a broader objective of analyzing the contribution of beef to food production. The whole food production has to be considered. It is not meaningful to add kg of animal products with kg of crop products since they are not equivalent in terms of human nutrition. Nutritional characteristics of the feeds, such as proteins, energy, acido-aminos, vitamins etc are common values that can be used to aggregate the different farm products. Here only the production of human edible proteins / energy in both animal products and vegetables will be consider in the calculation. To evaluate the contribution of farms to food production, we have to dissociate the feed edible by humans from the feed non edible by humans (Ertl et al., 2015; Laisse et al., 2019; Wilkinson, 2011). In the same way we dissociate edible animal products from non edible animal products (such as hide, bones, non-edible offal...) .

The calculation of the total quantity of food protein and energy produced by each farm that was edible by humans took into account all agricultural production on the farm (beef but also milk, cereals, etc., Table 1). For each animal product, the share of human edible protein and the share of human edible energy are defined as a percentage of the gross protein or gross energy of the agricultural product according to Laisse et al. (2019). For meat, these values depend on carcass yield, which varies according to breed and category of cattle (Table 2). In the case where animals are not sold directly to be slaughtered, but to other farms where they will be finished, they were treated as if they had been slaughtered. Regardless of the animal, 1 kg of bovine human edible meat is composed of 158 g of Gross Protein (GP) and contains 10.9 Mj of Gross Energy (GE) (Laisse et al., 2018). For cow's milk produced, it was assumed that it is 98% human edible which gives an identical share of human edible energy and protein of 0.98. The average GP content of 32 $g.l^{-1}$, and GE of 2.6 $Mj.l^{-1}$ of milk are assumed. For plant products, Table 3 gives the shares of human edible protein (SHEPV) and energy (SHEEV) (in % of gross protein and energy). The average composition for each type of concentrate (cow concentrates, weanling concentrates, finishing concentrates, etc.) was estimated (appendix 2), which made it possible to establish their human edible protein and energy contents in the same way as for other feeds.

Table 1: Method for calculating human edible protein and energy contained in meat, milk and cereals sold.

Animal or vegetable product	Calculation method
Meat and milk	HEP produced = animal product * GP *SHEPA HEE produced = animal product * GE* SHEEA
Crops sold and feed	HEP produced or consumed = feed or crops sold * GP * SHEPV HEE produced or consumed = feed or crops sold * GE * SHEEV

Notes: HEP: Human Edible Protein and HEE: Human Edible Energy, Animal product in kg of live-weight (kg of meat sold minus the kg of meat purchased) and kg of milk. Feed and crops in kg of Dry Matter (DM), GP gross protein and GE gross energy in kg of protein or $10^6 J.kg^{-1}$ of crop DM, human edible animal live-weight or milk); SHEPA (%) and SEEP(%) : Share of HEP and HEE in animal products, SHEPV(%) and SHEEV(%): Share of HEP and HEE in vegetable products.

Table 2: Share of human edible protein (SHEPV) and energy (SHEEV), gross protein (GP) and gross energy (GE) contained in each plant-based raw material used in animal feed and land competition of these crops.

Crops sold and feed	SHEPV % [a]	SHEEV % [a]	Gross protein ($g.kg^{-1}$ DM) [b]	Gross energy ($10^6 j.kg^{-1}$ DM) [b]	Land competition ($m^2.kg^{-1}$ DM) [c]
Wheat	66	67	126	18.3	1.33
Barley	61	63	112	18.4	1.48
Moist grain maize	15	63	92	18.6	1.04
Oats	84	79	108	19.5	2.08
Triticale	66	68	115	18.1	1.84
Rape	0	57	202	29.1	3.12
Soya meal from Brazil	60	38	526	19.8	1.51
Rapeseed meal	0	0	336	21.5	1.21
Dehydrated beet pulp	0	0	89	17.1	0.55
Pressed beet pulp	0	0	120	12.8	0.15
Beet molasses	0	0	142	15.5	0.26
Whole cow's milk powder for calves	30	30	254	23.3	1.38
Corn silage	10	32	78	18.8	0.89
Sorghum silage	57	43	59	18.4	1.17
Weanling concentrate	33	45	165	18.3	1.12
Cow concentrate	21	37	226	19.1	1.03
Finishing concentrate	29	41	193	18.9	1.2
Veal concentrate	30	44	197	18.8	1.06
Purchased grass-based forage	Non edible by human				1.43

Sources: [a] Laisse et al 2018, [b] Inra 2018. [c] ECOALIM (Wilfart et al., 2016) and AGRIBALYSE ® (Colomb et al., 2015) excepted for grass for which an average production of 7 ton of $DM.ha^{-1}$ was assumed; DM: Dry Matter.

Table 3: Carcass yield and Share of Human Edible Protein (*SHEPA*) and Energy (*SHEEA*) values for each category and breed of cattle in the study.

Animal category	Breed	Carcass yield (kg of Carcass. kg-1 of live-weight.100)	SHEPA (Kg of HEP. kg-1 of protein)	SHEEA (J of HEE. J-1 of energy)
Cow	Holstein	45.5	0.520	0.300
	Montbéliarde	47.0	0.530	0.305
	Salers or Aubrac	51.0	0.560	0.315
	Charolaise	52.5	0.570	0.320
	Aubrac	53.0	0.570	0.320
	Limousine	54.5	0.585	0.325
	Blanc Bleu Belge	61.5	0.635	0.345
Heifer	Holstein	47.0	0.530	0.305
	Charolais x Salers	54.0	0.580	0.325
	Limousine	55.5	0.590	0.330
	Blanc Bleu Belge	64.5	0.655	0.355
Young bull	Holstein	52.5	0.570	0.320
	Simmental	57.0	0.600	0.335
	Charolais	58.0	0.610	0.335
	Charolais x Salers	59.0	0.615	0.340
	Blanc Bleu Belge	64.5	0.655	0.355
Bull	Salers or Aubrac	54.0	0.580	0.325
	Charolais	57.0	0.600	0.335
	Limousin	58.0	0.610	0.335

Notes: HEP: Human Edible Protein and HEE: Human Edible Energy; see appendix 1 for the calculation

Other functional units are also relevant with other dimensions of the sustainability. For the territory, the most important functional unit is the services that come out of **one unit of land**. Regarding farmers, the amount of income that can be generated for each **worker** unit is of main interest.

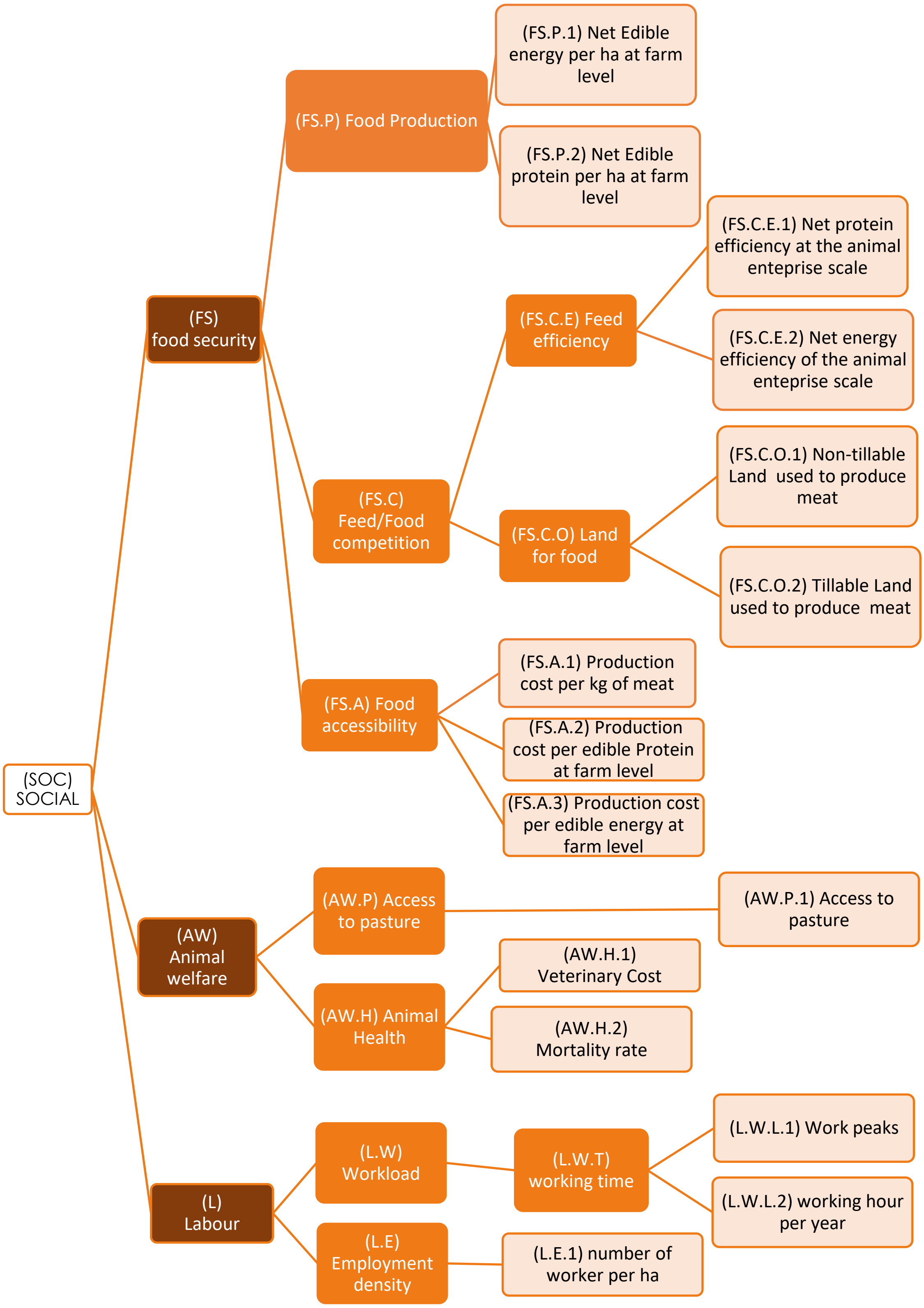
As those units express a different concept, it was decided in some cases to compute indicators according to several functional units to assess one criteria.

3.3.1 Utilized Arable Area

The utilised agricultural area basis includes the area of the holding (UAA) as well as the areas corresponding to feed purchases (Table 2).

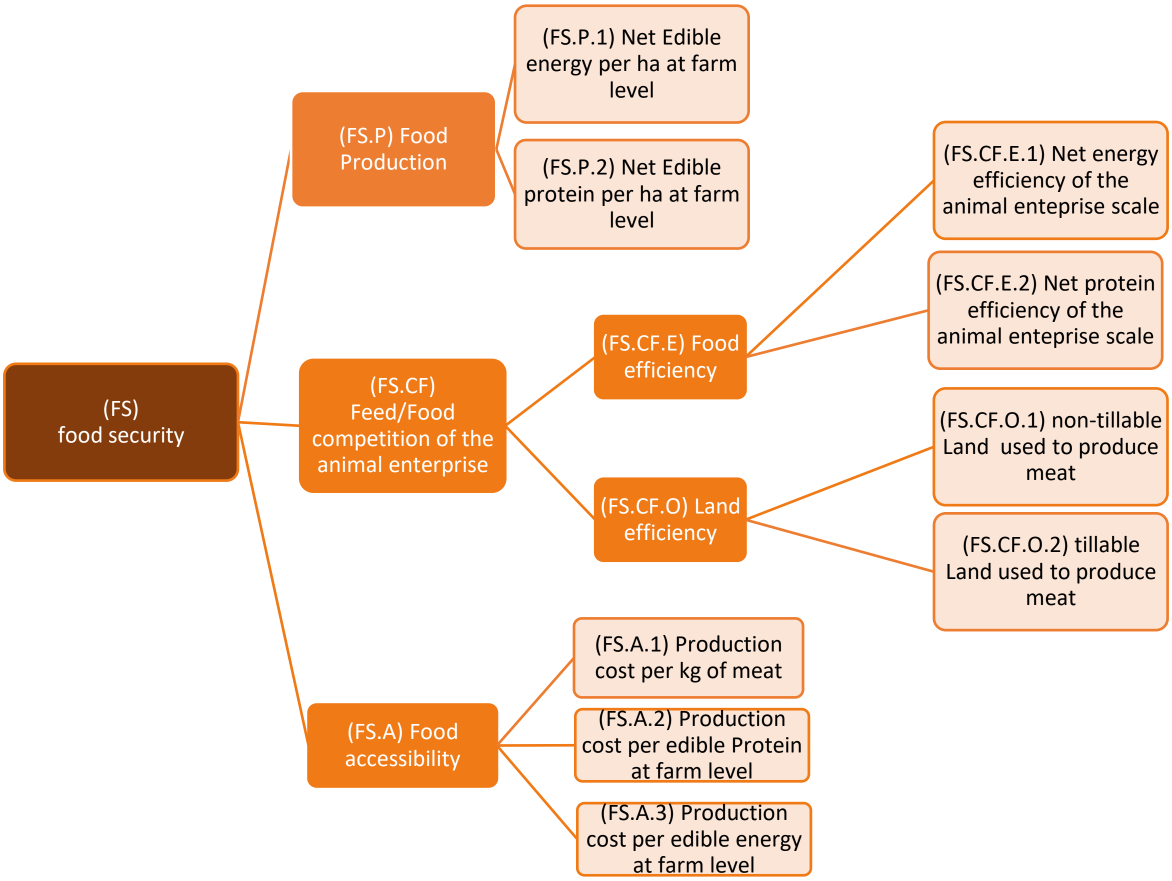
3.4 EVALUATION OF THE SOCIAL PILLAR

The social dimension has three components: Food Security (FS), Animal Welfare (AW) and Labour (L) that will be detailed in the following sub sections.



3.4.1 Food Security component (FS.)

Three criteria were considered (Figure 1): i) production of human edible proteins and energy at farm level in order to estimate the capacity of farms to feed a large number of people per unit of agricultural land, ii) competition between animals and human food production in order to assess whether the production system is efficient in using resources that could be directly used for human food and that are used for beef production, and iii) production costs of beef, protein and energy that give an indication of the economic accessibility of this food for the population. Some indicators were calculated at farm gate and took into account all inputs and outputs from the farm and included milk and crops sold so that it assessed the contribution of the whole farm to food security. Other indicators were calculated at beef production level to track the factors that could improve the beef production. These indicators only took into account the inputs used to produce meat (including inputs used to produce feed on the farm) based on allocation rules that are detailed in section 1.5. It is also computed at the farm level in order to assess if animal production improve the overall land productivity.



(FS.P.1) Net Human Edible Energy per ha and (FS.P.2) Net Human Edible Protein per ha

Objective of the indicator: The purpose of this indicator is to quantify the productivity of agricultural land to produce human edible protein and energy from plant and animals. If animals are produced on areas that are unsuitable to grow crops for human consumption or if they contribute to improve the productivity of lands used to produce crops for human consumption, the net energy produced per ha will increase.

Unit: HEE in 10^9Joule.m $^{-2}$ or HEP in kg of protein.m^{-2}

Calculation: The calculation of the total quantity of food protein and energy produced by each farm that are edible by humans take into account all agricultural production on the farm (beef but also milk, cereals, etc., Table 1). It is evaluated on a per hectare of utilised agricultural area basis, which included the area of the holding (UAA) as well as the areas corresponding to feed purchases.

FS.P.1:

$$\frac{HEE\ of\ (\ meat+\ milk+\ crops\ sold)}{Land\ (farm+\ equivalent\ of\ feed\ purchased)}$$

FS.P.2:

$$\frac{HEE\ of\ (\ meat+milk+crops\ sold)}{Land\ (farm+equivalent\ of\ feed\ purchased)}$$

The land equivalent required to produce the feed purchased are calculated by Life Cycle Assessment and come from the Agribalyse® database.

Comments: This indicator doesn't take into account differences in land production potential (soil fertility, climate, etc.). The productivity of land is an average value. This indicator should be evaluated relative to the production potential of the farm.

(FS.CF.E.1) Net energy efficiency and (FS.CF.E.2) Net protein efficiency

Objective of these indicators: Since the feed consumed by farmed animals sometimes includes a proportion of plants that could be directly consumed by humans, livestock production is a subject of debate in today's society (Laisse et al., 2017). However, animals also value feed that cannot be consumed by humans: fodder, co-products, etc. This indicator is designed to evaluate the ability of animals to produce more (or less) human edible energy than they ingest, and thus measures the protein efficiency of the farm's animal unit (producer or consumer).

Unit: Without unit

Calculation: The edible protein or energy efficiency of an animal production system is the ratio between the amount of edible protein or energy produced by animals and the amount of edible protein or energy needed to produce it. This ratio is calculated at the animal enterprise scale.

FS.CF.E.1

$$\frac{HEE\ of\ meat}{HEE\ of\ feed}$$

FS.CF.E.2

$$\frac{HEP\ of\ meat}{HEP\ of\ feed}$$

The formula to calculate Human edible energy (HEE) and protein (HEP)are provided in section 3.2.

Interpretation: If the ratio is >1, the animal production is a net producer of proteins for human consumption, if it is <1, animal production is a net consumer of human edible protein or energy.

Comments: On 100% grass systems, not consuming any protein that can be assimilated by humans, the ratio is not mathematically valid, the denominator is replaced by the value 0.000001. The primary objective was to assess the efficiency of meat production. However, it would have been necessary to be able to make allocations for dairy systems that also produce meat (veal, cull cows, etc.). Thus, it was decided to take all animal products (milk and meat) in order to avoid this bias.

(FS.CF.O.1) non-tillable Land and (FS.CF.O.2) tillable land used to produce meat

Objective of these indicators: The purpose of these indicator are to quantify the use of agricultural land to produce 1 kg of beef meat. We differentiate tillable lands that can be used to grow plants edible by human from non-tillable land where only grass and trees can grow. The feed/food competition will directly decrease if less areas suitable to grow human edible plants are used for animals. This competition will indirectly decrease if a higher production of more carcass with feed produced on non-tillable land spares the production of feed on tillable lands.

Unit: m^2/kg carcass of meat

Calculation: All the areas necessary for the production of animal, included areas outside the farm, are summed and divided by the total number of kg of beef carcass produced on the farm.

FS.CF.O.1:

$$\frac{Land\ (Non\ tillable)}{meat\ produced}$$

FS.CF.O.2:

$$\frac{Land\ (Tillable + equivalent\ of\ feed\ purchased)}{meat\ produced}$$

This calculation requires to distinguish on farm tillable land that is used to feed animals from tillable land used to sell crop products. This can be done my multiplying each area with a given crop by the ratio of the quantity of crop product (cp) consumed on the total quantity of crop product produced.

$$on\ farm\ tillable\ land\ used\ to\ produce\ feed\ (m^2) = \sum_{crop} HA_{crop} \sum_{cp} \frac{Consumption_{cp}}{HA_{crop} \times yield_{crop,cp}}$$

The land equivalent required to produce the feed purchased are calculated by Life Cycle Assessment and come from the Agribalyse® database.

Comments: This indicator takes into account the land production potential only partially by differentiating non-tillable areas from tillable areas. Non-tillable areas correspond to areas with important slopes, high elevation, unfavourable climate or shallow soils. These areas are currently not mechanizable or not profitable for crop production, nonetheless that doesn't mean that with other techniques and plant varieties or species these areas couldn't produce plants edible for humans.

• (FS.A.1) Production cost per kg of meat, (FS.A.2) per net energy, (FS.A.1) per net protein

Objective of the indicator: The hypothesis here is that if the farm is able to produce at a low cost, then the consumer will buy at a low price, which improves accessibility to food.

Unit: €/kg of beef carcass*;* €/kg de proteins, €/Mj

Calculation: Production costs are calculated at the beef production level per 1 kg of carcass produced, and also at farm level per 1kg of human edible protein and 1 MJ of human edible energy produced.

FS.A.1

$$\frac{Total\ expenses\ to\ produce\ meat}{meat\ produced}$$

FS.A.2

$$\frac{Total\ expenses\ of\ the\ farm}{HEP\ of\ (meat + milk + crops\ sold)}$$

FS.A.3

$$\frac{Total\ expenses\ of\ the\ farm}{HEE\ of\,(meat + milk + crops\ sold)}$$

The production cost of a product was estimated considering all farm costs over an annual production cycle and assigning them to a given product. They encompassed current costs (structural costs and costs related to the herd, crops and forage areas), depreciation (wear and tear and discounting of equipment and buildings) and supplementary costs (remuneration of labour and borrowed capital). The remuneration of farm labour was estimated on the basis of the number of worker units multiplied by the median net wage, per country available on the European statistics website Eurostat. The meat production cost indicators needed the isolation of consumption and costs necessary for meat production. However, it is often not possible to allocate fixed costs (material, labour, equipment etc.) between meat production and the other farm products. In this case, allocation rules are proposed (Table 4) in order to associate the forage area costs with the animal enterprise. These intra-consumed areas are estimated by dividing the amount of feed consumed by the animals by the average yield per hectare. Fixed costs (machinery, labour, land, etc.) are also allocated among the enterprises according to the guidelines presented in Table 4.

Table 4: Allocation method of costs to the animal enterprise.

Item	Hypothesis for costs	Allocation
Fertilisers and soil improvers	Proportional to the units of Nitrogen (N) applied to each crop consumed by animals.	$\frac{N\ on\ (MFA\ +\ IAC)}{N\ on\ UAA}$
Crop protection products	Equally distributed across all Annual Crops	$\frac{ha\ ICA}{ha\ CA}$
Seeds and seedlings	Equally distributed over all areas of crops sown in the year with a reseeding of TG every four years	$\frac{ha\ of\ (IAC + TG/4)}{ha\ of\ (AC + TG/4)}$
Other specific crop costs (analysis, small equipment, etc.)	Proportional to the hectares of annual crops, silage maize/2 and grassland/2	$\frac{ha\ \ of (IAC +\ MS/2 + grass/}{ha\ of\ (AC + MS/2 + grass\ /}$
Maintenance of buildings and equipment, fuel, contract work, depreciation, interest and financial costs and other charges	One hectare of non-fodder crop is equivalent in terms of capital use - excluding labour and land - to 1 LU (and the associated main forage area (MFA).	$\frac{LU}{LU + \text{ha of nfCA}}$
Wages and social insurance	1 LU requires double the hours of work than 1 hectare of cash crops (Veysset, 2014)	$\frac{LU}{LU + \text{ha nfCA}/2}$
Rental charges	All plots have the same value.	$MFA + IAC/UAA$

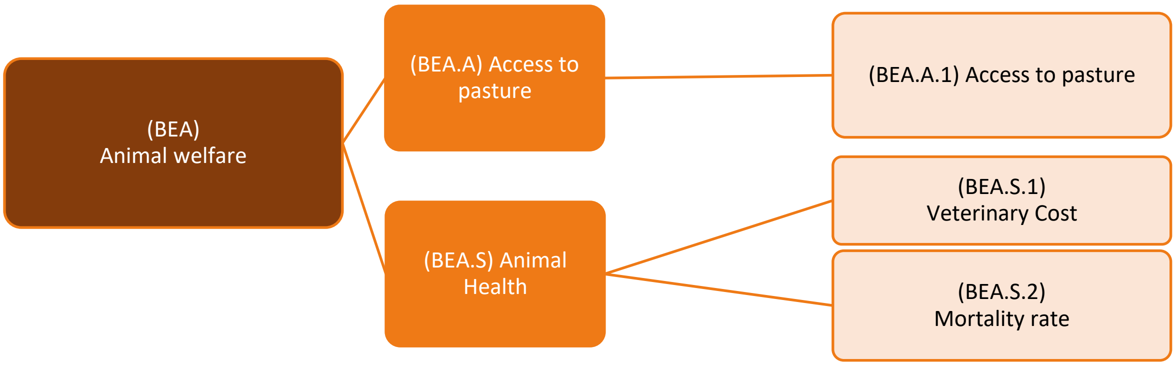
Note: AC: Annual Crops, IAC: intraconsumed annual crops, nfCA: non fodder annual crops, MS: Maize Silage, MFA: Main Forage Area, UAA: Utilised Agricultural Area, TG: Temporary grassland, LU: Livestock unit

For farms with both dairy and suckler cattle, feeds were divided between the two herds according to the diets described in each case-study. This made it possible to determine the areas used by each herd, that were needed to calculate the competition indicators for agricultural land use. Regarding the economic data, the feed and crop operational costs were divided between dairy and suckler cattle according to the feed consumed by each herd. For other costs, where no information is provided, the production cost allocation by the French Livestock Institute (Appendix 3) were used.

Finally, for farms where beef is a by-product of milk production, the biophysical allocation method of the International Dairy Federation (2010) was used where the Milk Allocation Factor = 1 - 6.04*(total live kg sold-purchased from the dairy herd)/kg total milk sold. This gives an allocation factor of about 80% for milk and 20% for meat which is applied to the feed of the dairy herd, the areas used and the economic costs.

3.4.2 Component: Animal welfare

The animal welfare component has to criteria: access to pasture and animal health which is appraised by a veterinary costs and mortality rate.



(BEA.A.1) Access to pasture

Objective of the indicator: Access to pasture is considered to be one of the factors of animal welfare in livestock farming (Mounier et al., 2007). Indeed, outdoors, animals can express most of their natural behaviours, and in addition, partially express their food preferences (Dumont, 1996). This indicator therefore assesses whether or not animals are grazing. This also reflects the consumer expectations identified by the ACCEPT project (IFIP, 2017).

Unit and calculation : without unit.

2 possible values:

- 0 (Unfavorable threshold): animals have no access to the pasture
- 10 (Favorable threshold): animals have access to the pasture

Comments: Climate can be a constraint to grazing animals, especially in areas where winters are cold and humid, or in areas where summers are hot and dry. One of the constraints that can influence the grazing of animals is also the distance between the pastures and the farm, for example on a farm without a mobile milking parlour for dairy cows. This indicator is based on the Welfare Quality© method, however in this method the hours per day spent on pasture are taken into account, but this is too precise for our study.

(BEA.S.1) Veterinary costs

Objective of the indicator: In some cases, better respect for animal welfare can lead to a reduction in veterinary costs (CIWF, 2011). Thus, this indicator has been constructed in such a way that it reflects animal welfare and more particularly animal health on the farm.

Unit: € / LU

Calculation: $\frac{Veterinary\ costs}{Total\ livestock\ unit}$

Interpretation: Veterinary costs (products and fee) take into account those specific to births. Thus, it is necessary to differentiate between the thresholds for holdings with births and those with only fattening.

Comments: A critique can be made of this indicator. Indeed, low veterinary costs can mean either good animal health and therefore little care, or negligence on the part of the farmer who does not treat his sick animals. However, we are working here with simulation data, all the necessary care of the animals will be recorded in FarmDyn, so there will be no possible negligence.

(BEA.S.2) Mortality rate

Objective of the indicator: In some cases, better respect for animal welfare can lead to a reduction in on-farm animal mortality rates (CIWF, 2011). Thus, the purpose of this indicator is to provide information on the mortality rate on the farm that reveals the quality of life of the animals, since it is easily understandable that if the animal dies, there is no welfare.

Unit: without unit

Calculation:

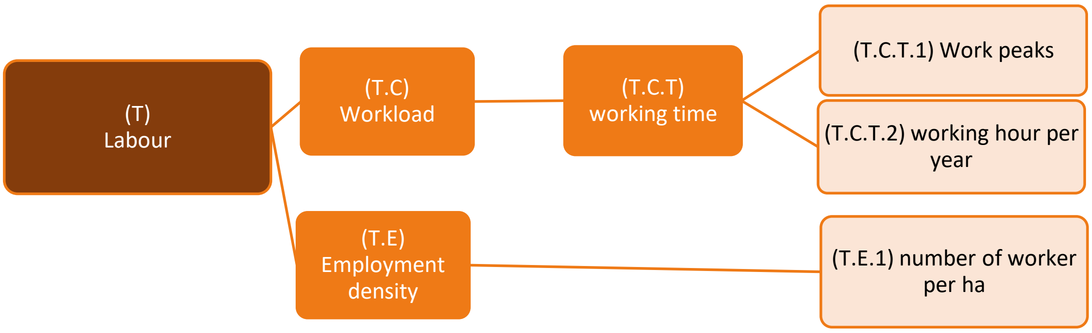
$$\frac{Number\ of\ dead\ animals\ during\ the\ year}{Total\ number\ of\ animals\ in\ the\ farm}$$

Interpretation: Birth farms have a higher overall mortality rate than pure fatteners since calf mortality is taken into account. The thresholds are therefore differentiated for these two types of systems.

Comments: A criticism can be made of this indicator, death is not always due to a lack of respect for well-being, but it is sometimes a death of "old age". This is a bias in the evaluation of this indicator.

3.4.3 Component: on-farm labour

The component has two dimensions: workload for the farmers with two criteria: working time and monotony, and employment density. The criteria workload is divided in two sub-criteria: working time that is assessed by two criteria (work peaks and working hours per day) and monotony that is accounted for by the number of activity. The criteria monotony is evaluated by the number of activities.



(T.C.T.1) Work peaks

Objective of the indicator: Working time is now one of the major concerns of farmers (Fagon et al., 2010). A distinction is made between on-call time, which is carried out daily, such as daily animal care (feeding, bedding, etc.) and seasonal tasks, which brings together specific tasks on the farm (harvesting, fence maintenance, grouped farrowing, etc.). The purpose of the indicator presented here is to identify peaks in work over a year. The number of months in which the average monthly working time exceeds an arbitrary threshold of 8 hours/day/worker is thus calculated.

Unit and Calculation: Number of month for which the average working hours exceed 8 hours/day/worker

- ## (T.C.T.2) annual working hour per worker

Objective of the indicator: In line with the previous indicator, this one aims to quantify the total working time necessary for the proper functioning of the operation over a year.

Unit and calculation: annual working hours /worker
Comments: the number of hours per worker is capped in the model. Nonetheless it can be below this threshold.

(T.E.1) Number of on-farm jobs generated on the farm surface

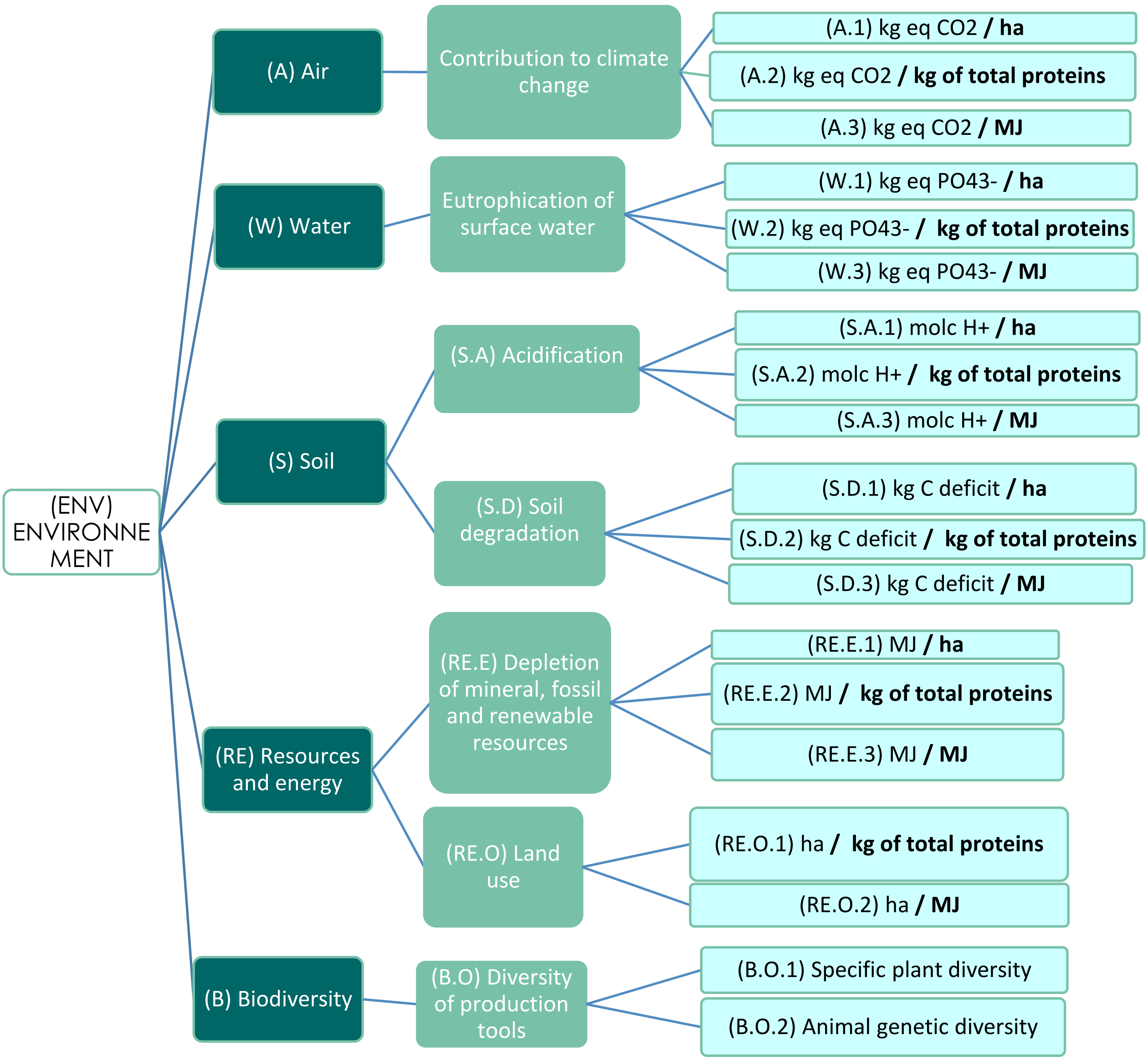
Objective of the indicator: The purpose of this indicator is to quantify the contribution of the farm to employment in the territory, i.e. more specifically, how many on-farm jobs generate the farm per Area Unit it occupies, especially since the number of hectares managed per farmer has been on an upward trend for several years (Fiorelli et al., 2007).

Unit and calculation: Number working hours / ha

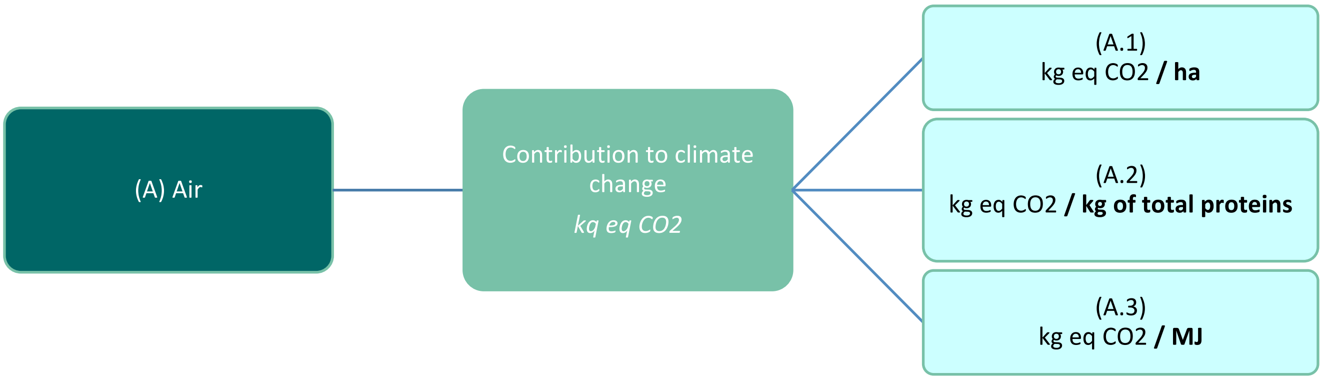
Comments: There is a bias regarding this indicator. Working hours spent on operations that are contractualized and therefore not performed by people working on the farm are not included in the indicator. However, this also contributes to employment in the territory. In addition, most agricultural products require activities additional to production such as slaughtering or milk collection (Fagon, 2010). However, these activities are not necessarily carried out locally and it is difficult to know the future of the products. For this reason, this indicator is restricted to the agricultural holding.

3.5 Environmental pillar

Five components represent the environmental pillar: Atmosphere (A), Water (W), Soil (S), Resources & Energy (RE) and Biodiversity (B). Each components are assessed by indicators calculated with three functional unit at farm level: land (agricultural area of the farm), energy and protein produced on farm (animal + crop).



3.5.1 Component: Air



(A.1-2-3) Contribution to climate change

Objective of the indicator: This indicator calculated by LCA aims to quantify the impacts of agricultural activities on the atmosphere. To do this, the equivalent kg of CO2 emitted is summed for each of the farm's products and inputs.

Unit

(A.1) $\frac{\text{kg éq CO2}}{ha}$ (A.2) $\frac{\text{kg éq CO2}}{kg\ of\ protein\ produced}$ (A.3) $\frac{\text{kg éq CO2}}{MJ\ produced}$

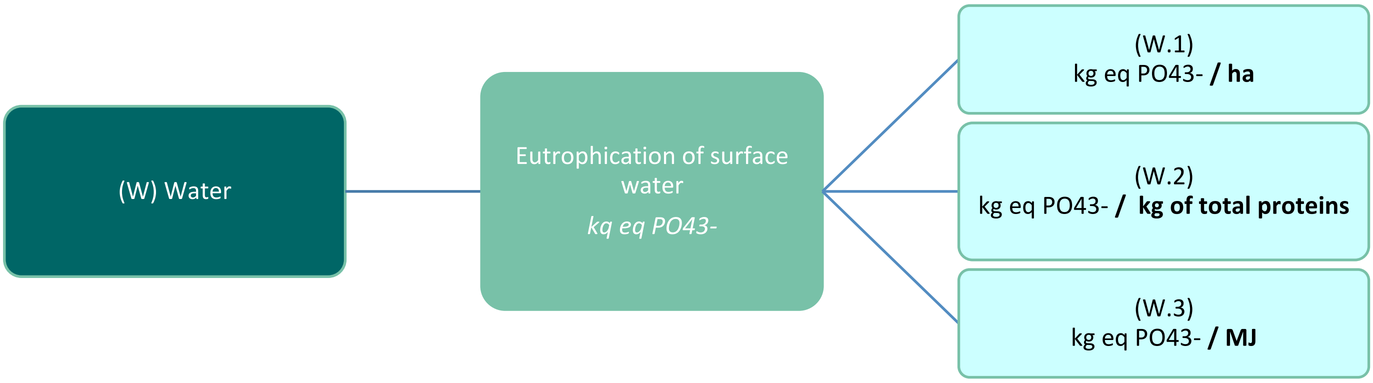
Calculation:

The data required for the calculation are:

- All the contributions to climate change of the farm's crop and livestock production and of the feed purchased for animal feed.
- UAA of the holding (A.1)
- kg of total protein produced on the farm (A.2)
- Total MJ produced on the farm (A.3)

Sources: Agribalyse® for raw production, EcoAlim for compound feed

3.5.2 Component: Water



(W.1-2-3) Eutrophication of surface water

Objective of the indicator: This indicator calculated by LCA aims to quantify the impacts of agricultural activities on water and particularly surface water. To do this, the equivalent kg of $PO4^{3-}$ emitted are summed for each of the farm's products and inputs.

Unit:

(W.1) $\frac{\text{kg éq PO43−}}{ha}$ (W.2) $\frac{\text{kg éq PO43−}}{kg\ of\ protein\ produced}$ (W.3) $\frac{\text{kg éq PO43−}}{MJ\ produced}$

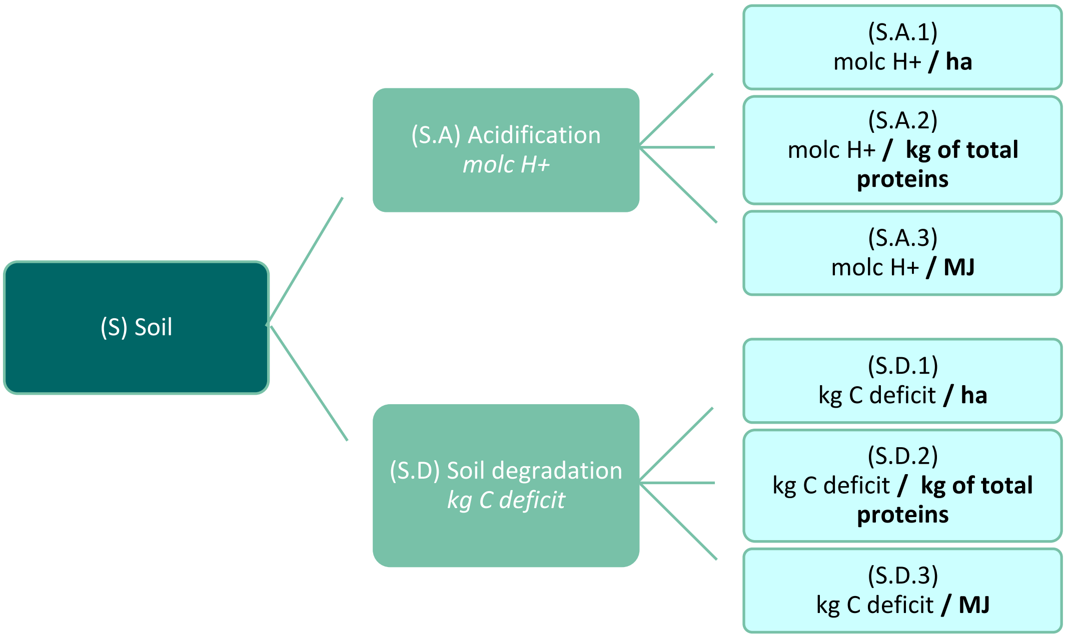
Calculation:

The data required for the calculation are:

- All the impacts of crop and livestock production from the farm and crop production purchased for animal feed on aquatic eutrophication.
- UAA of the operation (W.1)
- kg of total protein produced on the farm (W.2)
- Total MJ produced on the farm (W.3)

Sources: Agribalyse® for raw production, EcoAlim for compound feed

3.5.3 Component: Soil



(S.A.1-2-3) Acidification

Objective of the indicator: This indicator calculated by LCA aims to quantify the impacts of agricultural activities on the soil and particularly its acidification. To do this, the moles of H+ emitted are summed for each of the farm's products and inputs.

Unit: (S.A.1) $\frac{\text{molc H+}}{ha}$ (S.A.2) $\frac{\text{molc H+}}{kg\ of\ protein\ produced}$ (S.A.3) $\frac{\text{molc H+}}{MJ\ produced}$

Calculation:

The data required for the calculation are:

- All the impacts of crop and livestock production from the farm and crop production purchased for animal feed on acidification.
- Operating usable arable area (S.A.1)
- kg of total protein produced on the farm (S.A.2)
- Total MJ produced on the farm (S.A.3)

Sources: Agribalyse® for raw production, EcoAlim for compound feed

(S.D.1-2-3) Soil degradation

Objective of the indicator: This indicator calculated by LCA aims to quantify the impacts of agricultural activities on the soil and particularly its quality. To do this, the deficit kg C is summed for each of the farm's products and inputs. They represent in particular the loss of carbon by erosion or by mineralization of organic matter.

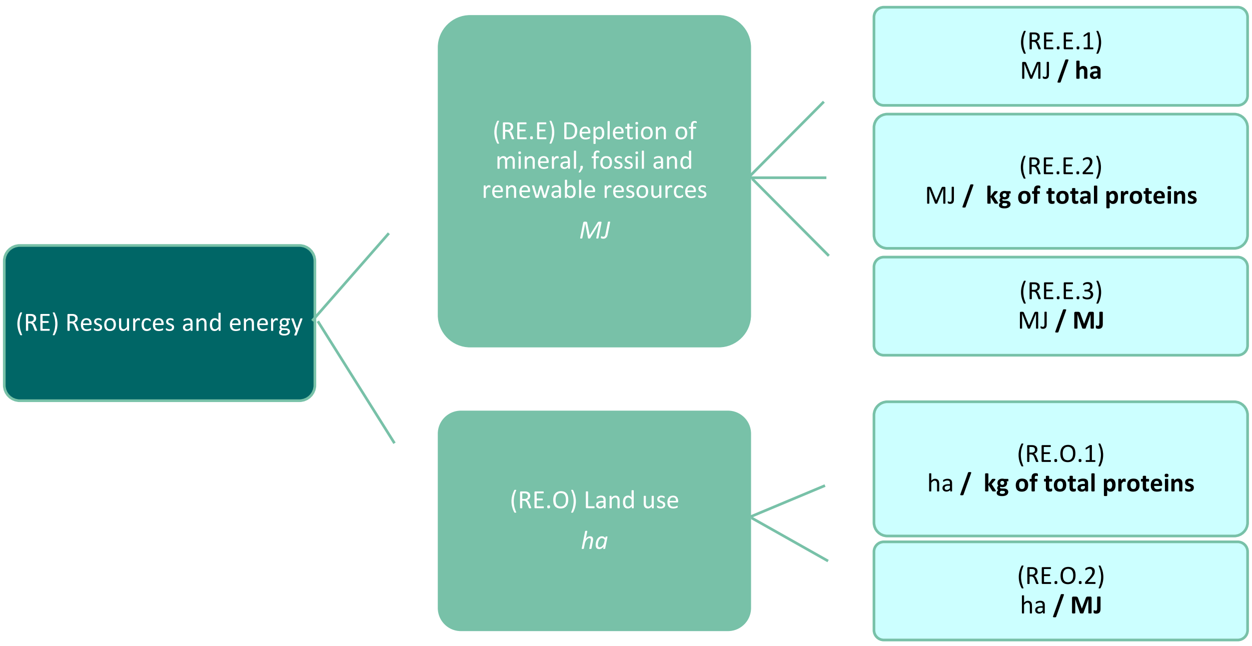
Unit: (S.D.1) $\frac{\text{Deficit kg C}}{ha}$ (S.D.2) $\frac{\text{Deficit kg C}}{kg\ of\ protein\ produced}$ (S.D.3) $\frac{\text{Deficit kg C}}{MJ\ produced}$

*Calculation:*The data required for the calculation are:

- All the impacts of crop and livestock production from the farm and crop production purchased for animal feed on soil degradation.
- Operating UAA (S.D.1)
- kg of total protein produced on the farm (S.D.2)
- Total MJ produced on the farm (S.D.3)

Sources: Agribalyse® for raw production, EcoAlim for compound feed

3.5.4 Component: Resources and energy



(RE.E.1-2-3) Depletion of mineral, fossil and renewable resources

Objective of the indicator: This indicator calculated by LCA aims to quantify the impacts of agricultural activities on resource depletion and energy consumption. To do this, the equivalent kg of MJ consumed is summed for each of the farm's products and inputs.

Unit: (RE.E.1) $\frac{\text{MJ consumed}}{ha}$ (RE.E.2) $\frac{\text{MJ consumed}}{kg\ of\ protein\ produced}$ (RE.E.3) $\frac{\text{MJ consumed}}{MJ\ produced}$

Calculation: The data required for the calculation are:

- All the impacts of crop and livestock production from the farm and crop production purchased for animal feed on the depletion of mineral, fossil and renewable resources.
- Operating UAA (RE.E.1)
- kg of total protein produced on the farm (RE.E.2)
- Total MJ produced on the farm (RE.E.3)

Sources: Agribalyse® for raw production, EcoAlim for compound feed

(RE.O.1-2) Land use

Objective of the indicator: The purpose of this indicator is to quantify the right-of-way on agricultural land. To do this, the areas used are summed for each of the farm's products and inputs.

Unit:

$$\text{(RE.O.1)} \quad \frac{\mathrm{m}^2}{kg\ of\ protein\ produced} \qquad \text{(RE.O.2)} \quad \frac{\mathrm{m}^2}{MJ\ produced}$$

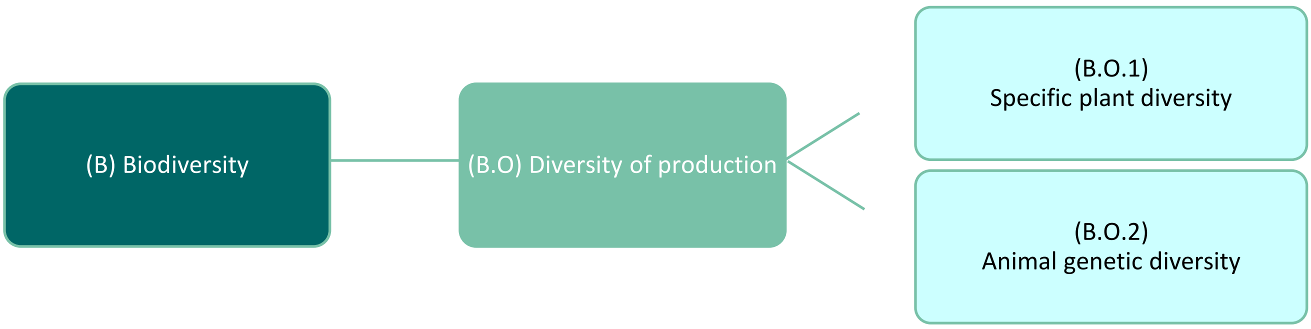
Calculation: The data required for the calculation are:

- All the areas necessary for the production of plants and animals on the holding and plant production purchased for animal feed.
- kg of total protein produced on the farm (RE.O.1)
- Total MJ produced on the farm (RE.O.2)

Sources: Agribalyse® for raw production, EcoAlim for compound feed

3.5.5 Component: Biodiversity

The component biodiversity is assessed through two criteria: Diversity of production tools and Diversity of productions.



(B.O.1) Specific plant diversity

Objective of the indicator: The purpose of this indicator is to assess the number of plant species. Indeed, the greater the number of plant species, the lower the risk of resistance to the field of specialization of weed flora (Ministry of Agriculture, Agri-Food and Forestry, 2018) and the greater floristic diversity (Achard de la Vente et al., 2018).

Unit: Number of « species » (grasslands can count several species)

Calculation: The value taken by the indicator corresponds to the number of plant categories present on the farm.

(B.O.2) Animal genetic diversity

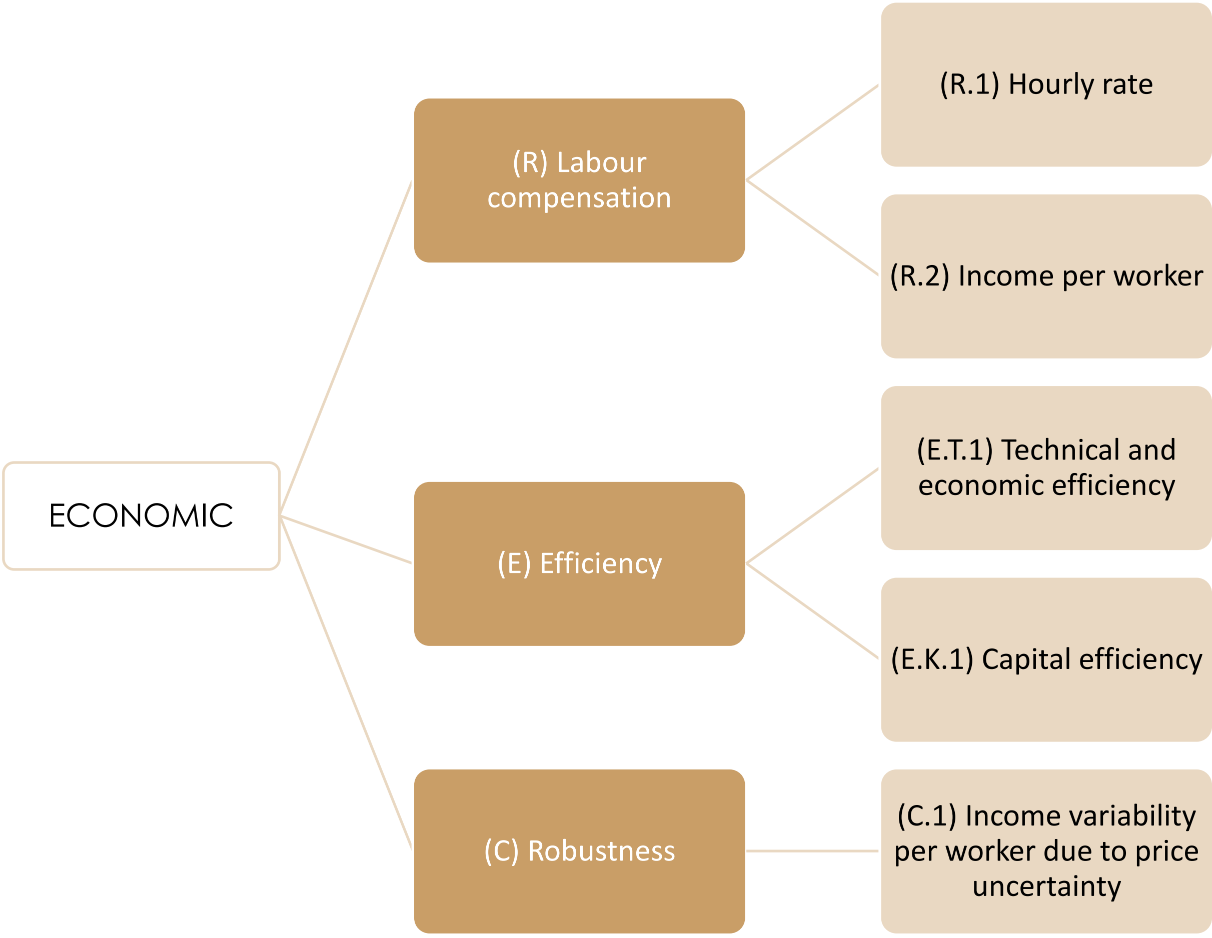
Objective of the indicator: The purpose of this indicator is to assess the number of breeds present on the farm. We then consider that from 2 breeds present, there is an effort on the part of the farmer towards genetic diversity. Indeed, the more breeds there are, the more technical the management of the herd is.

Unit: Number of breeds

3.6 Economic pillar

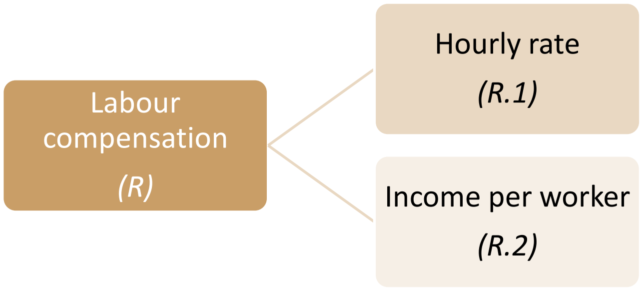
The economic sustainability of the farm will be assess through 3 components:

- Labor compensation, ie. the capacity to remunerate the work conducted on the farm
- Efficiency of the inputs and of the capital invested
- Robustness to quantify the ability of the farm to withstand a series of economic hazards (e.g. changes in products and/or inputs prices).



3.6.1 Component: Labour compensation

The capacity to remunerate the work conducted on the farm is appreciated through two indicators: Hourly rate and income per worker.



(R.1) Hourly rate

Objective of the indicator: The objective here is to quantify labour compensation by assessing the value of one hour of work on the farm.

Unit: € / h

Calculation: The data required are:

- Net operating income
- The total number of working hours excluding contractualized hours

$$\frac{Net\ operating\ income}{Total\ number\ of\ working\ hours\ excluding\ contractualized\ hours}$$

(R.2) Income per worker

Objective of the indicator: The objective here is to quantify labour compensation by estimating the disposable share of net operating income per worker over a year.

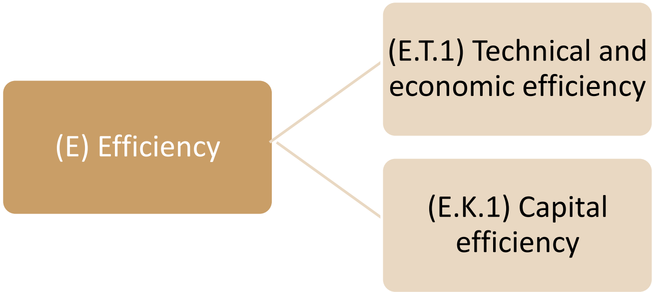
Unit: € / UTH

Calculation:

$$\frac{Net\ operating\ income}{Total\ number\ of\ labor\ unit\ on\ the\ farm}$$

3.6.2 Component: Efficiency

Efficiency is assessed through two indicators technical and economic efficiency and capital efficiency.



(E.T.1) Technical and economic efficiency

Objective of the indicator: The objective here is to quantify the technical and economic efficiency of the farm, i.e. its ability to produce wealth from the inputs it uses.

Unit: Without unit

Calculation:

$$\frac{Total\ gross\ production\ excluding\ aid}{Total\ intermediate\ consumption\ +\ depreciation}$$

(E.K.1) Capital efficiency

Objective of the indicator: The objective here is to quantify capital efficiency, i.e. the amount of wealth produced with the capital of the farm. If the capital is too large in relation to the wealth produced, this constitutes a risk for the exploitation.

Unit: Without unit

Calculation: The data required for the calculation are:

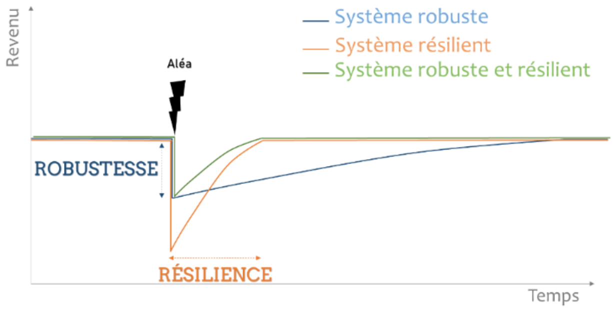
$$\frac{Net\ operating\ income}{Total\ capital\ excluding\ land\ and\ permanent\ crops}$$

Interpretation: For example, if the indicator takes the value 0.1, it means that it takes $\frac{1}{\mathbf{0,1}}$ = 10 years to repay the capital with the farm income. The higher this indicator is, the more efficient the operating capital is, i.e. more has been produced with little capital.

3.6.3 Component: Robustness

(C.1) Income variability per worker due to price uncertainty

Objective of the indicator: The robustness of a system can be defined as its ability to withstand a hazard. Resilience is the ability of a system to return quickly to its initial state after a hazard.



The robustness of the system can be assessed by subjecting it to various price uncertainties and by studying the income dispersion of the system. The robustness of the system will therefore be assessed via the coefficient of variation of net income per worker.

Unit: Without unit

Calculation: The data required for the calculation are:

- X price contingency constraints
- A series of X data on net operating income per UTH following each price contingency

$$Coefficient\ of\ variation = \frac{Standard\ deviation\ of\ net\ operating\ income}{Average\ net\ operating\ income}$$

4 Aggregation and choice of thresholds

It is necessary to weight and aggregate the indicators in order to be able to summarize all the information in a single note and thus conclude on the sustainability of the systems. However, aggregation has several methodological pitfalls (Schärlig, 1985), including: incommensurability, i.e., the fact that there is no common unit for all indicators, the subjectivity of weights, compensation between indicators and the loss of information when aggregating. Thus, different aggregation methods exist with their advantages and disadvantages. Three main groups of methods can then be mentioned:

- Methods based on a common quantitative scale. These involve a transformation of all quantitative indicators on the same scale, aggregation is then an arithmetic combination of indicators all having the same unit. This is the case for MAUT or AHP methods (Keeney et al., 1976 - Saaty, 1980). However, these methods have disadvantages such as the total compensation of the indicators.
- Methods based on over-ranking. The systems are compared two by two to obtain a ranking, such as the ELECTRE method (Roy, 1968). However, they represent a limitation in the aggregation of quantitative and qualitative indicators together.
- Methods based on decision rules, which are based on a hierarchical decision tree such as the DEXi tool (Bohanec et al, 2008).

Aggregation can be done according to two logics:

- Boolean logic, whose use is facilitated by the DEXi software (Bohanec et al., 2008). The indicators are put into classes as well as the aggregate score. Aggregation is based on "if... then" type decision rules: if the indicators meet one or more conditions, then the aggregate score will take the corresponding value. However, this logic imposes threshold effects and the decision rules are not explicit. Moreover, it does not limit compensation between indicators.

- Fuzzy logic, developed in the 1960s, based on the mathematical theory of subsets (Lairez et al., 2015). This approach is based on human reasoning rather than rigid calculations. It allows users to better understand natural phenomena, which are imprecise and difficult to model. Belonging functions are determined for each indicator to assess its degree of belonging to a given set. This means that the value of the indicator is transformed into a score (membership value) between 0 and 1, which can follow different functions (linear, hyperbolic tangent, etc.). Then aggregation consists in taking the minimum or product of the scores of the indicators ori-ltjk-tkt;èand calculating their barycentre. This logic then allows intermediate values to be processed when an indicator is found to be partially true or partially false, which is a major advantage.

The CONTRA® tool has been chosen to aggregate indicators since it combines the advantages of the hierarchical decision trees and uses the fuzzy logic that ensures transparency, adaptability, flexibility and limitation of compensations (Bockstaller et al., 2017).

The project partners have decided not to go to the final aggregation of indicators. They are indeed afraid of losing information by aggregating several indicators into a single one and of giving too subjective scores and weight to the different indicators. Consequently, only the principles of aggregation and the first thoughts will be presented.

I.1. Interpretation of indicators

In order to be able to interpret and aggregate the indicators, they have to be transformed on a common scale from 0 to 10; 0 being the worst score, 10 the best. As a result, functions of belonging to the "favorable" and "unfavorable" classes are determined in the CONTRA® tool. The most appropriate type of membership function for our study, which reduces compensations between indicators and eliminates threshold effects, is the hyperbolic tangent function. Depending on the value of the indicator, the tool determines its degree of favourable and unfavourable class membership and concludes with a score between 0 and 10 for this indicator. However, the transformations depend on the type of interpretation of each indicator, i.e. whether it is a performance or risk indicator. In the case of a performance indicator (e.g. "the higher the better"), the desired value is as large as possible. Thus, the higher the value, the better the score. In the case of a risk indicator ("the lower the better") the value sought is the smallest possible value. Thus, the higher the value of the indicator, the lower the score. For quantitative indicator "Bell-shaped: one optimum and two minima”, two unfavourable thresholds and one favourable threshold are set.

The "favorable" and "unfavorable" threshold values are entered by the user. These threshold can be determined either by bibliographical references, by expert opinion of by benchmarking. Benchmarking is the comparison of one´s performance with the performance of others engaged in a similar activity. Thresholds can then be defined as the best performing farms and the worst ones. Economic thresolds were for instance proposed for the French case studies based on a technical-economic database containing 95 French cattle farms that are part of the INOSYS breeding networks of IDELE and the Chambers of Agriculture, was extracted from the Diapason tool (IDELE et al., 2012). The 5th and 95th percentile of this distribution was then chosen for the unfavourable and favourable thresholds respectively for the French situation. The farm performance in the baseline situation (before the implementation of an innovation) can also be used as a benchmark. In this case, only improvement or regression relative to the initial state could be done, without possibilities to assess if the new state is good enough to be qualified as sustainable.

I.2. Weighting indicators

Indicators can be weighted according to the importance they are intended to be assigned to each other. The evaluation tree was sent to 12 experts who had already been confronted with the problems of assessing the sustainability of agricultural systems at the plot, farm system or territory level. These experts were from research institutes, technical institutes or Chambers of Agriculture. Four of them responded positively to this request. After collecting their profile and work theme, they were asked to assign weights to each indicator in order to establish the weights they felt were relevant (Appendix 8). As a result, the weighting process of each indicator by those experts as seen as difficult due to their respective specialisation fields that made them more sensitive to some dimensions. Thus, it was decided to let weighting free and to adapt it according to the users.

We have proposed three weighting scenarios with different ponderations. The « National statistics » scenario does not favour any indicators. Thus, the weights of the attributes of the same knot are equal, so there is no weighting. The « Farmer » scenario attempts to adopt a logic that could be that of a farmer. It would thus give greater importance to the economic pillar by assigning it a weight of 50%

compared to 20% for the environmental pillar and 30% for the social pillar. Within the economic pillar, it would focus on income (R) and within the social pillar, on workload. Eventually, the "Territorial community" scenario objective was to imitate the weightings that a territorial authority could assign according to the problems it would have to face on its territory. The example taken here is that of a territory with frequent mudslides, eutrophication is reported to be significant in watercourses, a local race is threatened and the territory is deserted. The environmental and social pillars are then favoured over the economic pillar. Within the environmental pillar, the Water and Soil components have more weight than the Resources and Energy and Biodiversity components. Within the Soil component, soil degradation indicators are the most important. Within the criterion Diversity of production tools, animal genetic diversity has a weight of 70% compared to 30% for plant specific diversity). Finally, within the Labour component of the social pillar, it is Territorial Employment that has a greater weight in relation to the operator's workload.

5 Conclusion and perspectives

The objective of deliverable was to propose a multi-criteria evaluation method to analyze feed/food competition in European beef farming systems and to appraise their global sustainability. This method had to be compatible with outputs from a bioeconomic farm model and sensitive to incremental changes produced by the implementation of innovations aiming at reducing the feed/food competition. This study presents the evaluation method based on other existing methods and constructed according to the constraints of the project. More than 40 indicators are organize in a tree that includes three main branches corresponding to the pillar of sustainability –social, environmental and economic-. Each pillar is then divided in criteria, subcriteria and indicators. Each indicator is then clearly positioned within the global evaluation. This method is particularly innovative in that it incorporates the assessment of feed/food competition in addition to the more usual dimensions of sustainability.

The first steps in the process for aggregation have been realized to aggregate these indicators into a single score. The CONTRA® tool has been identified since it can apply the fuzzy logic to an evaluation tree. Nonetheless several questions remain outstanding regarding the definition of thresholds and weighting: How this threshold should be defined? Is it relevant to apply the same interpretation thresholds and weightings of the indicators to each of the standard cases studied? Can we compare the systems studied with each other? Experts are usually embarrassment when they are asked to give threshold and weights. Scientists don't like to aggregate indicators as they are afraid of losing information and don't like weighting as they find it subjective. Nonetheless, when there are numerous dimensions it is also necessary to make choice in order to provide a synthetic analysis. One way could be to design a figure where some of the most relevant indicators, depending on the case studied, would be positioned on a common scale (score). This would allow us to observe the impact of innovation on each of these selected indicators. This method could be useful in highlighting trade-offs.

II. RÉFÉRENCES BIBLIOGRAPHIQUES

ACHARD DE LA VENTE L., BILLES L., ESTEVEZ A., GRANDJACQUES C., GUILLIER M., LYONNET A., MOYSAN A., PEREZ C., 2018. *Impacts d'un système de culture intégré sur la diversité et la pression en adventices.* 11 pages.

ALTEROCHE F., 2015. Démarche Herbopack : des croisés Hereford pour Charal. *Réussir bovins viande,* [En ligne], Disponible à l'URL : https://www.reussir.fr/bovins-viande/actualites/demarche-herbopack-des-croises-hereford-pour-charal:XRBHPOYL.html [Consulté le : 25 juin 2018].

ANSES, 2016. *Actualisation des repères du PNNS : élaboration de références nutritionnelles, Rapport d'expertise collective.* 196 pages.

BARBIER J.M., LOPEZ-RIDAURA S., 2010. Evaluation de la durabilité des systèmes de production agricoles : limites des démarches normatives et voies d'amélioration, *Colloque ISDA.* Montpellier, 28-30 Juin 2010, 9 pages.

BENDER A., 1992. Meat and meat products in human nutrition in developing countries. Rome : FAO Edition, 91 pages.

BOCKSTALLER C., BEAUCHET S., MANNEVILLE V., AMIAUD B., BOTREAU R., 2017. A tool to design fuzzy decision trees for sustainability assessment, *Environmental Modelling & Software*. N°97, pages 130-144.

BOINON J.P., 2011. Les politiques foncières agricoles en France depuis 1945, *Economie et statistique.* N° 444-445, pages 19-37.

BOHANEC M., MESSÉAN A., SCATASTA S., WESSELER J., GRIFFITHS B., HENNING KROGH P., ZNIDARSIC M., DZEROSKI S., 2008. A qualitative multi-attribute model for economic and ecological assessment of genetically modified crops, *Ecological Modelling*. N° 215, pages 1-3.

CHAMBRE REGIONALE D'AGRICULTURE LORRAINE, 2013. *La méthanisation agricole.* 4 pages.

CHAMBRE REGIONALE D'AGRICULTURE NORD-PAS-DE-CALAIS, 2013. *Les effluents d'élevage, mieux les connaître pour bien les valoriser.* 8 pages.

CIWF, 2011. *Les coûts de l'élevage, Les implications économiques du passage à un élevage plus respectueux du bien-être des animaux.* 26 pages.

CMED, 1987. *Notre avenir à tous. Rapport de la Commission mondiale sur l'environnement et le développement.* Oxford : Oxford University Press.

DELABY L., DOURMAD J.Y., BELINE F., LESCOAT P., FAVERDIN P., FIORELLI J.L., VERTES F., VEYSSET P., MORVAN T., PARNAUDEAU V., DURAND P., ROCHETTE P., PEYRAUD J.L., 2014. Origin, quantities and fate of nitrogen flows associated with animal production, *Advance in Animal Bioscience.* N°5, special issue 1, pages 28-48.

DOLLÉ J.B., FAVERDIN P., AGABRIEL J., SAUVANT D., KLUMPP K., 2013. Contribution de l'élevage bovin aux émissions de GES et au stockage de carbone selon les systèmes de production, *Fourrages.* N°215, pages 181-191.

DUMONT B., 1996. Préférences et sélection alimentaire au pâturage, *INRA Productions animales*. N°9, pages 359-366.

ERTL P., KOCLER H., HÖRTENHUBER S., KNAUS W., ZOLLITSCH W., 2015. The net contribution of dairy production to human food supply: The case of Austrian dairy farms. *Agricultural systems*. N°137, pages 119-125.

FAGON J., SABATTÉ N., 2010. *RMT Travail en Elevage, Référentiel travail en élevages bovins lait*. 36 pages.

FARES M., MAGRINI M.B., TRIBOULET P., 2012. Transition agroécologique, innovation et effets de verrouillage : le rôle de la structure organisationnelle des filières, *Cahiers Agriculture*. Vol. 21, N°1, pages 34-45.

FAO, 2006. *Livestock's Long Shadow, Environmental Issues and Options*. Rome, 390 pages.

FAO, 2012. *Pertes et gaspillages alimentaires dans le monde – ampleur, causes et préventions*. Rome, 41 pages.

FAO, 2013a. *Tackling climate change through livestock, a global assessment of emissions and migrations opportunities*. Rome, 139 pages.

FAO, 2013b. *Sustainability assessment of food and agriculture systems, SAFA Indicators*. Rome, 281 pages.

FAO - OCDE, 2016. *Perspectives agricoles de l'OCDE et la FAO 2016-2025*. Paris : Editions OCDE.

FIORELLI C., PORCHER J., DEDIEU B., 2007. Pourquoi faire de l'élevage quand on a un autre travail ?, *14e Rencontres Recherches Ruminants*. Paris, 5-6 décembre 2007, pages 389-392.

GEB-IDELE, 2011. Le marché de la viande bovine en Italie, *Dossier mensuel – Economie de l'Elevage*. N°414, 48 pages.

GEB-IDELE, 2016. Le marché mondial de la viande bovine, Dans la tourmente de l'économie globale, *Dossier Bovin Viande – Economie de l'Elevage*. N°468, 37 pages.

IBEA, 2013. Un outil de diagnostic de l'impact des pratiques agricoles sur la biodiversité. *Notice scientifique.* 127 pages.

IDELE, CHAMBRES D'AGRICULTURE, 2010. Calculer le coût de production en élevage bovins viande – Méthode nationale développée par l'Institut de l'Elevage dans le cadre du dispositif Réseaux d'élevage, *Réseaux d'élevage pour le conseil et la prospective*. Collection Thema, 8 pages.

IDELE, RESEAUX D'ELEVAGE, CHAMBRES D'AGRICULTURE, 2012. *Manuel d'utilisation de Diapason*. Paris : Collection Thema, 170 pages.

IFIP, 2017. *ACCEPT, La controverse de l'élevage : mieux la comprendre pour agir en faveur d'un élevage bien accepté*. 5 pages.

INCA, 2009. *Étude Individuelle Nationale des Consommations Alimentaires 2, Rapport*. 228 pages.

INED, 2015. Tous les pays du monde, *Population & Société*. N° 525, 8 pages.

KEENEY R. L., RAIFFA H., 1976. *Decision with multiple objectives. Preferences and value tradeoffs.* New-York : John Wiley & Sons.

KOCH P., SALOU T., COLOMB V., PAYEN S., PERRET S., TAILLEUR A., WILLMANN S., 2016. *Agribalyse® : Rapport méthodologique.* 343 pages.

LAIREZ J., FESCHET P., AUBIN J., BOCKSTALLER C., BOUVAREL I., 2015. *Agriculture et Développement Durable, Guide pour l'évaluation multicritère.* Dijon : Educagri, 226 pages.

LAISSE S., BEAUMONT R., TURINI T., DUSART L., GAUDRE D., ROUILLE B., BENOIT M., ROSNER P-M., PEYRAUD J-L., 2017. Efficience alimentaire des élevages : un nouveau regard sur la compétition entre alimentation animale et humaine, *Colloque du GIS Elevage Demain.* Paris, 17 octobre 2017, 11 pages.

LAISSE S., BEAUMONT R., DUSART L., GAUDRE D., ROUILLE B., BENOIT M., VEYSSET P., REMOND D., PEYRAUD J-L., 2018. L'efficience nette de conversion des aliments par les animaux d'élevage : un nouvel indicateur pour évaluer la compétition entre alimentation animale et humaine, *Soumis INRA Productions Animales.*

LENGERS B., BRITZ W., HOLM-MÜLLER K., 2014. What Drives Marginal Abatement Costs of Greenhouse Gases on Dairy Farms? A Meta-modelling Approach, *Journal of Agricultural Economics.* N° 65, pages 579-599.

LITT J., COUTELET G., FORTUN-LAMOTHE F., 2012. *Guide pratique DIAMOND*. 66 pages.

MARIVIN R., 2018. Nourrir le monde, *Cours personnel*. Nancy, Janvier 2018.

MINISTERE DE L'AGRICULTURE, DE L'AGROALIMENTAIRE ET DE LA FORÊT, 2018. *Ecophyto2018, L'allongement des rotations, un levier agronomique et environnemental.* 4 pages.

MEA, 2005. *Ecosystems and Human Well-being: current state and trends, Volume 1*. Washington, Covelo, London: IslandPress. 47 pages.

MEADOWS D.H., MEADOWS D.L., RANDERS J., BEHRENS W.W., 1972. *The Limits to Growth. A report for the Club of Rome's project on the predicament of manking*. Universe books.

MOUNIER L., MARIE M., LENSIK B.J., 2007. Facteurs déterminants du bien-être des ruminants en élevage, *INRA Productions animales*. N°20, pages 65-72.

PERVANCHON F., 2004. L'arbre de l'exploitation agricole durable. Construire en groupe son projet d'agriculture durable, *Travaux et Innovations*. N°110, pages 5-8.

POTHIN A., BERTRAND M., FORTUN-LAMOTHE L., 2017. Alimentations humaine et animale : évaluer la compétition sur les ressources et l'espace, *Douzièmes Journées de la Recherche Avicole et Palmipèdes à Foie Gras.* Tours, 5 et 6 avril 2017, 5 pages.

RENAUD B., 2015. Valoriser les coproduits issus de l'industrie alimentaire en alimentation animale : réglementation et leviers possibles, *Innovations Agronomiques*. N°48, pages 233-239.

RÉSEAU AGRICULTURE DURABLE, 2016. *Diagnostique de durabilité, Guide méthodologique*. 12 pages.

RÉSEAU D'INFORMATION COMPTABLE AGRICOLE, 2010. *Guide méthodologique*. 100 pages. Disponible en version française à l'URL : http://ec.europa.eu/agriculture/rica/pdf/site_fr.pdf ; et en version anglaise : http://ec.europa.eu/agriculture/rica/pdf/site en.pdf .

ROGUET C., GAINÉ C., CHATELLIER V., CARIOU S., CARLIER M., CHENUT R., DANIEL K., PERROT C., 2015. Spécialisation territoriale et concentration des productions animales européennes : état des lieux et facteurs explicatifs, *INRA Productions Animales*. Vol 18, N°1, pages 5-22.

ROY B., 1968. Classement et choix en présence de points de vue multiples (la méthode ELECTRE), *Revue Française d'informatique et de recherche opérationnelle*. N°2, page 8.

SAATY T.L., 1980. *The analytic hierarchy process: planning, priority setting, resource allocation.* New-York : McGraw Hill.

SADOCK W., ANGEVIN F., BERGEZ J.E, BOCKSTALLER C., COLOMB B., GUICHARD L., REAU R., DORE T., 2008. Exante assessment of the sustainability of alternative croppig systems: implications for using multicriteria decision aid methods. A review. *Agronomy for Sustainable Development.* Vol. 28, N°1.

SANTE CANADA, 2015. *Fichier canadien sur les éléments nutritifs, Guide d'utilisation.* 38 pages.

SCHÄRLIG A., 1985. *Décider sur plusieurs critères, panorama de l'aide à la décision multicritère.* Lausanne : Presses polytechniques et universitaires romandes, 304 pages.

SOLAGRO, 2016. *Afterres2050, Un scénario soutenable pour l'agriculture et l'utilisation des terres en France à l'horizon 2050*. Toulouse, 93 pages.

SCHÄRLIG A., 1985. *Décider sur plusieurs critères, panorama de l'aide à la décision multicritère.* Lausanne : Presses polytechniques et universitaires romandes, 304 pages.

TERRIER M., 2009. *Manuel de présentation de l'outil d'évaluation ex ante de la durabilité des systèmes d'activité des ménages agricoles pluriactifs dans l'Aude.* 75 pages

THORNTON P.K., 2010. Livestock production: recent trends, future prospects*, Philosophical transactions of the royal society B: Biological Sciences.* Vol. 365, n°1554, pages 2853-2867.

VAUDAUX-RUTH A., 2017. *Durabilité des systèmes de production de viande bovine européens : de la description globale des productions nationales à l'analyse des systèmes de production*. 59 pages.

VILAIN L., 2008. *La Méthode IDEA : indicateur de durabilité des exploitations agricoles : guide d'utilisation.* Dijon : Educagri, 180 pages.

WILKINSON J.M., 2011. Re-defining efficiency of feed use by livestock, *Animal*. N°5:7, pages 1014-1022.

WILFART A., DAUGUET S., TAILLEUR A., GARCIA-LAUNAY F., WILLMANN S., LAUSTRIAT M., MAGNIN M., GAC A., ESPAGNOL S., 2016. EcoAlim : une base de données sur les impacts environnementaux des matières premières utilisées en France pour l'alimentation animale, *Journées Recherche Porcine.* N° 48, pages 49-54.

Appendix 1: Share of energy and protein in animal products

The data available in terms of SHEPA and SHEEA from the literature do not cover all breeds and categories of animals present in the study. We constructed a linear regression line (r^2=0.98 for SHEPA and r^2=0.97 for SHEEA) from the data available in the literature (Laisse et al. 2018) in order to obtain, for each carcass yield value, the corresponding SHEPA and SHEEA value. In order to construct our Table 1, we chose to use the carcass yields by type of animal and breed from experimental stations (Idele, conference grand Angle 2019), which corresponds to more recent and complete data than those of Laisse et al (2018). We were then able to match each carcass yield in Table 1 with the corresponding SHEPA and SHEEA value.

For the carcass yields of animals not mentioned in GAV 2019 (bulls, Salers, Blanc Bleu Belge, and Montbéliard animals), the data were obtained from experts or breeding organizations. Due to the lack of data for cross-bred animals, the carcass yields of the two breeds were averaged. The same method was used for animals sold alive (weanlings), although these animals are not at this stage intended for human consumption but are exported to other holdings for finishing. The SHEPA and SHEEA used for weanlings are derived from Laisse et al (2018) and are presented in Table A. For newborn calves sold alive at a few weeks of age, the protein and available energy contents are given per whole calf depending on the breed (Table B). Since no carcass yield reference exists for newborn calves, we took a 20% yield from their SHEPA on the linear regression line.

Table A: Share of proteins (SHEPA) and energy (SHEEA) edible by humans for weanlings according to their breed, live weight and carcass yield. GP = Gross proteins, GE = Gross energy.

Weanling breed	**Charolais or Charolais x Salers**		**Limousin**		**Blanc Bleu Belge**
Live-weight (Kg)	300kg	450kg	300kg	450kg	x
Carcass yield (% of live weight)	53%	55%	55%	57%	59%
SHEPA (% GP)	57%	58%	58%	60%	61%
SHEEA (% GE)	35%	36%	36%	36%	37%

Table B: Kilogram of protein and kilocalorie of edible energy produced per calf according to its breed.

	Kg of proteins produced/calf sold		**Kcal of energy produced/calf sold**	
Calves breed	Holstein	Other breed or crossed breed	Holstein	Other breed or crossed breed
Total	9.2	10.9	93 900	110 900
Edible by human	3	3.5	31 500	37 200

Source : Laisse et al. (2018) Fiche méthodologique bovins lait

Appendix 2: Average composition of each type of concentrate used

Composition in %		Weanling concentrate 16	Cow concentrate L18	Finishing concentrate JB16	Calf concentrate 18
Cereals	Wheat	9.6	11.9		11.9
	Barley	4.7	8.1	9.3	9.9
	Moist grain maize	26.3	24.0	25.9	23.5
	Oats	5.5	0.8	6.0	0.7
	Triticale		1.7		0.3
Protein crops	Soya			0.2	0.6
Other concentrates	Dehydrated alfalfa (GP < 16% DM)		0.4	5.9	
	Concentré protéique de luzerne		1.0	1.4	0.6
	Urée	0.1	0.3	0.0	0.4
Meal	Soybean meal 46		2.0	2.5	2.5
	Rapeseed meal		5.4		5.7
	Hipro sunflower meal (Black Sea)	0.7	0.0	3.3	
	Sunflower meal partly shelled (France)	1.7		4.6	
	Unshelled sunflower cake (France)	7.2		0.5	
Cereal coproducts	Soft wheat bran	15.0		15.0	7.7
	Soft wheat white remoulding		7.8		7.3
	Wheatgrain (starch distillery > 7 % DM)		7.2		0.9
	Brewery grain (barley)		0.2		
	Cornbread	10.2		19.0	16.3
	Corn Gluten Feed		14.0		
	Wheat Gluten Feed	10.6		1.0	6.0
	Gluten 60 (Corn Gluten meal)	0.2	7.6	0.0	0.9
	Barley Radicelles		2.8		
Other coproducts	Dehydrated beet pulp	6.0		5.3	5.0
	Dehydrated citrus pulp		5.0		

GP: gross protein, DM: Dry Matter

Appendix 3: Allocation factor of the production cost used in the study from the French Livestock Institute (sept.2019):

	Lowland dairy herd	Suckler herd, production of young bulls from dairy calves
Structural costs		
Mechanisation	1	1.06
Buildings	1	0.52
Financial costs	1	1.28
General costs	1	0.78
Labour	1	0.32
Livestock operational costs		
Livestock costs	1	0.07
Veterinary costs	1	1.3