Evaluation of the contribution of 16 European beef production systems to food security

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Abstract:

CONTEXT

Livestock production, and more particularly ruminants, is criticized for its low conversion efficiency of natural resources into edible food.

OBJECTIVE

The objectives of this paper are to propose an evaluation of the contribution to food security of different European cattle farms through three criteria: 1) food production assessed by the amount of human-edible protein (HEP) and energy (HEE) produced at farm level, 2) feed-food competition at the beef production scale estimated in terms of net human-edible protein and energy and in terms of land used, and 3) food affordability assessed by the production cost of meat, protein and energy.

METHODS

The analysis is based on 16 representative beef production systems in France, Belgium, Ireland, Italy and Germany and covers cow-calf systems, finishing systems, dairy and mixed dairy- finishing systems, with or without cash crops.

RESULTS AND CONCLUSIONS

The results show that, at the farm level, systems producing both beef and milk or cereals have higher HEP and HEE production per hectare (up to 370 kg of HEP and 60000 10^6J.ha^{-1}) than specialized beef systems (up to 50 kg of HEP and 1600 10^6J.ha^{-1}) and have lower production costs (approximately €6 kg^{-1} of HEP in mixed beef system and €29 kg^{-1} of HEP in a specialized cow-calf-fattener system). Beef systems are almost all HEE net consumers. Results are more variable concerning net HEP efficiency. The cow-calf enterprises are mostly net producers of HEP but, in order to produce human edible meat, these systems need to be combined with finishing systems that are mostly net consumers of HEP. In most cases, cow-calf-finishing systems are net consumers of HEP (between 0.6 and 0.7) but grass-based systems using very little concentrates or systems using co-products not edible by humans are net HEP producers. The grass-based systems use more land area per kilogram of carcass but a major part of this area is non-tilled land, thus these systems are not in direct competition with human food production. The lowest meat production costs are the finishing systems producing the most live weight per livestock unit (LU) per year and dairy systems in lowland which share the costs between milk and meat.

SIGNIFICANCE

Although most of HEE and HEP efficient farms typically have higher meat production costs, some grassland based systems stand out positively for all indicators. These results pave the way for improvements of the contribution of beef production systems to food security.

Keywords: Food security, feed food competition, European livestock, beef production

Introduction

A necessary, but not sufficient, condition to ensure global food security as defined by the FAO (FAO, 1996) is to produce food in sufficient quantity and quality to feed all people at all times at an affordable price. Meat and milk from domestic herbivores provides 16% of global protein consumption, with 20% of meat and 83% of milk from cattle (FAOSTAT 2016 in Mottet et al., 2018). Due to the increase in the world population, which could reach 9.6 billion people in 2050 and with the projected rise in living standards, cattle production will need to increase by 60% between 2002 and 2050 at the global scale to meet the anticipated increase in demand (Alexandratos and Bruinsma, 2012). However, the development of diets based on high beef consumption seems incompatible with the objectives of reducing the pressure agriculture exerts on the planets resources and many studies envisage a reduction in meat consumption will be necessary to achieve sustainable development objectives (Willett et al., 2019). Livestock production, and more particularly ruminants, is indeed criticized for its low conversion efficiency of natural resources into edible food (water consumption, land and biomass use, greenhouse gas emissions per unit of beef consumed by humans), being less efficient than other food production methods (Gerber et al., 2015). However, ruminants have the capacity to make use of resources (roughage, co-products i.e. products that are produced as a consequence of the production of biofuels, human food, etc.) that cannot be consumed by humans but can be utilised as a source of feed for livestock and should therefore be able to contribute to human food security. To take into account this aspect of ruminant production systems, Wilkinson (2011) proposed an indicator to assess the net contribution of livestock to biomass, protein and energy production, taking into account only the portion of food consumed by animals that can be consumed by humans. Similarly, van Zanten et al. (2016) defined an indicator which weighted the areas used for animal consumption by the potential of this land to directly produce edible plant products for human consumption.

Several studies estimate the net contribution of cattle farming to food security. Using the GLEAM (Global Livestock Environmental Assessment Model) model Mottet et al. (2017) simulated that on a global scale nearly 7 kg of protein that is edible for humans is used, on average, to produce 1 kg of protein from cattle farming, but with significant disparities depending on the production system used. In the United States, Tichenor et al. (2017) estimated that land would have been used more efficiently if it had been dedicated to crops directly edible by humans, instead of grass-based beef or dairy production systems. Laisse et al. (2018) also estimated that, for two typical French beef production systems, the net protein efficiency of production (ratio of human edible meat protein to human edible feed protein) is less than one, demonstrating that both systems were net protein consumers. On the basis of this observation, which is rather unfavourable to ruminant farming, the project *SustainBeef* aimed to assess how European beef production could make a greater contribution to food security. To this end, a clear picture is required of the contribution made by different European beef production systems to food security. The objectives of this paper are to propose an evaluation of the contribution to food security of different European Union cattle farms, in order to constitute benchmarks for European beef production systems and to identify key drivers of food security and levers for improvement.

Sixteen case studies were selected in order to give a picture of the diversity of beef production systems that exist across five European countries (Belgium, France, Germany, Ireland and Italy) and which account for half of the dairy and beef cows in Europe (Eurostat 2016). These systems cover cow-calf systems (production of calves from a herd of suckler beef cows), finishing systems (finishing of calves), cow-calf-finishing systems (from the herd of suckler beef cows to the finishing of calves) and dairy systems (these cattle are mainly reared for their milk but also produce meat). The *SustainBeef* Project proposed an evaluation tree to assess the sustainability of the beef farms for the social, environmental and economic pillars. Each of the pillars is characterised by different components, which are in turn assessed by a number of criteria that can be measured by indicators (Bockstaller et al., 2009). The current study focused on the food security component of the social pillar. Food security was assessed using three criteria that fall within the concept of physical availability and economic accessibility defined by Jones et al. (2013) and the food security index (2020). The boundary of the studied cases is the farm gate, consequently the distribution and consumption of food that are also important in the evaluation of food security are not considered in this analysis.

1. Materials and methods

1.1 Presentation of case studies

The food security indicators were calculated from data of 16 European beef production systems. A case study representative of a region in a European country described the technical choices made by the farmer in terms of animal husbandry, land use and investments and provides information on the economic results of this system. These case studies were chosen to explore the diversity of beef production systems in the five countries studied according to three main criteria: country of origin, system type (cow-calf, fattener, dairy, etc.), plant resources used (all grass, etc.) and their land type (mountain, plain, proximity to a cereal basin). Briefly, a cow-calf-fattener system is a farm that breeds and fattens animals on the farm. A specialised cow-calf system gives birth to the animals on the farm and raises them to the weaning stage (weaned animal, 7 to 10 months old) and then sell them to the fattener. A specialized finishing system only fattens animals purchased from cow-calf farms. Almost half of all the case studies also sold grain crops. The farming systems examined included two mountain grass based cow-calf systems in France, one lowland grass based in Ireland, and in Belgium two associated with crops. One dairy system, without calf finishing in a grassland area found in Belgium, another associated with a suckler herd in mountain areas in France. In addition, one grass-based finishing system is in Ireland, two intensive systems in Italy and one in Germany (Figure 1).

The general characteristics of each case study for the reference year 2016 is presented in Table 2. More details are available in the supplementary material. Most of the case studies used were created for the needs of the current project as existing European references were not sufficiently detailed: the Farm Accountancy Data Network (FADN) does not distinguish between the different beef cattle production systems (cow-calf, cow-calf-finisher), agri benchmark offers very synthetic sheets, without any system described for Belgium. The French case studies were built by the technicians of the INOSYS farm network (Charroin et al., 2005) based on a set of real viable farms. In the other countries, real farms were selected by experts from the DAEA (Department of Agricultural Economic Analysis) and ELEVEO-AWE group (Walloon Breeders' Association) networks in Belgium, by TEAGASC for Ireland, and the CREA network for Italy and for the University of Bonn for Germany. In Ireland, data for the cow-calf and finishing systems were derived from the Irish National Farm Survey (FADN) database and the integrated system was derived from research data from the Teagasc Beef Research Centre, Grange, Co. Meath. The data available in these case studies and their presentation were harmonised between participating institutions. Details include the structure of the farms (number of workers (WU), utilised agricultural area, herd size, distribution of areas, etc.), the areas farmed (yield, fertilisation, crop sold or intra-consumed, etc.), the herd size (average composition of the herd over a year, animals bought and sold, breed, category, sex, live weight, age, etc.), the feeds used (quantities ingested per category of animal for each type of feed, grazing periods) and the economic results (details of charges and products). However, farm IT-F2 was excluded from the farm-level indicators because its cash crop enterprise was not represented in the case study, making these indicators irrelevant.

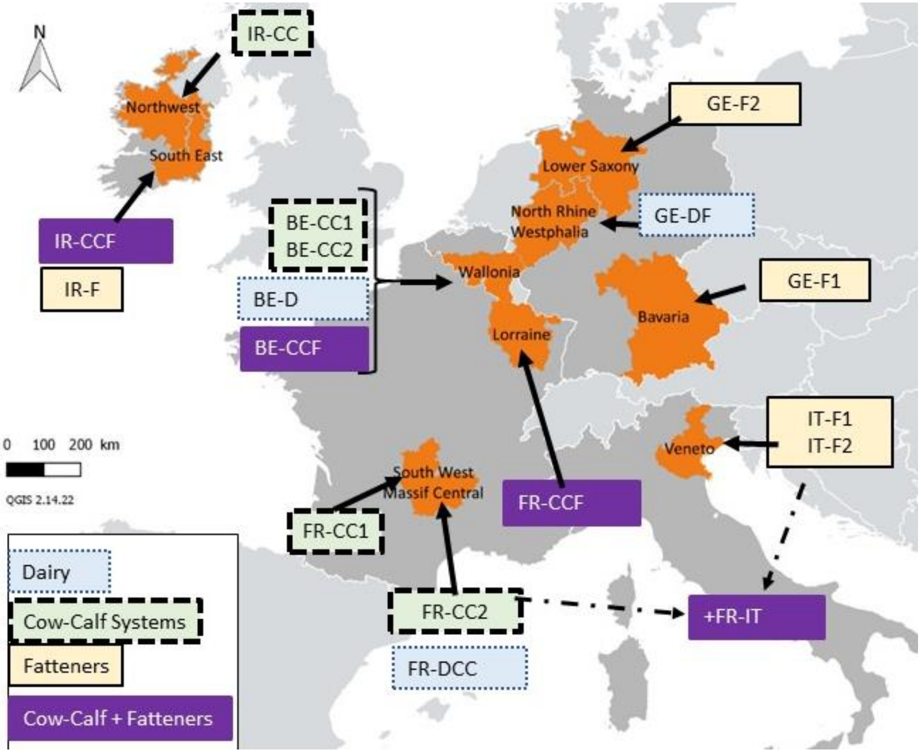

Figure 1: Localisation of the 16 European beef production systems

There is a complete cow-calf-finishing system in every country except Italy: grass based beef cattle in Ireland, and mixed crop-beef cattle in France and Belgium, mixed crop-dairy cattle in Germany. For Italy, in order to study the system as a whole, i.e. from birth to the slaughter of the animals, a reconstruction of the meat production chain was made (FR-CC2+IT-F2) by aggregating a specialised French cow-calf system (FR-CC2) with the corresponding specialised Italian fattener system (IT-F2). This is considered as a representative system, as a large number of calves finished in Italy are imported from the Massif Central in France (GEB-Idele, 2016) The reconstituted farm encompasses the entire production of the French farm in addition to the Italian farm: the Italian farm, which fattens 913 animals, has been reduced to 55 young cattle produced to adjust to the 55 weanlings sold by the cow-calf system (all charges and consumption have been reduced proportionally).There is, however, a time gap of forty days between the time of sale of the French weaned calf and the date the Italian farm purchases its young male for finishing. To overcome this discrepancy it is assumed the French weanling is fed a basal diet of hay (4 kg DM/weanling per day) and concentrates (3 kg gross/weanling per day), with the animal operational costs adjusted accordingly to an assumed 2.5 LU, in accordance with the data per LU of the source (French) case. The differences between the farm profiles were reflected in their share of "finished meat" (kilogram live-weight of animals ready for slaughter). This share varied from 0% for a cow-calf system where all the animals, including cows, are fattened on another farm, to 100% for fattener or cow-calf-fattener systems (Table 2). The type and quantity of feed consumed by the animals was the basis for the calculation of the consumption of resources that are edible by human, such as cereals. Cow-calf farms consume little concentrated feed. Grass resources are generally sufficient to cover the needs of the growing animal. Finishing systems require considerably more concentrated feed in energy for their animals to deposit fat. However, these values vary from farm to farm depending on their degree of intensification, such as IT-F2 which uses four times as much feed as GE-F2 where animals exhibit low average daily gains. Two of the farms with a dairy herd and cow-calf-fattener system have intermediate feed consumptions. The German dairy farmer GE-DF uses a large amount of corn silage due to its zero-grazing herd management.

Table 2: Main characteristics of the case studies, quantity of meat produced.

Name	Cow-Calf (CC) systems of Dairy (D) systems without finishing							Fattening (F)					Cow-Calf or Dairy+ Finishing (CCF or DF)				
	FR-CC1	**FR-CC2**	**IR-CC**	**BE-CC1**	**BE-CC2**	**BE-D**	**FR-DCC**	**IR-F**	**IT-F1**	**IT-F2**	**GE-F1**	**GE-F2**	**IR-CCF**	**FR-CCF**	**BE-CCF**	**GE-DF**	**FR-CC2 +IT-F2**
Labour (Worker Unit)																	
Family	1.5	1.5	0.5	1	2	1.5	2	0.5	1	1	2	2	0.5	2	1	1	1.6
Employee						0.5	0.1			2						3	
Animal Production																	
Breed *(*: crossbred,li: Limousin, sa: Salers, au: Aubrac, ch: charolais ; bb: Blanc Bleue Belge ; ho: Holstein ; si: Simmental)*																	
	li	sa, sa*ch	li*ch	bb	bb	ho	au, mo, mo*ch,	**ch**	*ch	sa, sa*ch	ho	si	li, ch	ch	bb	ho	sa*ch
Herd Size (LU)	113	96	34	138	250	109	128	64	129	387	113	192	61	113	217	165	122
Cow Sold																	
head	14	9	5	34	68	18 D	12 D 7 B	0	0	0	0	0	5	13	42	45	9
Liveweight	734	660	734	750	750	650	620 D 655 B						661	800	740	688	660
Young animals *(W: beef weaned calf, H heifer, C: dairy calf, YB: young bull, S: Steer; age in months*																	
Head Sold	39W 17H	55W 6H	19W	35W 2H	92W 5H	32C 2H	34W 32C	89 S	351 YB	719 YB	410 W 64 YB	107 YB	15 S 9H	29 YB 15H	43	65 YB 15 C	55 YB 6H
Age at purchase	/	/	/	/	/	/	/	12	7	11	1	2	/	/	/	/	/
Age at sales	W 9 H 28	W 10 H 30	W 8	W12 H 17	W8 H 20	C1 H18	W 11 C 1	30	17	18	W9 YB 18	YB 22	S 30 H 30	YB 16 H 31	YB&H 20	YB 22 C 4	18
Liveweight at sales	W312 H615	W283 H814	W 306	W289 H400	W300 H475	C80 H400	C68 W378	680	520	687	W215 YB 715	YB : 685	S 681 H 712	Y 736 H 717	YB&H 600	YB550 C 82	YB 687
Meat Production (kg live-weight.LU^{-1}.$year^{-1}$)																	
	297	320	201	270	325	138	214	383	816	630	845	334	312	350	262	409	397
Percentage of finished meat (total kg alive for slaughterhouse/total kg alive x 100)																	
	64	34	22	0	66	83	45	100	100	100	48	100	100	100	100	99	100
Milk Production (1000 Liter)																	
Per Farm						489	300									396	
Per Cow						7	6.1									7.5	
Share of milk sales*:* Milk sold (€)/Total outputs (€)																	
	0	0	0	0	0	88	65	0	0	0	0	0	0	0	0	73	0
Crop Production (ha)																	
Total UAA	95	96	32	134	118	54	113	43	34	8	58	45	40	249	123	225	97
Grassland	*89*	*96*	*32*	*122*	*64*	*54*	*108*	*43*	*0*	*0*	*5*	*3*	*40*	*60*	*47*	*27*	*96*
Maize & Sorgum	*0*	*0*	*0*	*0*	*10*	*0*	*0*		*34*	*8*	*18*	*42*		*10*	*14*	*77*	
Alfalfa														*5*			
Cereals	*6*	*0*	*0*	*12*	*44*	*0*	*5*				*35*			*174*	*59*	*103*	*1*
Sugar beet															*3*	*18*	
Share of crop sales *: Crops sold (€)/(crops + animal product sold) (€) x100*																	
	0%	0	0	11	19	0	0	0	0	0	21	53	0	68	25	47	0
Animal Feeding																	
Stocking rate ($LU.ha^{-1}$ of Main Forage Area)																	
	1.3	1	1.1	1.1	3.4	2	1.2	1.6	3.9	53	4	4	1.5	1.5	3.4	1.6	1.3
Feed consumed (kg DM.LU^{-1}.day^{-1}) *: Conc.: concentrate feed, co-prod.: co-product, maize silage, Harvested grass*																	
Conc.	0.9	0.9	0.2	0.5	1.3	2.4	1.8	3.3	7.6	9.3	1.6	1.5	0.8	0.9	1.1	3.3	2.6
Co-prod.	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	2.5	1.1	0.0	0.0	0.0	0.0	0.7	0.0	0.2
Maize sil.	0.0	0.0	0.0	0.0	1.3	1.6	0.0	0.0	0.9	6.1	5.1	2.8	0.0	2.3	2.5	14	1.2
H. grass	4.5	5.5	8.4	5.6	2.8	3.3	7	3.9	1.5	0	0.7	3.6	4.0	3.4	2.5	3.4	4.6

Notes: FR: France; IR: Ireland; BE: Belgium; IT: Italy; GE: Germany; LU: Livestock Unit, UAA: Utilised Agricultural Area

1.2 The evaluation tree of the systems' contribution to food security and the functional units

Three criteria were considered (Figure 2): 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.

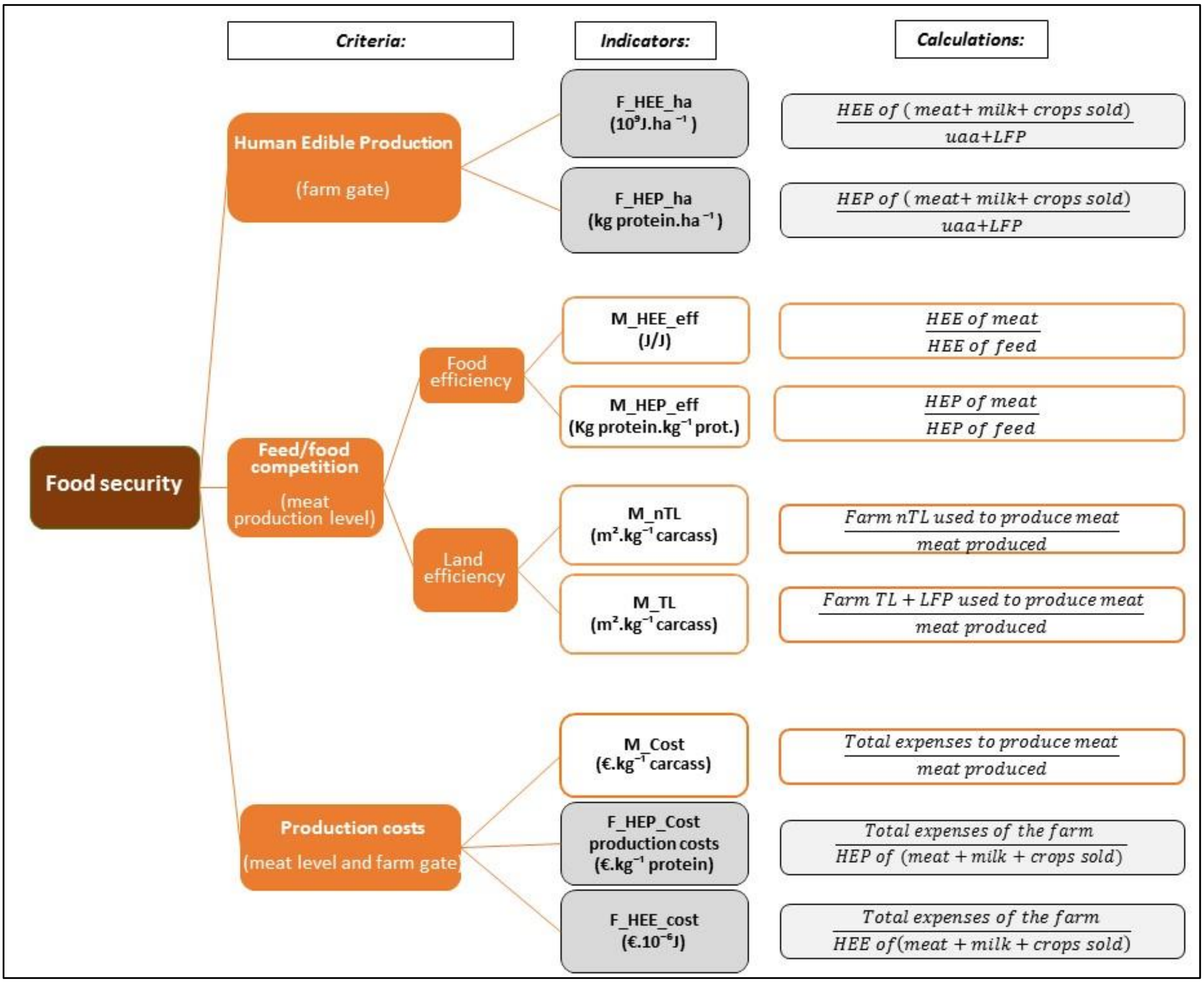

Figure 2: **Food security evaluation tree.**

Notes: in grey: farm gate indicators, in white: meat production level indicators that include purchased inputs and inputs to produce the feed produced on the farm; HEE: Human Edible Energy and HEP Human Edible Protein; UAA: Utilised Agricultural Area; TL, nTL, LFP are resp. Tillable Land, non-Tillable Land and Land equivalent for the purchased feed; J joule.

1.3 Farm gate protein and energy production

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 2). It was evaluated on a per hectare of utilised agricultural area (UAA) basis, which included the UAA of the holding as well as the areas corresponding to feed purchases (Table 3). 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). Meat production depends on carcass yield, which varies according to breed and category of cattle (Table 4). Giblets and human edible by-products which are also produced when slaughtering beef are included in the meat production estimate. 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 4 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 2: Method for calculating human edible protein and energy contained in meat, milk and cereals sold.

Animal or vegetable product	Calculation method
Meat, (including giblets and human edible) by-product 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 SHEEA(%) : Share of HEP and HEE in animal products, SHEPV(%) and SHEEV(%): Share of HEP and HEE in vegetable products.

Table 3: 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 4: 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 ≥15 m.o	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 ≥15 m.o.	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 ≥24 m.o.	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. m.o. month old

1.4 Feed-food competition

Feed-food competition was assessed by two indicators estimated at the beef production scale, the efficiency of conversion of edible resources in edible animal products, and the use of agricultural land. The ratio of human edible proteins (or energy) produced and used evaluated the net efficiency of conversion of plant proteins (or energy) into beef protein (or energy). An efficiency greater than 1 means that the system produces more human edible protein (or energy) than it consumes. Conversely, an efficiency between 0 and 1 means that the production of meat is a net consumer of protein (or energy). The use of agricultural land is assessed though the amount of tillable and non-tillable land required to produce one kilogram of meat carcass. Non-tillable land corresponds to permanent grassland. These areas are not currently in competition with human food because they may be of low productivity or not accessible by machinery and (or) European Agricultural policy restricts their cultivation (European Commission, 2020). Nonetheless, higher pressure on arable land or climate change might lead to conversion of a part of these permanent grasslands into tillable lands in the future (Havlík et al., 2012). The arable areas (cereals for feeds, temporary grassland, fodder crops, etc.) are considered to be in direct competition with the production of human food. It was assumed that the land required to produce the purchased feed is arable land (including fodder).

1.5 Production costs

The third criterion used to characterize food security is the production cost of agricultural products that reflects the potential price at farm gate. This was 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. 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 provided in the farm case studies multiplied by the median net wage, for 2016, per country available on the European statistics website Eurostat.

1.6 Allocations between crops sold, milk production and meat production

The feed-food competition and meat production cost indicators needed the isolation of consumption and costs necessary for meat production. However, in the profit and loss accounts of farms, costs are often entered by major items without details of their allocation. For mixed livestock farms, it was necessary to define allocation rules (Table 5) in order to associate the forage area costs with the animal enterprise. These intra-consumed areas were estimated by dividing the amount of feed consumed by the animals by the average yield per hectare. Fixed costs (machinery, labour, land, etc.) were also allocated among the enterprises according to the guidelines presented in Table 5.

Table 5: 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	$\frac{ha\ \ of(IAC+\ MS/2+grass/2)}{ha\ of\ (AC+MS/2+grass\ /2)}$
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.

2 Results

2.1 Human edible protein and energy production at farm gate

At farm level, Human Edible Protein per hectare (F_HEP_ha) production varies from 20 to 394 kg per hectare of utilised agricultural area (Figure 3). Systems selling milk and cereals, in addition to meat, have a higher F_HEP_ha than systems producing only meat. This is explained by the high proportion of HEP contained in cereals (60-70% on average) and the large quantities of milk produced. The GE-F2 farm produces less HEP than other diversified farms because it sells corn silage, which contains only 10% of HEP. IT-F1 stands out as a relatively important producer of F_HEP_ha, although it does not sell milk or cereals, its animals are mainly fed a diet based on co-products that require little land for their production (0.3 m².kg^{-1} for beet molasses compared to 1.6 m² per kg for soybean meal, Table 1).

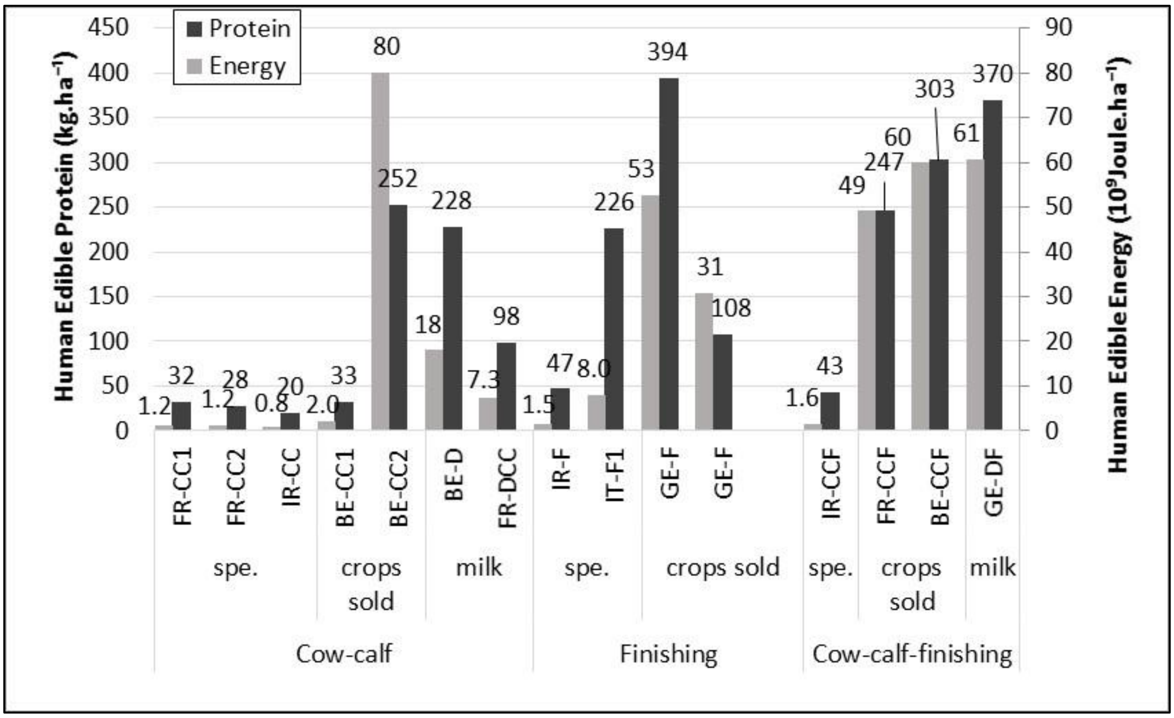

Figure 3: Net production of human edible protein *(F_HEP_ha)* and energy per hectare *(F_HEE_ha)* of utilised agricultural area at farm level.

This is even more characteristic for farm Human Edible Energy production per hectare (F_HEE_ha), where farms also selling milk and cereals produce significantly more F_HEE_ha (from 2031 to 79977 $10^6 J.ha^{-1}$) than farms selling only meat (from 759 to 8022 $10^6 J.ha^{-1}$) because of the very significant difference in HEE content of meat compared to other products.

2.2 Efficiency in the use of human edible resources for beef production

Almost all systems are net consumers of Human Edible Energy (HEE) at beef production scale with efficiencies lower than 1, due to the low share of HEE present in the meat compared to that present in the resources used (Figure 4). Only the IR-CC system is a net producer of HEE (1.1 HEE Joule produced per HEE Joule consumed) due to its low consumption of concentrates (Table 5).

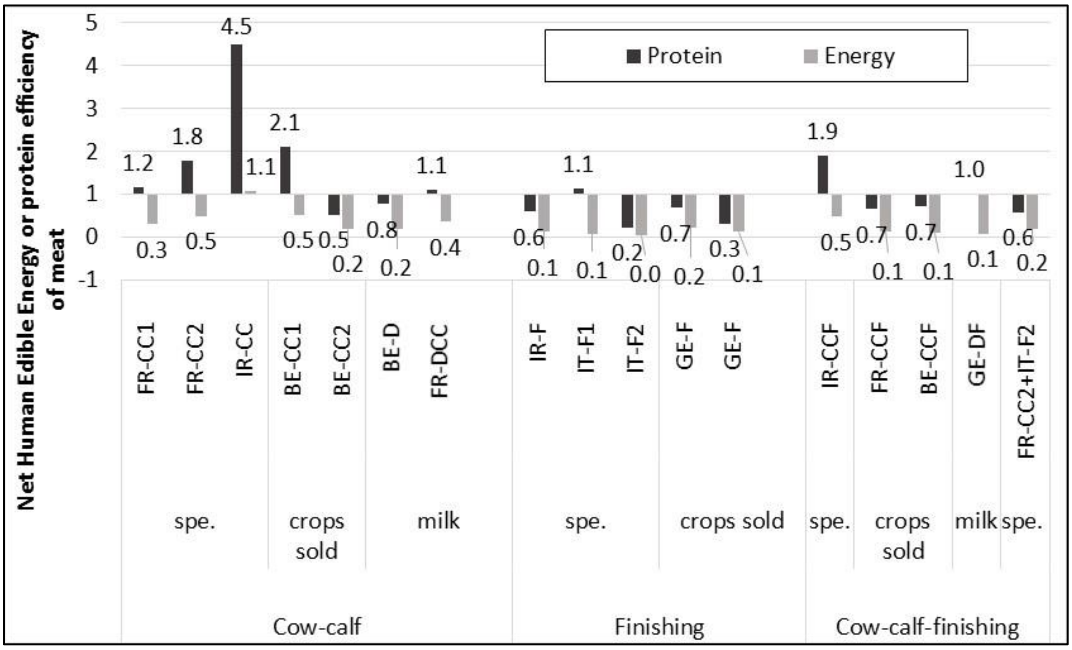

Figure 4: Net Human Edible Protein and Energy Efficiencies of meat production *(M_HEP_eff and M_HEE_eff)*

Notes: M_HEP_eff= $\frac{HEP\ of\ meat}{HEP\ of\ feed}$ *and M_HEE_eff=* $\frac{HEE\ of\ meat}{HEE\ of\ feed}$ *(see Figure 2). Calculations are based on the farm case studies described in Table 2.*

Human Edible Protein efficiency (M_HEP_eff) at beef production scale is more favourable for beef production systems particularly those using low inputs of concentrates, such as cow-calf systems, which are net producers of HEP (efficiencies > 1 in Figure 4). The Irish cow-calf system using almost exclusively grass has the highest M_HEP_eff with 4.5 kg of HEP produced per kilogram of HEP consumed. The Belgian BE-CC2 cow-calf system with a high use of concentrates (1.3 kg $DM.LU^{-1}$ per day), is a HEP consumer. Most of the finishing systems are net consumers of HEP because of their higher use of concentrates, despite higher animal productivity. The Italian fattener IT-F1 is a small producer of protein (efficiency of 1.1) due to its strong animal growth and its use of co-products and wet grain maize.

Except for one case study, cow-calf-finishing systems that take into account the entire meat production cycle are predominantly net consumers of HEP. The reconstituted cow-calf-fattener system "FR- CC2+IT-F2" has a M_HEP_eff of 0.6, a combination of the cow-calf phase with an efficiency of 1.8 and the finishing phase with an efficiency of 0.2. This demonstrates the importance of considering full systemic approaches. The French and Belgian cow-calf-fattener systems have similar values (0.7). The Belgian dairy farm BE-D is also a protein consumer (efficiency of 0.8) due to its low meat productivity (138 kg of live weight. LU-

^{1}.an^{-1} while the average productivity of the cow-calf system studied is 230 kg.LU^{-1}.an^{-1}). However, two out of five cow-calf fatteners are net producers of protein. The cow-calf-fattener IR-CCF produces almost twice as much protein (efficiency of 1.9) because the animal's diet is almost exclusively grass- based (only 0.8 kg of DM of concentrate.LU^{-1} per day) and the GE-DF finishing dairy farm is in balance with a net efficiency of 1, thanks to the allocation of 80% of the herd's feed to milk production and good meat productivity. This data shows that beef production can be a net protein producing system if the systems are adapted and oriented towards the greater use of grass and co-products with a limited use of concentrates.

The cow-calf systems, cow-calf-finishing(except GE-DF in zero grazing) and the Irish finishing systems use more Tillable and non Tillable Land areas directly and indirectly (in the production of purchased feed) per kilogram of carcass (M_TL + M_nTL), from 19 to 92 m² of tillable and non-tillable land per kilogram of carcass, but a major part of these areas are non-arable land (Table 6), corresponding to the high proportion of permanent grassland in their crop rotation (78% on average). Two cow-calf farms stand out with a high use of M_nTL (>20m².kg^{-1} of carcass), which is explained by the use of temporary grassland. The more intensive German finishing systems and the more intensive German dairy-finishing system use less surface area per kilogram carcass (5 to 16 m².kg^{-1} of carcass), but 93% of this surface area is arable land, which could therefore be used for human consumption.

Table 6: Indicator of competition for agricultural land use and production costs.

	FR-CC1	FR-CC2	IR-CC	BE-CC1	BE-CC2	BE-D	FR-DCC	IR-F	IT-F1	IT-F2	GE-F1	GE-F2	IR-CCF	FR-CCF	BE-CCF	GE-DF	FR-CC2+ IT-F2
Land used for meat production																	
M_nTL *(m².kg^{-1} carc)*	23	58	80	37	11	87	32	27	0	0	1	1	38	27	12	1	34
M_TL (m².kg^{-1} carc)	29	2	1	21	8	5	3	7	7	16	4	15	2	9	9	9	7
Production Costs																	
M_Cost *(€.kg^{-1} carc)*	6.6	7.3	8.9	5.1	6.1	4.4	6.9	4.3	2.4	4.2	2.8	4.9	6.6	7.3	8.9	5.1	6.1
F_HEP_cost *(€.kg^{-1} prot)*	39	43	53	27	10	9	19	26	15	na	8	22	29	5	7	6	na
F_HEE_cost *(€.10^{-6}J)*	1.0	1.1	1.4	0.4	0.03	0.1	0.3	0.8	0.4	na	0.06	0.1	0.8	0.03	0.04	0.04	na

Notes: TL and nTL: Tillable and non-Tillable Land in and out of farm; M_Cost meat production cost, F_HEP_cost and F_HEE_cost production costs of Human Edible Protein and Energy at farm gate. na: not available

2.3 Feed production costs

Farms selling milk and cereals have lower production costs for human edible protein (F_HEP) and energy (F_HEE) at farm gate than those farms that produce meat-only (Table 6), due to the dilution of the costs allowed by the large quantities of F_HEP_ha and F_HEE_ha produced. These costs range from €7 to €53.kg^{-1} of HEP and €0.04 to €1.4 per 10^6 J HEE for meat-only farms and €5 to €29.kg^{-1} of HEP and €0.03 to €0.75 per 10^6 J of HEE for other farms.

Beef production costs range from €2.4 to €8.9 per kg of carcass produced (Table 6). The systems with the lowest production costs (from €2.4 to €5.4 per kg of carcass) are the finishing systems due to their higher meat production per LU and per year (Table 5). Cow-calf systems have the highest meat production costs, although there is a high variability between them (from €4.4 to €8.9 /kg carcass). These higher costs for cow-calf systems can be explained by their lower animal productivity due to the sale of young non finished animals: the daily growth of animals during the rearing phase is lower than the finishing phase of most systems (Table 5).

In cow-calf systems, operational costs are relatively low compared to structural costs and represent 26% of total costs (Figure 5). In particular, the cost of purchased feed represents only 12% of the total costs on average, except for BE-CC2 which is the most intensive per animal and per hectare of forage area, and therefore it is the most intensive consumer of concentrates. IR-CC is the smallest farm in the cases studied, labour productivity (volume of beef output per worker) is among the lowest, and its level of machinery costs (including contractor charges) is quite high in respect to its size, resulting in very high mechanisation and labour costs and a very high production cost per kilogram of beef produced. This farm thus has the highest production cost despite very low feed purchases. For finishing systems, feeds represent the largest production cost item, especially for IT-F2, which is a very intensive animal feed system purchasing all its feed, (i.e. 16.5 kg DM.LU^{-1} per day of concentrates, cereals, co-products and maize silage). However, in order to really measure the cost of meat and thus its accessibility to the greatest number of people, it is necessary to study complete cow-calf -fattener systems. These present intermediate costs varying from €4.4 to €6.5.kg^{-1} of carcass. The GE-DF dairy farm which finishes its calves has the lowest meat production costs among cow-calf-fatteners due to the burden sharing between milk and meat. Due to its extensive system of production and very low feeding costs, the Irish IR-CCF is also one of the most competitive. Feed costs of all systems are higher in Germany and Belgium than in France and Ireland, due to their higher stocking rate which reduces their feed sufficiency. The French and Irish systems are more self-contained feed-wise, but the lower feed purchases are partially offset by higher mechanisation costs partly due to multiple grass harvests.

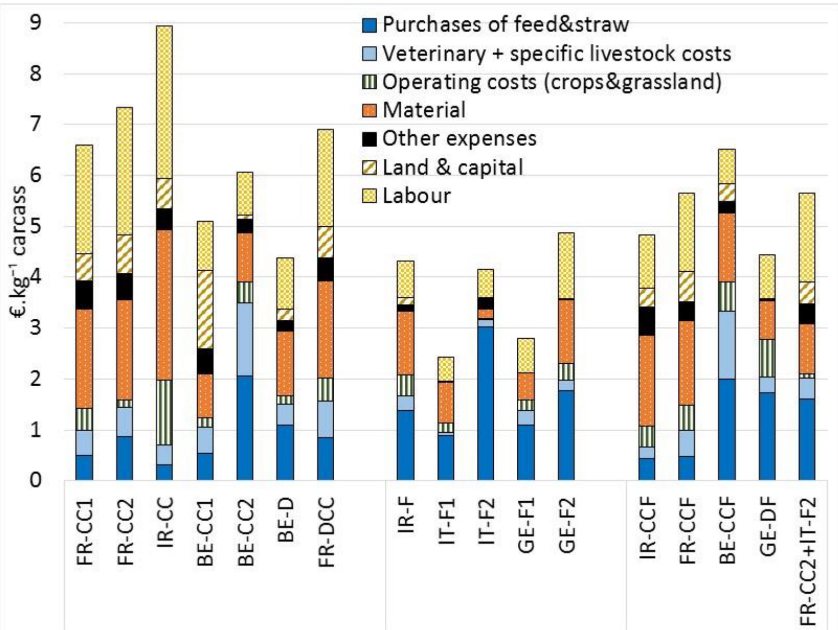

Figure 5: Beef production costs (€.kg^{-1} of meat carcass produced)

2.4 Correlations between indicators

Farms that produce larger amounts of F_HEP_ha and F_HEE_ha have also lower F_HEP and F_HEE production costs (Table 7). Most of these farms sell cereals and milk in addition to beef meat (Table 5). They also have lower meat production cost but with more exceptions: IR-CCF which is a grass-based system had low meat production cost but high F_HEP and F_HEE costs, BE-CCF (cereals and high stocking rate) had low F_HEP and F_HEE costs but high meat production costs. F_HEP_ha and F_HEE_ha are negatively correlated with the M_HEP and M_HEE efficiencies of meat production and with Meat production cost (significant for F_HEP_ha) , i.e. farms producing a high amount of edible protein and energy due to the volume of crops or milk produced have a beef unit that is less efficient in converting edible feed into edible protein or energy. M_HEP and M_HEE efficiencies of meat production are highly correlated. Farms with high M_HEE efficiency of meat production have generally higher production cost, use more non-tillable land (Table 7). Nonetheless, IR-CCF is efficient in terms of M_HEP and M_HEE and exhibits low meat production cost.

Table 7: Correlations (Spearman) between the different indicators

	Production per ha		Feed/food competition				Production Cost		
	F_HEP_ha	F_HEE_ha	M_HEP_eff	M_HEE_eff	M_TL	M_nTL	M_cost	F_HEP_cost	F_HEE_cost
F_HEP_ha	**1.0**	**0.9**	**-0.7**	**-0.7**	0.2	**-0.6**	**-0.5**	**-0.9**	**-0.9**
F_HEE_ha	**0.9**	**1.0**	**-0.7**	**-0.7**	0.4	**-0.6**	-0.3	**-0.9**	**-1.0**
M_HEP_eff	**-0.7**	**-0.7**	**1.0**	**0.7**	-0.4	0.5	0.3	**0.6**	**0.7**
M_HEE_eff	**-0.7**	**-0.7**	**0.7**	**1.0**	-0.5	**0.8**	**0.6**	**0.7**	**0.6**
M_TL	0.2	0.4	-0.4	-0.5	**1.0**	**-0.5**	-0.2	-0.3	-0.4
M_nTL	**-0.6**	**-0.6**	**0.5**	**0.8**	**-0.5**	**1.0**	**0.5**	**0.5**	**0.5**
M_cost	**-0.5**	-0.3	0.3	**0.6**	-0.2	0.5	**1.0**	0.4	0.3
F_HEP_cost	**-0.9**	**-0.9**	**0.6**	**0.7**	-0.3	**0.5**	0.4	**1.0**	**0.9**
F_HEE_cost	**-0.9**	**-1.0**	**0.7**	**0.6**	-0.4	**0.5**	0.3	**0.9**	**1.0**

Notes: in grey: farm gate indicators; HEE and HEP: Human Edible Protein and Energy, F_HEP_ha and F_HEE_ha : farm gate production of HEP and HEE per ha of usable area, M_HEP_eff and M_HEE_eff net efficiency of HEP and HEE at meat production level, M_TL and M_nTL Tillable and non-Tillable Land (in and out the farm) used to produce meat; Values in bold are different from 0 with a significance level alpha=0.10

3 Discussion

The objectives of this study were to propose an evaluation tree of the contribution to food security for different cattle farms, to constitute references for European beef production systems and to identify opportunities for improvement.

The first criterion evaluated was energy and protein production at farm level. The data shows that while farms specialized in beef production produce no more than 43 kg of human-edible protein and 1600 MJ of energy per hectare, systems selling milk and cereals in addition to meat have higher production levels, up to 370 kg of protein and 60000 MJ/ha. In this context, Garnett (2009) and Van Zanten et al. (2018) recommend reserving arable land for crops that can be directly consumed by humans and using only leftovers and co-products for animals. Although beef production is less efficient on the basis of these metrics than cereal or milk production, some complementarities should not be overlooked: manure fertilizes crops and temporary grasslands are essential in crop rotations (limiting the development of weeds, diseases and pests by disrupting their biological cycles, providing nitrogen to the soil through legumes, carbon sequestration in the soil, etc.) as pointed out by Benoit et al. (2020). In order to measure this contribution, it would be necessary to compare long-term human edible food production with and without temporary forage crops and grasslands. In order to improve the production of protein and energy from the cattle herd, favoring dairy cows of dual-purpose breeds producing both milk and meat or with more beef cross-bred calves when resources are sufficient are interesting options to explore (Zehetmeier et al., 2012).

The second criterion is feed-food competition. Concerning the efficiency of the studied beef production systems, we find net HEP efficiencies between 0.6 and 0.7 and net HEE efficiencies between 0.1 and 0.2 for the French, Belgian and Italian-French cow-calf systems. These results confirm those of Laisse et al. (2018) on two French cow-calf calf-fattener systems with net HEP conversion efficiencies of 0.67 and 0.71. Mottet et al., (2017) also reported a HEP efficiency of 0.6 for ruminant farms worldwide. As Benoit et al., (2020) point out, most ruminant systems consume more HEP than they produce. We highlight a significant difference between the cow-calf phase of the animals, which is generally a net producer of HEP (on average 1.7, min 0.5 and max 4.5) and the finishing phase, which is a net consumer (on average 0.6, min 0.2, max 1.1). Extensive systems are often presented as virtuous and opposed to intensive feedlot systems (Gerber et al., 2015). However, in Europe and elsewhere, these systems are often linked because animals from extensive 'breeder' systems often pass through intensive 'finishing' type systems before being consumed by humans. In this paper, such an example was the Franco-Italian system (breeder in France and fattener in

Italy) which is a net consumer of HEP as most of the cow-calf finishing systems are whereas the cow-calf-phase is a net producer of HEP. The net protein efficiency of this reconstituted system is not greater than that of the French farm, where the two phases (cow-calf and finishing) are carried out. It could be concluded that specialization does not improve the net protein efficiency, however the pedoclimatic contexts of these farms are different and a larger sample of farms would be needed to confirm this statement.

Within each phase it appears that HEP efficiency can be improved by using plant resources that provide little or no competition with human food demand such as grass and food co-products. The most HEP efficient cow-calf system is based exclusively on grass, as in the Irish cow-calf system (net edible protein efficiency of 4.5). For fatteners, two strategies emerge: the production of animals with a high daily gain and fattened from feed co-products (alternative Italian system: IT-F1), or the finishing of animals on grass, which implies slower growth. In the Irish systems, grasslands are managed quite intensively based on rotational grazing and a high level of mineral fertilization. The estimated results for dairy systems are more difficult to compare in the literature since the allocation between milk and meat production is generally not made (Ertl et al., 2016; Laisse et al., 2018). Producing some milk on a beef farm does not necessarily appear to be the best solution for improving the protein efficiency of meat, although milk production is a plus at the farm level. This can be explained by slightly more intensive systems with a higher use of feed in competition with humans. The negative correlation between HEP and HEE production per hectare at farm level and HEP and HEE efficiencies at beef production scale can be explained by a higher consumption of cereals by animals in crop-livestock farms: since cereals are produced on the farm they may be more widely used as a source of animal feed.

Concerning land use, the results of Beauchemin et al. (2011), Mogensen et al. (2015) and Nguyen et al. (2010) present values between 40 and 150 $m^2.kg^{-1}$ of carcass from beef cattle, and between 9 and 50 $m^2.kg^{-1}$ of carcass for dairy cattle. The estimated values for the systems studied are within this range, although some cow-calf finishing systems have higher performances (21 $m^2.kg^{-1}$ of carcass for the Belgian cow-calf finishing farm). The breeder-fattener systems studied use between 2 m^2 for Irish grass based systems and 9 m^2 of tilled land per kilogram of meat carcass produced. The most effective way to reduce the area of tillable land is to reduce the consumption of human edible concentrates by the herds. To improve the efficiency of use of non-tillable land, better management practices should be adopted that would allow for better use of the grassland by animals, including improving grassland productivity by over-seeding, or choosing beef breeds that make better use of grassland resources without greatly reducing meat productivity per hectare.

The final criterion is the cost of producing food that can be consumed by humans. Few studies have estimated the cost of producing meat by taking into account all the factors of production, as this requires relatively detailed technical-economic data. The meat production cost estimates of the French Livestock Institute are on average €8 kg^{-1} carcass for breeder systems, €4.5 kg^{-1} of carcass for finishing systems and €7 kg^{-1} of carcass for breeder-finishing systems in France. The values found in this study are in the same order of magnitude (resp. €6.5 kg^{-1}, €3.8 kg^{-1} and €5.4 kg^{-1}), although generally lower and characterized by a great variability. The systems with the lowest meat production costs are the finishing systems producing the highest amount of live-weight per LU and dairy systems in lowland areas which share the costs between milk and meat. The cost seems to be highly impacted by the farm size. A small farm will find it more difficult to amortize its equipment and to remunerate labor.

Conclusion

This study provides an indication of the contribution of cattle farms to food security both at farm and beef production levels, integrating food production, feed-food competition and production costs, as well as proposing avenues for improvement. This data has been estimated only on a sample of case studies. Although they have been chosen to be representative of existing farming systems they should not be considered as average values for each country. The results show that the production of milk, but especially cash crops, makes more efficient use of arable land in terms of human edible protein (HEP) and energy

(HEE) production at farm level and in terms of production costs compared to beef only production. Nonetheless these farms are less efficient at converting HEP or HEE in beef feed into HEP or HEE in beef carcass. This raises the question of how greater efficiencies in beef production can be achieved on crop livestock systems. The grassland-oriented systems and the use of food co-products are the most effective system in terms of increasing the HEP and HEE efficiency of beef production and should then be favored on non-tillable land.

Many trade-offs exist between indicators which means that no farm is excellent on all of the food security criteria considered. Although most of HEE and HEP efficient farms typically have higher meat production costs, some grassland based systems stand out positively for these three indicators. These results pave the way for improvements of the contribution of beef production systems to food security. However, further research is required to estimate the impacts of potential innovations to improve the contribution of beef production to food security on the other dimension of sustainability and to identify barriers to their development in each territory.

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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