The use of feed for the production of meat, egg and cheese in Sweden

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Abstract

Livestock converts feeds into various products (meat, milk, hides and hundreds of other products) and services (from drought power to ecosystem function and company) for humanity. Feed production and grazing constitute a major share of the costs for livestock production. Feed production is also the major cause of environmental impact of livestock production. This study documents and analyses updated data regarding the feed composition and the amount of feed, expressed in dry matter, used for the following Swedish animal-based products: 1 kg of human edible meat of pork, chicken, lamb, beef and 1 kg of cheese and 1 kg of egg without shell. It calculates edible meats in a more elaborated way than carcass weight or boneless meat often used in lifecycle assessments, including all that is currently used for human food. In addition, it is the first study to define human edible protein in feed under Swedish conditions. This is then linked to the edible protein in animal products to calculate an edible protein conversion ratio.

Milk has the lowest feed use of the studied products, 0.77 kg of feed in dry matter is used to produce 1kg of milk. It has also the highest ratio of 2.4 kg of human edible protein for each kg of edible protein used as feed. This is reflected in the results for cheese. For the meats, the feed use per kg edible meat is lowest, and almost the same, for chicken and pork. Cattle and sheep have very high feed use, meanwhile they use less human edible protein to produce human edible protein in the form of animal products than the monogastric animals. Eggs has a lower feed use than any of the meats, but also a low protein conversion ratio.

The choice of allocation method has a huge impact on the results and will always include value judgements. The study demonstrates that it is hard to use one-dimensional indicators, such as feed use, to capture the complexities of the agriculture and food system.

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Table of content

1 Summary

1.1 English summary

Feed use in livestock production is central from a number of perspectives. Livestock converts feeds into various products (meat, milk, hides and hundreds of other products) and services (from drought power to ecosystem function and company) for humanity. Feed production or grazing constitute a major share of the costs for livestock production. Feed production and animal metabolism are also major causes of environmental impact. To have correct data for feed use is therefore a pre-condition for assessment of the environmental impact of livestock production.

This study documents and analyses updated data regarding the feed composition and the amount of feed, expressed in dry matter, used for the following Swedish (produced in Sweden, and made from animals raised in Sweden) animal-based products: 1 kg of human edible meat of pork, chicken, lamb, beef, 1 kg of cheese and 1 kg of egg without shell. In addition to this, clear figures on the amount of soy used for each product are presented.

There has been no comprehensive study which combines the feed use and the edible food from livestock in Sweden. This report calculates edible meats in a more elaborated way than carcass weight or boneless meat often used in lifecycle assessments. The calculations are, as far as possible, based on similar methods and allocation principles for all the relevant products. Through cross checking of the data with data for the feed available the results are validated. In addition, it is the first study to define human edible protein in feed under Swedish conditions. This is then linked to the edible protein in animal products to calculate an edible protein conversion ratio (EPCR).

The calculated feed use is supposed to reflect the average Swedish commercial production, based on feed rations supplied by industry sources or independent research. Consideration is taken of factors that impact feed use, such as mortality, variations in age at slaughter, variations in breeding systems and races. The calculations also include feed to the parent animals and recruitment animals. Actual feed use is mostly considerably higher than theoretical feed rations, which are based on optimal conditions. Therefore, the calculated feed rations were compared with data from the feed industry, total crop harvest, estimates of waste and loss, statistics for the use of grain, trade statistics and other research and adjusted if there were major differences.

Apart from clarifying the feed used, the study also elaborates on how big share of the animal that is edible, i.e. used for human food consumption. Feed use efficiency reports from the livestock industry has normally expressed the feed use per kg live weight, while feed use calculations in life cycle assessments mostly focus on carcass weight or boneless meat. But the whole carcass is not eaten, primarily not the bones, and there are parts of the animal that are not part of the carcass weight (organs, fat and some meat) which are edible. Human edible is defined as products which are eaten as food or processed into food (sausages etc.) in Sweden or exported to markets where they are consumed as food (e.g. pig feet, chicken wings). In addition, potentially edible meat has also been calculated, including parts of the animal which are not eaten in Sweden or exported as human food, but could be eaten (table 1). The difference between human edible and potentially edible indicates the potential for increasing the

valorisation of a bigger part of the animal as human food. This potential is biggest for beef followed by chicken. It is clearly a low-hanging fruit when it comes to lower the ecological footprint of livestock production if a bigger part of the animal is actually consumed.

Milk has the lowest feed use of the studied products, 0.77 kg of feed is used to produce 1kg of milk. Even calculated on a dry matter basis it still use less feed than egg production, which otherwise has a high feed conversion ratio. For the meats, the feed use per kg edible meat is lowest, and almost the same, for chicken and pork. This is perhaps surprising as feed conversion of chicken is mostly said to be superior of other animals. The reason for this is that feed conversion is mostly measured against live weight while the share of a pig that is edible is higher than of a chicken.

Cattle and sheep have very high feed use. This is a result of the digestive system of ruminants. While consuming a lot, they also have the ability to digest feed which is too coarse for the monogastric animals, pigs and hens. This also results in that they use less human edible protein to produce human edible protein in the form of animal products. The monogastric animals use feed protein that is more easily digested. Milk has the highest ratio of 2.4 kg of human edible protein for each kg of edible protein used as feed. Notably, the calculation of protein conversion has not taken into account the higher nutritional value of animal proteins compared to the protein in their feed. It has also not considered other nutrients for which animal products are important.

The use of soy is high in chicken production, 0.45 kg per kg edible meat, and also considerable in egg production. In beef and milk production the share of soy in the feed is very small and even expressed per kg product it is small, but as the total milk production is big, more than one fifth of all soy is used in milk production.

Table 1 Feed use and edible protein conversion ratio

	kg per CW	kg per kg HE	kg per kg PE	EPCR	Use of soy per kg
Egg	NA	2.43	2.43	0.67	0.25
Chicken	2.41	3.26	2.80	0.68	0.44
Milk	NA	0.77	NA	2.39	0.02
Cheese	NA	3.27	NA	2.39	NA
Beef	19.65	24.59	19.53	0.90	0.05
Pork	3.25	3.21	3.13	0.82	0.15
Sheep	36.20	41.01	35.66	-	-

CW=carcass weight

HE=human edible

PE=potentially edible

EPCR=edible protein conversion ratio

For sheep, the data is of rather low quality and the results should not be considered as robust, which is the reason for why no value for EPCR or soy use are presented. For beef there is also considerable uncertainties relating to the many actors and big variations in the sector. The production of pork and milk, and even more so chicken and eggs, is more standardized and more large-scale which makes the data more certain.

In order to make calculations there are a number of allocation choices to be made. In many cases, the choice makes only a small difference. That is the case for most by-products from slaughtering. But the following allocation choices have a considerable impact on the results.

- Between milk and meat in the dairy production;
- between cheese, cream and whey in cheese making; and
- between the skin, wool and the meat from lamb.

As far as possible, the principle for allocation has been biophysical, i.e. the allocation of feed is based on the actual need of feed for different products. In the dairy processing, allocation has been based on the partitioning of dry matter. For minor by-products and for sheep, economic allocation has been used. The report also discuss a possible partitioning of feed use for ruminants (cattle and sheep) between meat and ecosystem services such as maintaining the landscape, bio-diversity, carbon sequestration and soil improvements. No such allocation is included in the final results, but it could lead to a very substantial reduction in figures for feed use for meat from ruminants.

It is tempting to discuss the results in terms of “efficiency” but the author advice against it. Feed conversion and protein conversion ratios are often opposite both in comparisons between different animals as well as between different systems for the same animal. Monogastric animals have low feed use but also a low edible protein conversion ratio, while ruminants consume much more feed but less human edible feed. Much of the increased efficiency of livestock production has been a result of less use of roughage, straw, food waste, scraps and other low quality feeds and increased use of high quality feeds.

While feed use is important, one should not draw too many conclusions about the respective products as there are many linkages in the production systems, e.g. impact on crop rotation, recycling of nutrients in manure and in by-products and the close ties between milk and beef, where one can’t produce milk without also producing meat. What is a weakness from one perspective such as feed use per kg edible product can be a strength from another perspective as in the case of grazing cattle and sheep. The study demonstrates that one-dimensional indicators, such as feed use, don’t capture the complexities of the agriculture and food system, and this also makes it questionable to use the data for comparisons between products and between countries. This is further emphasized when taking the impact of allocation choices into account.

1.2 Svensk sammanfattning

Foderanvändningen är central i djurhållningen. Djuren omvandlar foder till olika produkter (kött, mjölk, hudar, skinn, ull och hundratals andra produkter) och tjänster (från dragkraft till ekosystemtjänster och sällskap). Foderproduktion och bete utgör den största kostnaden i animalieproduktionen. Foderproduktionen och djurens metabolism är också huvudsakliga orsaker till djurhållningens miljöpåverkan. Korrekta data för foderanvändningen är därför en förutsättning för att bedöma djurhållningens miljöeffekter.

Denna rapport dokumenterar och analyserar åtgången av foder, uttryckt som torrsubstans för följande svenska (producerade i Sverige från djur uppfödda i Sverige) animalieprodukter: 1 kg ätbart kött av lamm, gris, kyckling och nöt, 1 kg ost och 1 kg ägg utan skal.

Detta är den första studien i Sverige som räknar ut den totala foderanvändningen i Sverige och sätter den i relation till mängden livsmedel från djurhållningen. Studien definierar och beräknar den verkliga mängden ätbart kött och inte enbart slaktvikt eller benfritt kött som ofta används i livscykelanalyser. Beräkningarna i rapporten är i stor utsträckning gjorda med liknande metoder och principer för allokering för alla de studerade produkterna. Den beräknade foderåtgången har jämförts med tillgången på foder för att validera resultaten. Studien är också den första som definierar andelen och mängden mänskligt ätbart protein i foder under svenska förhållanden och ställer detta i relation till mängden mänskligt ätbart protein i djurprodukter för att på så sätt beräkna en omvandlingsfaktor för mänskligt ätbart protein (EPCR). Särskilda beräkningar av mängden soja som åtgår för varje produkt har också gjorts.

Beräkningarna reflekterar den genomsnittliga svenska kommersiella produktionen och baseras på foderstater från branscherna och oberoende forskning. Hänsyn har tagits till dödlighet, variationer i ålder vid slakt, variationer i olika uppfödningssystem och för olika raser. Beräkningarna inkluderar föräldradjur och rekryteringsdjur. Den verkliga foderanvändningen är mestadels betydligt högre än teoretiska foderstater och foderomvandlingsberäkningar eftersom dessa bygger på optimala förhållanden. Den beräknade foderanvändningen har jämförts med data från foderindustrin, skördestatistik, uppskattade förluster och svinn, statistik över användningen av spannmål, handelsstatistik samt annan forskning. Om det varit betydande avvikelser har beräkningarna reviderats.

Utöver att fastställa foderanvändningen utvecklar rapporten också hur stor del av djuren som är ätliga, dvs. används till mänsklig mat. Foderomvandlingsdata från de olika branscherna avser normalt sett foderanvändning per kg levande vikt, medan foderanvändning i livscykelanalyser oftast ställs i relation till slaktvikt eller benfritt kött. Men hela slaktkroppen äts inte, särskilt inte benen, samtidigt som det är ätliga delar av djuret som inte är en del av slaktkroppen (inälvor, fett och vissa köttdetaljer). Mänskligt ätbart kött definieras som produkter som äts som livsmedel eller används som råvaror i beredda livsmedel (korv mm) i Sverige eller som exporteras till marknader där de används som livsmedel (t.ex. grisfötter och kycklingvingar och vissa organ). Vidare har också mängden potentiellt ätbara produkter beräknats. Dessa inkluderar sådant som inte äts i någon utsträckning att tala om men som kan ätas (och har ätits historiskt), se tabell 1b. Skillnaden mellan det mänskligt ätbara och det potentiellt ätbara indikerar en potential för att använda en större del av djuret till mat. Potentialen är störst för nötkött följt av kyckling. Det är en så kallat lågt hängande frukt för att minska djurhållningens ekologiska fotavtryck att en större del av djuret används som livsmedel.

Tabell 1b Foderförbrukning (ts) och proteinomvandling

	Kg foder per kg slaktvikt	Kg foder per kg ätligt	Kg foder per kg potentiellt ätligt	EPCR	Kg soja per kg ätligt
Gris	3,25	3,21	3,13	0,83	0,15
Kyckling	2,41	3,26	2,80	0,69	0,44
Lamm	36,20	41,01	35,66	-	-
Mjölk	-	0,77	-	2,39	0,02
Nötkött	19,65	24,59	19,53	0,90	0,05
Ost	-	3,27	-	2,39	-
Ägg	-	2,43	2,43	0,67	0,25

EPCR=proteinomvandlingskvot

Mjölk har den lägsta foderanvändningen av de studerade produkterna, 0,77 kg foder används för att producera 1 kg mjölk. Även om man räknar på torrsubstans används det mindre foder till mjölk än för ägg som annars har en låg foderanvändning. För kött är foderförbrukningen lägst, och nästan helt lika, for kyckling och gris. Detta är kanske förvånande eftersom kyckling oftast anses ha den högsta foderomvandlingsförmågan. Orsaken är att man oftast mäter det i förhållande till levandevikt, men det är en högre andel av grisen än kycklingen, som är ätlig.

Nöt och får har mycket hög foderanvändning. Detta är ett resultat av deras matsmältningssystem. Samtidigt som de konsumerar mycket kan de också smälta foder som är för grovt för de enkelmagade djuren, höns och gris. Det betyder också att de använder betydligt mindre mänskligt ätbart protein för att producera ätbart protein i form av animaliska produkter. Mjölk har det högsta utbytet mänskligt ätbart protein per kg ätbart protein i foder, 2,4 kg. Tar man hänsyn till bio-tillgänglighet och fördelning av aminosyror är utbytet ännu bättre. Djurprodukter har också andra värdefulla näringsämnen.

Användningen av soja per kg ätlig produkt är högst i kycklingproduktionen med 0,45 kg soja per kg ätligt kött. Även äggproduktionen använder mycket soja per kg ätlig produkt. I absoluta tal använder mjölkproduktionen mest soja, men per kg produkt är användningen dock liten, cirka 0,02 kg per kg mjölk.

För får och lamm är dataunderlagen bristfälliga samtidigt som det är mycket stora variationer i hur uppfödningen går till. Därför presenteras inga resultat för sojaanvändning och proteinutbyte och även resultaten för foderanvändning får anses vara osäkra. Det är också betydande osäkerhet vad gäller nötkött på grund av stora variationer i uppfödningen. Resultaten är säkrare för gris, mjölk, kyckling och ägg eftersom dessa produktionsgrenar är mer standardiserade. För gris fanns också redan ett bra underlag för foderanvändningen.

För beräkningarna är det nödvändigt att fördela, allokera, foder mellan de olika produkterna och bi-produkterna. I många fall har principerna för fördelningen ingen stor betydelse, men i vissa fall spelar det stor roll:

- Fördelningen mellan mjölk och kött i mjölkproduktionen,
- fördelningen mellan ost, grädde och vassle i ostproduktionen, och

- fördelningen mellan skin, ull och kött i fårskötseln.

I så stor utsträckning som möjligt har biofysisk allokering tillämpats, dvs. foder har fördelats utifrån foderåtgången för de olika produkterna. I mejeriledet har allokeringen baserats på andel av torrsubstansen. För mindre bi-produkter och för får har ekonomisk allokering tillämpats. Rapporten diskuterar också, samt ger exempel på, möjligheten att hänföra en del av foderanvändningen till ekosystemtjänster som bevarande av landskapet, biologisk mångfald, kolbindning och jordhälsa. Ingen sådan allokering är inkluderad i de slutliga resultaten men det kunde leda till avsevärt lägre värden för foderanvändning per kg ätlig produkt från idisslare.

Det kan vara frestande att diskutera resultaten i termer av ”effektivitet”, men författaren avråder från detta. Foderomvandlingskvot och proteinomvandlingskvot är ofta motsatser både i jämförelser mellan djurslagen och mellan olika uppfödningsformer inom ett och samma djurslag. De enkelmagade djuren har låg foderanvändning men har också låg proteinomvandlingskvot medan idisslarna äter stora mängder foder men mindre mänskligt ätbart foder. En stor del av den ökade produktiviteten i animalieproduktionen har uppnåtts genom att foder med lågt näringsinnehåll (grovfoder, avfall och biprodukter med lågt näringsvärde) har ersatts med mer koncentrerade foder.

Även om foderanvändning är viktigt kan man inte dra för långt gångna slutsatser av detta eftersom det är många kopplingar i jordbruks- och livsmedelssystemen, exempelvis påverkan på växtföljder, återcirkulation av näringsämnen via gödsel och bi-produkter samt den starka kopplingen mellan mjölk och kött, där mjölkproduktionen bygger på att kött produceras och konsumeras. Det som är en svaghet från ett perspektiv, exempelvis hög foderanvändning, kan vara en styrka från ett annat, som för betande nötkreatur eller får. Rapporten visar att endimensionella indikatorer, som foderanvändning, inte kan fånga in alla dessa komplexa samband och detta gör att man kan ifrågasätta om det är meningsfullt att använda sådana indikatorer för jämförelser mellan produkter eller mellan samma produkt från olika system eller länder. Detta understryks ytterligare av att val av metod för allokering kan ha stor betydelse för resultaten.

2 Introduction

2.1 In which context this study is made

In 2015, WWF Sweden launched a consumer Meat Guide, looking at how different kinds of meat, but also eggs and cheese, affect our planet. Since then, WWF Finland, Austria, France and Estonia have also launched the same kind of guides and WWF Belgium and Portugal are on their way. From May 2020 these WWF offices are part of the EU funded project called Eat4Change, with the overall objective to shift toward more sustainable diets and food production systems, particularly in livestock production. The different meat guides take somewhat different aspects into account. All look at the impact on climate and biodiversity, as well as the use of chemical pesticides. Some also look at eutrophication, the use of antibiotics and animal welfare. All communicate with a traffic light system of green, yellow and red, to indicate the best vs. the worst choices.

One challenge for the assessment of climate footprint and pesticide use in the guides is that it is based on the feed composition, figures that are most often difficult to find and/or outdated. There is a clear need for a better understanding of the feeding strategies of different production systems in Sweden, since these figures are key in both analysing the climate and pesticide impact in the guide. In addition, the composition of the feed has also a great impact on land-use which directly and indirectly has impact on bio-diversity. This study is the first attempt to quantify the total use of feed for all important livestock production systems in Sweden and put that in relation to the food that is produced. In order to do so, also the actual quantity human food derived from livestock is determined.

The flow of feed to livestock is the biggest flow within the Swedish agriculture system, with approximately 55% of the total harvest from croplands being directly used as feed. Permanent grasslands represent an additional flow and there are considerable streams of rest products from food and bio-energy industries used as feed (Rundgren 2021). To understand these flows of feed is therefore key for understanding the Swedish food system. While not being within the scope of the report, it should also be noted that feed costs constitute a major share in most livestock production. In egg production it is around ¾ of all costs, 10 times higher than labour costs, in pig and beef production approximately half and in milk production more than half (Länstyrelsen Västra Götaland 2023). The results of the study can therefore also be relevant for those interested in farm economy.

2.2 Scope of the study and report

This study documents and analyses updated data regarding the feed composition and the amount of feed used for the following Swedish animal-based products (produced in Sweden, and made from animals raised in Sweden): 1 kg of edible meat or potentially edible meat of pork, chicken, lamb, beef and one kg of cheese and 1 kg of the edible part of an egg. In addition to this, figures on the amount of soy used for each product are presented and the human edible protein conversion ratio is calculated.

2.3 Definitions

Complete feed is a feed that covers the whole nutritional needs of the animals.
Compound feed is any mix of feed.

Concentrates are feeds with special characteristics (protein, energy, minerals) which are complemented with grains and/or roughage according to animal species.
Ley is the production of grasses and herbs for silage or hay on croplands.
Premixes are complex mixtures of vitamins, minerals, trace elements and other feed additives.
Roughage is fodder with a high fibre content. There are three main forms of roughages: (1) dry roughages (hay, straw), (2) silages (fermented plant matter), and (3) pastures.

2.4 Abbreviations

CW	Carcass weight	The weight of the animal body after dressing when blood, hide (if relevant) and organs are taken away.
DM	Dry matter	
EPCR	Edible protein conversion ratio	Express how much human edible protein that is used as feed to produce human edible protein in livestock products.
FPCM	Fat and protein corrected milk	A standardized measure for milk that takes into account its content of fat and protein.
HE	Human edible	Any part of the animal which is primarily consumed as food for humans, either in Sweden or in export destinations.
LCA	Life cycle assessment	
LW	Live weight	The weight of a living animal.
PE	Potentially edible	Products that could be eaten, but are not currently eaten to any extent.
SBA	Swedish Board of Agriculture	

2.5 Indicators and functional units

The functional unit in this case is for meats: one kilogram of human-edible meat (see more below), for egg: one kg egg without shell, for cheese: one kg of a hard cheese with 26% fat. The indicator is feed use expressed as kg dry matter (DM) divided in appropriate categories of feed.

For meats, human-edible meat (in the rest of the report called just edible meat) is defined as any part of the animal which is primarily consumed as food for humans, either in Sweden or exported. I.e. edible meat will also include edible organs such as liver, kidneys as well as meat which is not part of the carcass. Edible meat doesn't include the bone fraction of retail cuts such as ox tail or pork chops. For ease of comparisons with other research, results are reported for carcass weight (CW), edible meat and potentially edible meat. In some cases, live weight (LW) is also identified. Notably, while most feed use efficiency studies are based on live weight, most life cycle assessments are made for kg of carcass weight and not for "boneless meat" or "edible meat". For eggs, the edible part of the egg is without shell. For cheese, the whole product is considered edible.

Feed is expressed as dry matter (DM) as that is a better representation of how the various feed materials contribute to the feeding of the animal, than using fresh (trade) weight. In pig rearing, for example, there is various wet feeds used, and their relative importance would be grossly exaggerated if one express feed use in raw weight. In Swedish feed rations, hay, pasture and silage are mostly expressed as dry matter which means that if one uses fresh weight, their relative contribution appear to be smaller than for other feeds if they are compared with grains which mostly have less than 90% dry matter.

The use of DM for the indicator means that the feed use per kg meat may appear lower than normal industry estimates. On the other hand, the fact that the study includes feeds also for parent animals, takes into account waste, mortality and other factors as well, makes the feed use higher than if just based on typical feeding rations for producing animals.

2.6 System boundaries

All feed in Sweden, regardless if produced on-farm, purchased from other farmers or from food industries, imported, or derived from waste streams are included in the calculations. The functional unit is measured at the exit of the whole sale meat packer, dairy factory or egg packer, i.e. waste in further processing in secondary meat processing (sausage making etc.) or retail packing of cheese or meat or losses in the retail trade, restaurants or points of consumption is not considered. Feed for parents or recruitment is included. Product specific system boundaries are discussed under the respective chapters.

2.7 Sources and references

Sources used directly in the main report are included as a reference in the running text. Sources used for the calculations are indicated in the supplementary file. In some cases there is a reference to the relevant worksheets of the supplementary file indicated by [S#]. All references are found in annex 1.

2.8 Acknowledgements

This report is written by Gunnar Rundgren, commissioned by WWF Sweden, based on the sources listed. Comments on drafts of the report were received by Jenny Jewert, Sofia Nordlund and Anna Richert from WWF Sweden. In addition, drafts of the relevant parts of the report, were submitted for comments to various industry associations or companies that had submitted data. The final document remains under the sole responsibility of Gunnar Rundgren.

3 Method

In general, the methodology used is the same as those used for lifecycle assessments (LCA), even though *the scope is limited to the actual use of feed and not the impacts of this use*, which mostly is the scope for LCAs.

3.1 Collection of data top-down and bottom-up

In order to assure that data are robust and reliable, data has been collected both bottom-up and top-down. The total quantity of feed from the calculation bottom-up and the calculation top-down should match. If not, there is some error in the data, which merited further investigation.

3.1.1 Bottom-up

Bottom-up data are based on rations that have been collected from reliable sources, if possible from several sources which have been combined. The feed used for parent animals, replacement animals, eggs etc. are included. The rations have been multiplied with the number of animals that, on average, have consumed the rations, including estimates of animals that die before slaughter either on farm, during transport or because of outbreak of disease.

For cattle, the bovine registry (CDB) makes it possible to trace all animals and their fate, including movements and age of slaughter or death. For other animals, industry sources and slaughter statistics have been used. The number of animals culled as part of government interventions to control disease were provided for a 5 year period by the SBA (SBA 2023c).

For feed used, an additional 0.5% of waste/loss in the storage and handling is applied for non-roughage. A tool from Hushållningssällskapet (2021) set in-farm storage loss of feed grain at 2%. A lot of grain is supplied also from farms to the feed industry where losses are lower. On the other hand commercial farmers may store grain for longer periods and sell it later on. The waste factor is, however, only applied for grains and pulses as there would be many complications to use it also for by-products. A 9% loss is calculated for storage of silage. Waste at feeding is added for ruminants' consumption of silage according to industry estimates, while no other waste at feeding is considered for other animals. The use of seed for the production of feed has not been included (see more under 11.2).

3.1.2 Top-down

The total quantity of feed available is calculated from SBA harvest statistics, feed industry statistics 2018-2021, trade statistics 2019-2021, SBA grain balance 2017/2018 and investigations of all major food industries which have by-products used for feed. The feed industry statistics have indications which feedstuff that is used for which kind of animals. For the total harvest, various sources have been used to allocate the harvest to different uses: export, seed, left on field, grazed, fed on farms (including sold to other farmers), to feed industry, bedding, to non-food industry (starch, biofuels etc.), food industry and shops, direct consumption (sold to consumers from farms), biogas, combustion and on farm losses. In order to make it possible to compare data with the total quantities of feed available, rations for all other animals, horses, goats, reindeer, fish and pets have also been calculated from various industry sources, according to Rundgren (2021) [S7, S13].

3.1.3 Produced quantities

The national statistics of slaughter, milk deliveries and egg packing are used to make the calculation of the total volume produced. Estimates of home consumption and losses underway are added. For each meat the share of edible meat and potentially edible meat is calculated. For all products, by-products and their value are determined. See more below.

3.1.4 Allocation

The process of allocation is about partitioning the share of the total feed used between the product in question and by-products or between co-products (e.g. in the case of milk and meat from dairy production). Almost all scientific studies of allocation is about allocation of environmental impacts in LCA-methodology. Feed used is not an environmental impact but a resource used (for which the production has environmental impacts). Nevertheless, the principles for allocation developed for LCAs can also be applicable for feed use. As is noted below, this is not always the case, however.

ISO standards provide the guideline for allocation in LCA (ISO 2013):

(1) allocation should be avoided a) by creating sub-processes or b) applying a system expansion approach[1]; System expansion can be used to calculate the impact of the main product, by substituting the impact of the by-products with the impact of the avoided production of other products in the market. In the case of feed use, the system expansion approach is clearly not applicable. For example, in a review of milk LCAs when authors used system expansion the meat resulting from the milk production was considered substitution for other kinds of meat (beef from beef cattle or pork) (Kyttä et al 2021). A comparison of different allocation methods for wool and meat from sheep shows that system expansion where lambs meat was substituted for beef resulted in negative emissions for the wool (Wiedeman et al 2015).

(2) If allocation cannot be avoided, allocation should be based on the underlying physical relationships between products or functions. In the actual case it would mean that the use of feed should be allocated to the various fractions according to their feed (energy) requirements. Here the term bio-physical is used to separate it from pure physical measures such as mass.

(3) When bio-physical allocation cannot be used, the allocation method should be based on another relationship between the products or functions. It can be mass allocation, where resource use is linked to the respective weight of the product and co-products, excluding waste. Another option, commonly used, is economic allocation, where resource use is allocated to product and co-products, excluding waste, according to their economic value.

The ISO standard leaves room not only for the choice of method but also for how a particular method is implemented (Kyttä et al 2021). In addition to the ISO standards, practitioners and sector organizations have developed own methods.

[1] The term "system expansion" is sometimes used for two different approaches: (1) assessing avoided burden/substitution and (2) expanding comparable systems by adding functions so that the systems include production of similar functions. There is a considerable debate about this in the LCA community.

Allocation based on economic value will result in lower shares for the by-products as most of them are less valuable than the meat. If one would allocate after nutritional content the partitioning would be closer to the results of the mass allocation than that of the economic allocation, as most edible by-products are nutritionally comparable with the meat. Many of the by-products, such as some of the offal, pig feet and chicken wings are exported for a much lower market value than their nutritional value (Schultz 2021, Industry data 2023, Alsterberg 2012, SBA 2022b). Allocation based on food energy would make fat the most important product as fat has more energy than other parts of the body (Rundgren 2021).

By and large, there is no allocation method that is perfect and the choice of allocation method is best chosen in accordance with the purpose of the LCA. Notably one can't compare results unless the same allocation method is used. Even then, system expansion and economic allocation is dependent on fluctuating market factors. An analysis made at different times can come to widely different results even if the same method is used (see example under allocation meat-milk).

The main principle in this report is to use biophysical allocation as far as is possible and makes sense. Economic allocation is, however, used for some by-products. For sheep and lamb, economic allocation is applied also for the partitioning between meat, pelt and wool. The impact of the choice of allocation is discussed in each chapter, and results are often presented for different allocation methods.

Manure

The proportion of the feed intake (calculated on C content which is rather close to the DM content) that is converted into manure was calculated by Rundgren (2021) to be between 19 percent for poultry and 49 percent for cattle. Depending on the circumstances, manure can be considered a by-product with a value or an internal resource that is recirculated[2]. The former is particularly the case when the production is based on purchased feed, a situation not uncommon in poultry production. Poultry manure has a substantial commercial value, especially when dried and pelletized. For instance Leip et al (2009) calculate the value of manure to 6% of the total income of a case of poultry production in Brazil and 18% when it was valued for its nutrients content compared to the use of mineral fertilizers. Manure can also be a source of biogas and by-products from slaughter are used as feedstock for biogas as well as for the production of bio-diesel. The review of Kyttä et al (2021) of milk and beef environmental LCAs revealed that manure was handled as a by-product in 18 studies with allocation of up to 27% of the total impact.

Ruminant farming in Sweden as well as pig farming is to a large extent land based and manure is mostly recycled to the fields. However, it is possible also in this case, that the manure is used primarily for other crops than the feed crops. Nevertheless, the author has chosen not to allocate any feed to the production of manure for any of the products. It would be somewhat perverse that a farm that sells its manure would show a lower feed use than one that doesn't, and it would be equally strange to allocate feed use to manure that is used to produce the feed consumed by the same animals in the case manure is recycled on the field.

2 In some circumstance it is also considered a waste with a cost of riddance, but that is not the case in Sweden.

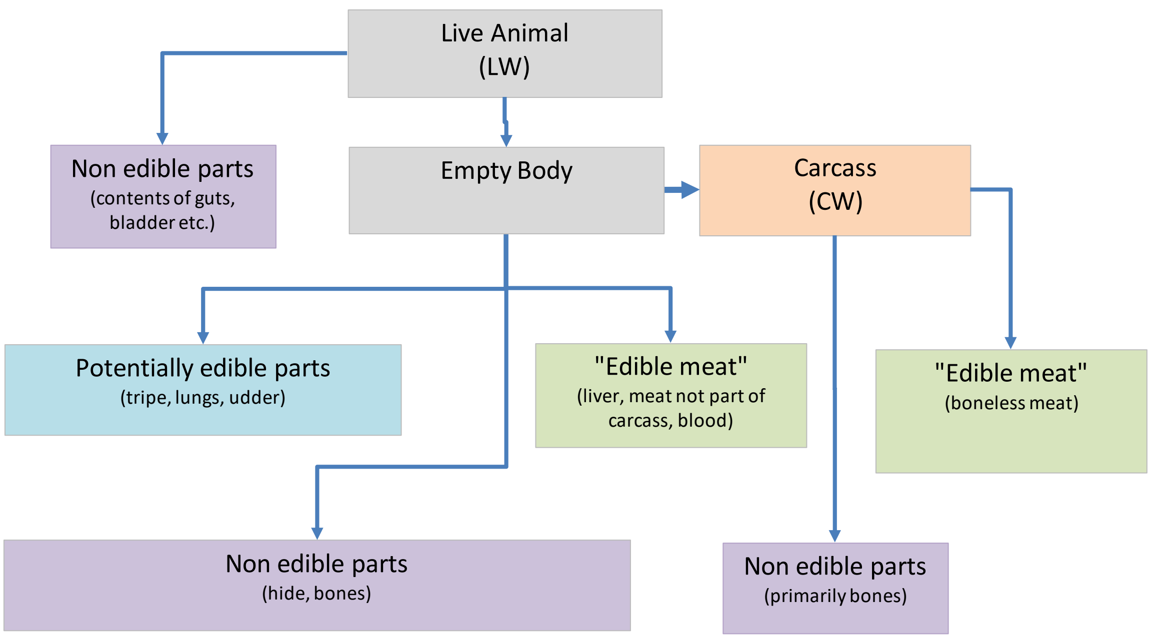
3.1.5 Relationship between allocation method and functional unit

There is a certain relationship between the allocation method and the functional unit. E.g. if the functional unit carcass weight or boneless meat is chosen, other human edible products (organs etc.) are considered by-products, but if human edible food is chosen the allocation of feed to the liver will be the same as for meat (see more below).

3.2 Calculation of edible meat and allocation of feed to by-products

In feeding recommendations and research about feed use efficiency, it is normally *live weight (LW)* that is discussed. In LCAs studied, various weight measures are used, such as live weight, empty body weight (excluding the contents of the gut, bladder etc.), carcass weight (CW) or boneless meat. Surprisingly often, research articles are not defining well what they mean with “meat” (Kyttä et al 2021). As a basis for calculating meat production, live weight is not very relevant as huge parts of the live weight is not meat. Carcass weight is therefore the normal standard when discussing meat production. The carcass weight is also the basis for payment in Sweden and the official slaughter statistics record the carcass weight.

Figure 1 The (de)composition of a live animal.



Carcass weight is, however, also a blunt measure when it comes to meat yield, especially when the meat of different species is compared. If the carcass is weighed still warm (“hot”) or after cooling also affects carcass weight with approximately 2% (SJVFS 2004). The cold carcass weight is the official carcass weight in Sweden, and thus the one discussed in this paper. The carcass is cut up into retails cuts and in some of the retail cuts there are still bones (e.g. pork chops, chicken drumsticks). Beef cuts are normally boneless except for ox tail and shank, while lamb cuts often includes bone (Blomberg 2022). In addition, there is also meat that is not part of the carcass, such as the ox chin, ox tail, skirt steak from both cattle and pigs, butcher's steak from cattle, pig feet and head etc. There are also offal, fat, blood and other products which are also used as food (some of which are exported) and offal, blood and other products which could be used as food but isn't. Finally, there are various by-products which are never used as food (hide, feathers, and contents of guts). There are also considerable quantities of fat that are not part of the carcass weight and other fat that is trimmed away in cutting the carcass. This fat is normally not counted in the "boneless meat" figure but it is normally also used in food production, i.e. included in minced meat, sausages and alike, especially the fat from pigs.

Edible meat has been calculated as boneless meat share of carcass weight + the details which are mainly used as food either in Sweden or exported as food. Other products (e.g. tripe) are edible in principle and eaten in some cultures but only to a very limited extent in Sweden and are not exported as food. Those are classified as *potentially edible.* In the chapter for the respective meat, this is explained in more detail. Notably, there are technologies to convert bones into edible food products, both traditional ones with the production of stock or marrow from bones or more modern methods such as the production of hydrolysates (Pap et al 2022, Sandström et al 2022). This has, however, not been considered in this study.

4 Beef and cheese

4.1 The cattle sector

The cattle sector in Sweden can roughly be divided into three systems. 1) Dairy production 2) Cow-calf breeding of meat races and 3) Feeding of animals for slaughter. Of 15,200 operations having cattle in June 2021, 19% had dairy production, 66% had meat production with mother animals and 15% had specialized meat production without mother animals (SBA 2022a).

The dairy production is most streamlined and there are now less than 3,000 dairy farms, with an average of 100 cows. 92% of all dairy cows are in operations with 100 cows or more. The dairy cows consume around 60% roughage, most in the form of silage, 30% grain and the 10% protein crops. In most cases the dairy farms sell the bull calves, after an early weaning, to specialized feeding operations. Normally, they raise their own replacement heifers. As a result of a rapid turnover of dairy cows, 24% of the cattle meat is from dairy cows (SBA 2022a). In addition, most of the calves born come from the dairy sector which means that the total contribution of the dairy sector to the meat production is much more than half.

Cow-calf production is mostly based on grazing. In winter, the feed is predominantly silage. Some of the producers sell calves after weaning to feeding operations, others raise the offspring to slaughter age. Many of the cow-calf operations are small, the average number of cows is 21 (SBA 2022a).

The feeding operations are mostly indoors and cattle, mostly bulls, are fed with a high share of grains and protein concentrates. They also have a rapid throughput as animals grow fast and are mostly slaughtered at an age of 60-80 weeks. There are, however, also feeding operations with steers (also some bulls) or heifers which often are grazing. Most steers originates, perhaps surprisingly, in the dairy production (SBA 2022a).

Around 3% of the cattle are slaughtered at the farm; the proportion of calf is much higher than in the slaughterhouses, especially in dairy operations where bull calves are slaughtered for home consumption (SBA 2022a).

The share of organic milk production is around 17% (SBA 2023i) and the share of organic cattle meat slaughtered is 15% (SBA 2023h). A considerable share of the organic bull calves are sold to conventional feeding operations (Andresen N. et al 2023).

4.2 Method

Compared to chicken, egg and pigs, there is much more variation in the production of beef in Sweden. Theoretical calculations of feed use would mostly assume that animals are fed an optimal ration and that they are sent to slaughter at an optimal age when feed conversion rates are still rather high. E.g. the economic production models (*SWE:bidragskalkyler)* for meat from dairy cattle bulls calculate with a typical age of slaughter of 16 month and a carcass weight of 290. For that 3000 kg DM of feed is calculated. The feed conversion rate is therefore around 11 kg DM per kg CW if the carcass weight of the calf is deducted (Länsstyrelsen Västa Götaland 2021). In reality, a minor share of the bulls are slaughtered at that age. There is a peak between 16 and 20 month but many bulls live up to 2 years or more (SBA 2022a). Clearly this will impact feed use as there is more feed spent on maintenance when animals live longer. In addition, not all producers operates with optimal efficiency.

The amount of feed used in the cattle system, both dairy and beef, were calculated based on typical feed rations for a dairy cows, suckler cows, replacement heifers, bulls, steers in various ages, taking into account the actual age pattern for slaughter. This was multiplied with the average number of live cows 1 July 2018-2022 and for the other categories the number of animals slaughtered in average 2018-2022. Detailed statistics of the number of animals dying on farms or being refused at the slaughter house was used to include the feed consumed by these animals. The calculated amounts of feed are also compared to the overall availability of feed as determined by Rundgren (2021) as well as the statistics from Foder och Spannmål (2023).

Other factors considered in the calculation were:

Storage losses ley silage	9%
Feeding losses roughage	5%
Annual replacement dairy cows	35%
Annual replacement suckler cows	20%
Age at first calf	27 month
Calving interval	12 month

6% of the cattle die of other reasons than slaughter the first year. Of those 2/3 die in the first ten weeks. 1.5% die in the second year and less than 1% the following years. The mortality is considerably higher for calves born in dairy farms than in mother cow farms and higher for male calves than for female calves (SBA 2022a). To cater for mortality, 13% more heifer calves are calculated as replacement than the final number of replacement heifers which are the same as the number of dairy cows dying every year. This doesn't take into consideration the gradual reduction in number of dairy cows. In the end, with the allocation method chosen, where the feed for the recruitment is allocated to meat, the share of heifers for recruitment compared with those raised for meat doesn't affect the results much.

4.3 Cattle rations and feed use

Feed rations [S11], including feed waste, but not storage waste, were developed based on Cederberg and Henrikson (2020), Henriksson, Cederberg and Swensson (2014), Länsstyrelsen Västra Götaland (2021) and Einarsson et al (2022). Dairy bulls are calculated to live in average 21 month and "beef bulls" 19 month (SBA 2022a). Note that the feed rations are composed of rather large categories of feed. In a following step a differentiation of the feed was made, largely based on Einarsson et al (2022). In that step, pulses were added and a corresponding quantity of protein feed and grain was reduced, and various grains and protein feed were separated. As the pig rations were very detailed and the poultry rations were rather detailed, the details in feed use for cattle is based on that total use of known protein feeds and by-products should match. Within the cattle category, by-products and pulses were allocated to dairy cows, even if there could be some such use for beef cattle (table 2).

Table 2 Feed use in dry matter for milk and beef in Sweden

	Milk	Share	Meat	Share
Roughage	1,370,857	59.8%	2,371,406	81.7%
Wheat	82,015	3.6%	109,094	3.8%
Barley	160,612	7.0%	195,459	6.7%
Oats	34,173	1.5%	22,728	0.8%
Triticale	58,094	2.5%	77,275	2.7%
Other	6,835	0.3%	50,001	1.7%
Peas	30,600	1.3%		0.0%
Beans	30000	1.3%		0.0%
By-products	191,000	8.3%		0.0%
Soy beans whole	16000	0.7%	2300	0.1%
Soy bean meal	40,000	1.7%	3,000	0.1%
Beet pulp and other	80,000	3.5%	5,000	0.2%
Other protein feeds	190,869	8.3%	65,252	2.2%
	2,291,054	100.0%	2,901,515	100.0%

Comparison with other research

Einarsson et al 2022 come to a very similar conclusion regarding the total feed use for the cattle sector, which is understandable as mostly the same sources have been used.

4.4 Production of cattle meat and milk

The production of cattle meat is derived from the slaughtering statistics. 142,000 ton of carcass weight were produced in average 2018-2022 [S14]. There are rather small variations over the years and as many cattle live several years it is not apparent how to exactly compare one year's use of feed with one year's volume of slaughtered meat. But as variations in both number of animals and the number of slaughtered animals is small, this doesn't affect the results much.

In average, 2,757,000 ton of milk was delivered annually to Swedish dairies 2018-2022. That corresponds to 2,878,000 tons of fat and protein corrected milk (FPCM) which is the international standard for milk and the unit used in this study.[3] Approximately 5.5% was left on farms for household consumption, direct sales, calves and waste. Based on industry data and assessments, 3% is assumed to be used for calves and 2.0% for own consumption, direct sale, artisanal cheese-making or delivery to micro-diaries (they don't report to SBA) and 0.5% being waste, as a result of medication or contamination [S16].

4.4.1 Defining edible meat for cattle

Live weight, carcass weight, boneless meat and edible meat

The normally applied relationship of a carcass weight of 50% of live weight seems to be a somewhat too low value. A review of Blomberg (2022) with data from Sweden and countries with similar conditions

[3] In Sweden, Energy Corrected Milk is also frequently used. In ECM the quantity is 2,874,000 ton.

reports carcass weights between 45% and 62% of live weight. The calculations in this study have the carcass weight as the basis. The review of Blomberg (2022) reports values between 59% and 80% meat share of the carcass for cattle. Noe et al (2017), Wennerberg (1953), Clune et al (2017), USDA ERS (2023) and Fjelkner-Modig (1983) report values between 67% and 73 % boneless meat. Notably they don't include the fat in the meat. This is estimated to be between 12% and 14% according to Noe et al and Wennerberg, respectively. Conroy et al (2010) established a mean value of 19% bones of the carcass weight for cattle, this corresponds quite well with Fjelkner-Modig and is used here. Boneless meat is thus 81% of the CW. Adding those parts which are readily eaten, 82% of CW is edible meat. Adding the potentially edible fractions, 103% of the carcass weight is edible (96% if tallow is excluded), table 3.

Table 3 Boneless meat, edible meat, potentially edible meat and by products, cattle

	Edible meat	Potentially edible
"Boneless meat" share of carcass weight	81%	81%
Boneless meat weight (kg)	110,854,940	110,854,940
Food by-products (kg)	5,847,520	35,771,436
Total "edible meat"/potentially edible meat	116,702,460	146,626,376
"Edible" meat as share of carcass weight	82%	103%
By products value of total value	2.9%	2.6%

As edible has been counted: butcher's steak, cheek, sweetbread (only calves), oxtail 40% meat, skirt steak, tongue, other skull meat, liver and heart. Potentially edible are: tallow, penis, kidney, blood, throat, lungs, leaf and reed tripe, legs 40% meat, rumen and honeycomb, spleen, testicles and udder. Casings, cow feet, hide, uterus and bones have been considered not edible by-products [S14].

Some of the products in the edible meat category are for various reasons not sold as food in Sweden, in particular when handled in small slaughterhouses. But equally a considerable share of the products in the second category is actually eaten (tallow, kidneys, legs) either in Sweden or abroad. A study from 2012 estimates that more than 50% of the liver and tongue are sold in Sweden while more than 90% of the hearts and kidneys are exported (Alsterberg 2012). Notably, all casings have been classified in the category of products that are not eaten, despite the fact that some proportion is used for sausage manufacturing. Trade statistics reveal that more than 6,000 tons of unspecified beef meat is exported annually for an average price of SEK1.2 per kg and almost 8,000 tons of cattle organs for an average price of SEK6.9 (SBA 2022b). The latter is probably sold for human consumption.

After defining the edible meat, there is still the question of allocation of feed to other by-products. Their value has been estimated to be 2.6% and 2.9% respectively (higher for the edible meat scenario as more products are classified as by-products) of the total value of all products after slaughter and cutting and it seems reasonable to use economic allocation in this stage.

Comparison with other research

Strid et al (2022) come to similar conclusions as this study; they calculate that actual food use corresponds to 92% of the CW and that potentially 101% of the CW could be used for food. The main difference is the use of tallow.

Under French conditions the following distribution (table 4) of uses *based on empty body weight* is calculated by Le Feon et al (2020) for average beef reared in stall. Their conclusion is thus that most of the weight is human food. Notably, in their calculation no extramuscular fat goes to food.

Table 4 partitioning of beef as percent of empty body weight under French conditions

Use	Mass partition	Economic partition
Pet Food	5.3%	0.4%
Processed Animal Protein	6.2%	0.9%
Gelatine	9.6%	0.0%
Skin tannery	7.6%	12.6%
Human food	55.2%	84.6%
Fat and greaves	16.1%	1.5%
	100.0%	100.0%
After Le Féon et al 2020		

Also from France, Laisse et al (2018) estimate that between 57 (for dairy cow) and 62 percent (for young animals) of the live weight is suitable as human food which is more or less the same results as ours. They also conclude that 59-66 percent of the protein is in the human food fraction. Similarly, as in this research, there is a considerable gap between what is potentially edible and what is currently mostly sold as food products. Approximately 50% of the live weight (87% of CW) is actually sold as food according to them, somewhat higher than this research (82% of CW).

4.5 Allocation and by-products for cheese

The allocation process of feed to cheese goes through two steps. First, there needs to be a calculation of the partitioning between meat, calf and milk, and secondly there needs to be an allocation of feed between cheese and whey. If the cheese is not full fat (most cheeses are not) there will also be an partitioning between cheese and cream (which may or may not become butter).

Allocation between milk and meat

During her relatively short life a dairy cow produce some 27 ton of milk as well as 2.6 calves and when she is slaughtered her carcass weight is around 314 kg. She thus produce both milk and meat (some of the "meat" is in the form of a live calf). 3.5% of the dairy cows die on farm or during transport and thus don't produce any meat (SBA 2022c). With a recruitment rate of 35%, the feed needed to raise the heifers to an age of 27 month represents 19.6% of the total feed requirement of dairy cows and recruitment. The average carcass weight at slaughter of heifers born 2017 in dairy farms was 299 kg (SBA 2022a). This means that there is little growth in carcass weight from heifer to cow [S16].

It can, therefore, be argued that the feed consumed by a living dairy cow is used to produce milk and a calf and thus *no allocation* is needed following the first option of the ISO standard. One weak point in this approach is that the rather high mortality of the replacement animals will not be considered as part of the milk production system, but will booked on meat production.

A biophysical allocation is based on the feed used to produce milk and live animals (or meat) respectively. There is a formula developed by the International Dairy Federation to calculate this that also takes into account the feed use efficiency is higher for milk than for bodily growth of the animal. This often leads to an allocation to milk of around 88% (IDF 2015). When the IDF formula is used, the allocation to FPCM milk in Sweden according to the collected information is 86.8%. The IDF formula makes no allocation for the calf as such, but the calves used for recruitment are included in "milk" and the others are included in the live weigh (meat).

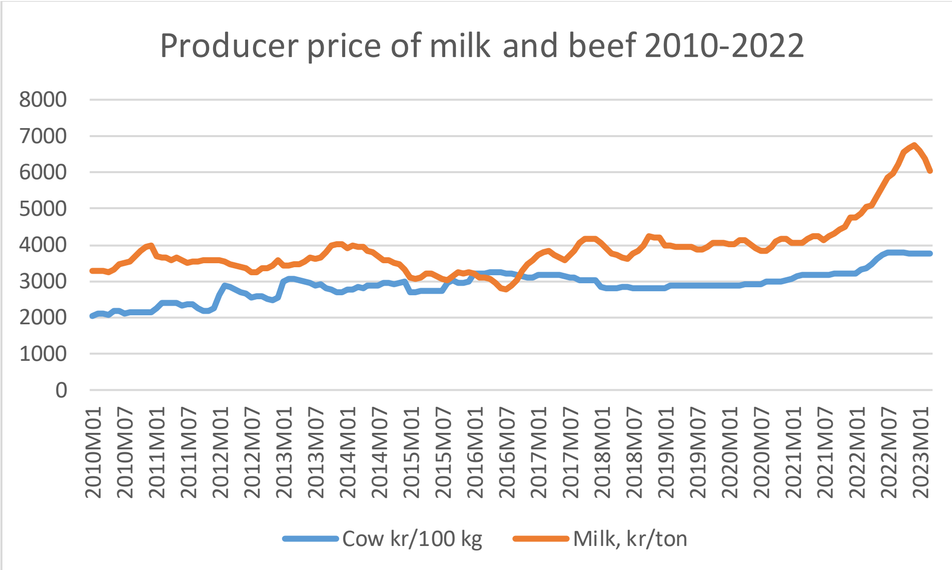
One can also apply another biophysical approach where the feed needed to raise replacement heifers is counted as feed for meat production. With this biophysical approach the feed allocation to milk will be the same regardless how rapid cows are replaced by new heifers and the feed needed to produce a certain quantity of meat from heifers is not linked to the productivity of the milk cow. In essence, this is more or less the same as the "no allocation" option. Compared to the IDF formula, it has the advantage that it allocates the *various feeds* to milk or meat according to their use. E.g. the heifers use 19% of the total feed, but only 3% of the protein feeds and 50% of the grazing. By using the biophysical allocation the differences in feeding regimes between heifers and dairy cows can be upheld throughout the system, which is not possible with other methods.

Notably, the biophysical allocation as well as the IDF option still "favours" meat from dairy compared to meat from suckler herds as the feed for the mother cow is allocated to the milk. By basing the allocation on the meat from the culled cows instead of the meat from the heifers this favour is slightly reduced as the weight gain between heifer and cow (some 15kg CW) is covered by the milk production. On the other hand, considered as meat production, the feeding of heifers to 27 months age is sub-optimal from a feed use efficiency perspective[4], i.e. when heifers are fed for the purpose of slaughter they will, normally, be slaughtered earlier.

Finally, one can use economic allocation based on market prices of milk and meat respectively. The result is, however, not consistent with the actual feed used for growth and would, often, result in that meat from dairy cows would use even much less feed than with the other methods. It would also fluctuate with FPCM yield and replacement rates as well as relative market prices of FPCM and beef which can fluctuate wildly (figure 2). A biophysical approach is therefore preferred here. Considering the fact that meat production is already "favoured" in both the IDF model and in the authors calculation because the mother cows are fully allocated to milk, it seems more reasonable to use the author's calculation based on that all the feed needed to the recruitment is allocated to meat.

[4] Note that the discussion here is only about feed use, there are other reasons to let heifers become older such as improved meat quality or opportunities to use natural grazing.

Figure 2 Producer price beef and milk 2010-2023



Milk used as feed

Approximately 3% of the milk produced is used on farms as feed for calves. In the calculations, all of this has been allocated to the recruitment heifers and are therefore included in the meat for the biophysical allocation chosen. In the IDF allocation there is no special provision for this as the end use of the milk is not relevant in the formula. For economic allocation, the value of the milk as feed should be used. It was estimated to 50% of the wholesale value by the author. One could argue that the milk used as feed should be included in the milk produced and subsequently reduce the DM of feed used per kg FPCM. But a considerable share of the milk used for calves is probably milk which could not be delivered to the dairy because it comes from cows that are sick or where the milk has quality issues, i.e. the milk would have no alternative use.[5]

Allocation to the calf

The extra feed used to produce a live calf by a dairy cow is calculated to be 1.5% of the total feed intake based on Swedish feed recommendations (Johansson 2020) for the last three months of gestation or 2% using the calculations by Hietala et al (2015), see more below. An economic allocation based on the average price for live calves leads to a 2.9% allocation of feed to the calf. It seems reasonable to stay with the biophysical approach also for the calf using the 2% value from Hietala.

[5] One could, of course, also argue that the milk content of the milk powder used for calves should be deducted from the milk quantity being available for dairy products, or that milk unfit for human consumption used for calves should not be counted as feed at al as it has no alternative use and no costs.

Table 5 Comparing different allocation methods for milk - meat

	milk for consumption	calves	feed milk	growth (meat)
IDF	84.2%		2.62%	13%
Biophysical	78.9%	2.0%		19.1%
Economic	86.2%	2.9%	1.4%	9.5%

Comparison with other research

A review of allocation methods used in 232 life cycle assessment of milk and beef concludes that biophysical allocation and economic allocation is most common regarding the allocation *between milk and meat* when applied to dairy systems. Many studies used own, combined or no methods for allocation (Kyttä et al 2021).

Most LCAs made in Sweden have used economic allocation – which is a major reason for why meat from the dairy system has been considered much more efficient than the meat from suckler cows. With the biophysical approach, the difference between the meat from the dairy sector and from the beef sector is smaller, but still exist.

A recent life cycle assessment of Finnish beef use a slightly different approach to establish a physical basis for allocation. The total *enthalpy* (a kind of energy measure) and the corresponding feed use of the cows' life cycle was divided into enthalpy of the lactation, gestation and growth, distributing the enthalpy for maintenance according to the relative share of the activities. This led to an allocation of 75% to the milk, 2% to the calf and 23% to growth (meat) (Hietala et al 2021).

4.6 Results beef

The feed use for 1 kg of edible meat from cattle is 24.6 kg DM and for 1 kg of potentially edible meat 19.5 (table 6).

Table 6 Feed, in kg dry matter, used to produce 1 kg meat

	DM feed per kg	**Allocation to by-products**	**Net DM per kg**
Kg DM per kg CW	20.65	1.00	19.65
Kg DM per kg edible meat	25.18	0.59	24.59
Kg DM per kg potentially edible meat	20.04	0.51	19.53

The feed is dominated by roughage (82%) with grains constituting most of the remainder (14%), see table 2).

4.6.1 Comparisons with other studies or research

This report is to our knowledge the first to combine detailed feed data with detailed data of (de)composition of animals and showing the impact of different allocation choices. As noted earlier, Einarsson et al (2022) comes to similar conclusions regarding the feed use in the cattle sector, even if they distribute the feed used differently between milk and meat. All the LCAs made for environmental impacts of milk or beef production will have underlying calculations of the feed used, but it is not always easily derived from the published papers or even from supplementary materials. In the report from Ahlgren et al (2022) the feed use per CW is less than 10 kg DM for bulls from dairy cows and in the range of 11-12 kg for most other beef. The main difference is that their calculations is based on models for rather good conditions and optimal age of slaughter and good slaughter yields (see also for sheep). In addition, they have allocated the recruitment heifers fully to milk production.

4.7 Calculation of feed use for milk and cheese production

In order to calculate feed use for cheese production one has to first establish the feed use per kg FPCM. Based on the cattle rations as explained above and statistics for milk production the use of feed DM per kg FPCM (excluding waste but including feed milk) was 0.765, based on biophysical allocation as discussed above (table 7, [S16]).

Table 7 Feed use for milk production

Feed (DM)	DM per kg milk	
Grain	0.113	14.7%
Ley	0.411	53.7%
Pulses	0.020	2.6%
Byproducts	0.062	8.1%
Grazing	0.042	5.4%
Protein concentrates	0.108	14.1%
Mineral feed	0.011	1.4%
Milk / milk powder	0.000	0.0%
Total	**0.765**	

4.7.1 Cheese-making from milk and allocation between cheese, cream and whey.

A 26% hard cheese was selected as the main representation of cheese as it corresponds to the popular brand *Hushållsost*, a hard cheese with 26% fat.

The International Dairy Federation recommends using allocation of the raw milk used for various products to be based on milk solids (dry matter), i.e. each product is allocated milk (and in this case the feed used for producing the milk) corresponding to its relative share of the dry matter derived from the milk (IDF 2015). In the case of a full fat (>35%) cheese there are two products, cheese and whey, which in turn can be transformed to whey powder. For cheese with a lower fat content, such as the main representative of the cheese category a 26% fat cheese, there is also cream taken from the milk before cheese-making. The cream can in turn be processed into butter and butter milk.

From 9.37 kg of FPCM, 1 kg of *Hushållsost* cheese, 0.33 kg of cream and 0.55 kg of whey powder is produced (table 8). On a dry matter basis the cheese represent 46% of the weight, the cream 12% and the whey 42%. There is more feed needed to produce one kg of fat than one kg of protein or carbohydrates and fat has almost the double energy value compared to the other macroelements of milk. A biophysical allocation would therefore lead to a higher share for the cream (the exact proportion has not been calculated).

Table 8 Production of cheese and by-products

	kg	Total DM content	Fat g	Protein g	% of milk DM
Qtty of milk needed	9.37	1241	392	325.1	
Qtty of cheese produced	1.00	566	260	246.0	45.6%
Total cream produced	0.33	150	132	6.9	12.1%
Whey		524	0	72	42.3%
Whey powder (95% DM)	0.55				

In Scandinavia, a brown whey cheese, *mesost* or whey spread, *messmör*, is popular, in Italy *riccotta* is also made from whey. However, most whey in commercial dairies in Sweden will be used either as animal feed or made into a whey powder that is used in food products and whey protein products (Rundgren 2021). The value of whey turned into whey cheese is almost the same as the value of cheese while the value of whey as animal feed is low. The value of food grade whey powder is in between. An economic allocation between cream, cheese and whey in the form of whey powder, based on a five year European average market wholesale price (Agriculture and Horticulture Development Board 2023b), results in an allocation of 76% to the cheese, 11% to the whey and 13% to the cream. Economic allocation has the disadvantage to be very dependent on market factors and would also lead to that a premium cheese would use much more feed than a "bulk" cheese or that a longer storage (and thus a higher price) would lead to lower feed use. In the end, it seems reasonable to apply the mass allocation suggested by the IDF [S17].

Comparison with other research

In the LCA for a similar 26% cheese Berlin (2002) used an allocation factor of 67.8% for the cheese, but that was an allocation of climate impact for a whole dairy factory (and therefore not only feed use) and is thus not comparable. Moberg et al (2019), also for climate impact, use an economic allocation of 94% to the cheese and 6% to whey, not considering any cream production, i.e. a cheese with a fat content >32%. On the other hand, they also use the allocation factor of 50% for cream and skimmed milk, respectively, which is a considerably higher allocation to cream than in this study. In an LCA of dairy production, Flysjö et al (2014) raw milk is allocated between product groups based on the fat and protein content of the products, where protein is valued at 1.4 times that of fat. Using that formula here would allocate 81% to cheese, 13% to cream and 6% to the whey.

The internal monitoring of farms in Denmark, Germany, Great Britain and Sweden, supplying Arla, reports that 1 kg of DM is used to produce 1 kg FPCM, including the recruitment heifers (Arla Foods 2023). This corresponds fairly well to the calculations here with a result of 0.97 kg DM per kg FPCM. Henriksson et al (2013) has values for the feed use per kg of milk, including recruitment, of 0.90 – 0.92 kg DM.

4.7.2 Losses

During storage cheese lose some weight, but the calculation of the milk used is for the cheese as ready to sell and water evaporation is thus already included. There are some other losses in cutting, but they are small and most of the “loss” can be sold to the food industry and thus used as food (Klingberg 2023). Therefore, no provision is made for losses in the calculation.

4.7.3 Results cheese

With the main option of biophysical allocation between meat and milk and mass allocation between cheese and by-products, the quantity feed use per kg of 26% Hushållsost is 3.27 kg DM. The difference between allocation methods are shown below. Using economic allocation all through would lead to a 81% higher feed use (table 9).

Table 9 Feed, in kg dry matter, used to produce 1 kg 26% cheese

	Economic allocation meat-milk	Biophysical allocation meat-milk
Based on economic allocation in dairy	5.93	5.45
Based on dry matter allocation in dairy	3.56	3.27

Based on the relative content of dry matter in different kinds of cheeses the feed use per kg, *based on a biophysical allocation*, can be higher or lower than the value calculated for a 26% fat cheese. A few examples are shown in table 10.

Table 10 Use of feed per kg cheese for some different cheeses depending on dry matter content

Cheese hard 10% fat	-14%
Cheese camembert 23% fat	-16%
Cheese hard 26% fat	+0%
Cheese hard 38% fat	+11%

4.8 Variations

In general, the variation between farms can be very big which can be seen in the statistics for age and weight at slaughter. This study doesn’t include any comparison of the use of feed between conventional and organic cattle. There is, however, no big difference in feed use between organic and not-organic suckler herd, dairy cows or heifers (Einarsson et al 2022). The main difference is in the feeding of male animals for slaughter, where the share of grain and concentrates are higher in conventional than in organic production and grazing is more prominent in organic production.

4.9 Ecosystem services

For both beef and cheese (note that this discussion is also relevant for sheep) one could consider also allocating some of the feed to the provisions of other services than the provision of meat or cheese and their by-products. A study by Geyertz et al (2023) concluded that <1–48% (for beef) and 11–31% (for milk) of climate impacts could be allocated to ecosystem services such as maintaining semi-natural grasslands (SWE:*naturbetesmarker*), preserving certain animal breeds etc. Below we discuss three such services which, in different ways, can be quantified: the grazing of semi-natural grasslands, carbon sequestration in grasslands and ley farming, and the value of the forage crops in crop rotations. *The discussion below serves primarily to give a better understanding of how one can approach these issues, the figures and calculations are estimates based on rather simple calculations.*

4.9.1 Grazing services

The grazing of seminatural grassland is an important eco system service. At present, farmers get support through various eco schemes to graze such lands as part of the EU Common Agriculture Policy (CAP). This is primarily done by farms with suckler cows or steers, but it can also be practiced by dairy farms especially with dry cows and heifers. In addition to the CAP payments there can be payments from municipalities, regions, charities and even private landowners. One way to allocate feed to this could be based on the relative income from the grazing as part of the total income (this is the case in the article of Geyertz et al (2023)). A suckler cow produce a half year old calf annually for a value of approximately SEK7,000 (Länstyrelsen Västra Götaland 2021). Meanwhile it will consume grass from, in average, more than 1.5 hectare of grazing on semi-natural grasslands (Hessle and Danielsson 2023). The environmental payment for those grasslands amounts to SEK3,950 per hectare in 2023 (SBA 2023b). In such a case, 45% of the total income would be attributable to the grazing of semi-natural grasslands.

Another approach to allocate feed to the grazing service is to take the total sum paid to farmers for grazing, distribute it between cattle, horse and sheep and then compare it to the total value of the slaughtered animals. That would give a value to be distributed to the whole sector and not only to the animals that are actually grazing. Which method is preferred depends on what the purpose is. Within the scope of this report, meat production from four different species, it is the average that is of interest. A back-of-the envelope calculation (table 11), using the slaughter value of beef and sheep only, excluding horses and dairy cows shows that payment for grazing represent approximately one fifth of the income from beef and sheep meat.

Table 11 Value of grazing service compared to meat

Income of slaughtered beef	5,956,824,000	SEK
Income of slaughtered sheep	13,962,540	SEK
Sum meat income	5,970,786,540	SEK
Payment per hectare for grazing semi-natural grasslands	3,950	SEK
Area	400,000	hectares
Sum income from grazing	1,580,000,000	SEK
Total income	7,550,786,540	SEK
Share of income for grazing	21%	

An alternative would be to qualify how high proportion of the feed used that comes from grazing, that would essentially be a biophysical allocation. For all cattle, the share of feed from grazing is around 18%, of which less than half is from seminatural grasslands (Rundgren 2021). Most of the grazing is done by the suckler cow system, where grazing contributes more than half of the total feed intake. Allocating all feed from grazing semi-natural grasslands to environmental service would then reduce feed use for the calves born by suckler cows with more than 50%. The advantage of a biophysical allocation is that it is not dependent on political and market changes. This allocation could thus be applicable even if there weren't any support schemes for grazing.

There are also environmental values (biodiversity, nutrient cycling) from grazing in croplands. There are, however, no environmental support schemes for that. On the one hand, this demonstrates the limitation of using economic allocation for environmental services. On the other hand, whether there is economic value or not in an environmental service is of huge relevance for the actual choices of the farmers.

4.9.2 Carbon sequestration and other values of ley production

The growing of ley contributes to carbon sequestration in soils and is considered the main reason for why carbon content of Swedish soils have increased substantially over the last 20 years corresponding to around an average of 250 kg C[6] per hectare and year (Poeplau et al 2015). A modelling study by Hammar et al (2022) estimated carbon sequestration rates 200 kg of C per hectare and year for beef production. Based on soil monitoring data, Henryson et al (2022) observed that soil organic carbon concentration was correlated with proportion of ley at farm scale. For dairy farms, this corresponded to 1.4 Mg CO_2 per hectare, or approximately 0.22 kg CO_2 per kg FPCM. The EU plans to introduce carbon payment for agriculture. The price for CO_2 emissions in the EU trading system was in average €86 per ton in the period June 2022 to May 2023 and the long term trend is increasing (tradingeconomics.com 2023). Carbon payments could then represent around 5% of the income of a dairy farm and thus reduce the feed use accordingly, would economic allocation of feed be used. With the calculated total roughage diet of a suckler cow of in total 3.8 tons DM per year, the corresponding carbon sequestration from ley and grazing lands could amount to at least 1.5 ton of CO_2 per cow which means that carbon payments could be around 15 % of the total income per cow (Länsstyrelsen Västra Götaland 2021).

A biophysical approach could be to allocate feed use and carbon sequestration according to their respective energy or carbon content. E.g. Rundgren (2021) estimated that the carbon removed from ley grasslands with the harvest is in the range of 2700 kg per hectare. This can be compared with the estimated carbon sequestration of 600 kg C per hectare and year (Hammar et al 2022).

In addition to carbon sequestration, leys also contributes to a better soil structure and makes nutrients available for other crops. The yield of wheat will regularly be considerably higher (400-800 kg per hectare) if the wheat follows after ley than if it follows another grain (Länstyrelsen Västra Götaland 2021, Nilsson et al 2023). This represents a 10% increase in yield and certainly a much higher increase in net income as there are no or low costs associated with the extra yield. This value is, however, not captured if ley is grown continuously, which is the case in some cattle and sheep farms.

By and large, there are reasonable arguments to allocate some feed for ruminants (also including sheep) for the maintenance of environmental services. On the other hand, it seems as if the LCA methodology is less well suited to capture the complexities of ecosystem services. When the choice of allocation method

[6] In order to convert 1 kg C to 1 kg CO_2, multiply with 3.67.

and the market and political conditions have a huge impact on the results, it is probably the method that should be questioned.

5 Sheep and lamb

Sheep-breeding is a small sector in Sweden with half a million animals and a total production of around 5,000 tons of meat. Around 80% of the meat comes from lamb. The market share of Swedish sheep and lamb has been around 30% the last five years (LRF statistikplattform 2023). The number of sheep farms is around 8,700. The average farm had 34 adult animals 2016 and the average number of lamb were also 34. A majority of the sheep owners have sheep to maintain the landscape and because they like them and not primarily for economic or productive reasons; 17% of the farms have no lambs as they don't keep the sheep for meat production at al. Most of these producers have less than 25 sheep (Carlson and Segerkvist 2018). According to the statistics of the Board of Agriculture (2023d) more than 10% of all sheep are on units which are smaller than 2 hectare of arable land or has less than 20 sheep. They have also just 5% of sheep less than 1 year in December in average, meaning that they have a very low recruitment rate and thus lamb production.

5.1 Method and calculation

For lamb and sheep the data of feed use on national level is considered too weak to make meaningful calculations top down. Also in the production, despite the low total number of sheep the system of raising, the breeds and general orientation (meat, skin or wool) and time of slaughter varies a lot. In addition, home slaughter is common which makes it difficult to ascertain the total quantity of meat produced. The estimate used here is 9%.

As discussed above, there is a considerable share of the sheep that are kept for landscape management and as pets. Therefore 10% of the sheep has been taken out of the calculations (called "hobby sheep" below). Assuming that most of those die of age or illness it is also assumed that they don't produce any meat for human consumption at all. For the remaining sheep a recruitment rate of 20% is estimated. Based on uncertain industry estimates 75% is counted as giving birth at 12 months and 25% at 24 month age (Strömne 2023).

5.1.1 Feed rations

As a starting point for calculations, the feed rations used by Ahlgren et al (2022) were used, albeit somewhat modified and corrected (Carlsson 2023). According to the official statistics of the SBA the share of lamb slaughtered in the months August to November was 48 %. In addition, more than half of all sheep in Sweden are located in the two production areas *Götalands mellanbygder* och *Götalands skogsbygder* (SBA statistic database 2023f). Therefore the feed rations used for autumn lamb in *Götalands skogsbygder* was selected to represent sheep production in general. The model data was complemented with estimates of the feed for ram and recruitment ewes as well as data for feed waste and rejects.

The model data assumed that 1.67 lambs are produced per ewe, while the public statistics show that 1.16 sheep (lamb, sheep and rams) per ewe is slaughtered (deducting the 10% which are not producing. With a 3% mortality of ewes that corresponds to 1.19 lamb per sheep. According to a survey by the Board of agriculture the average age at slaughter for lamb was 7 months which is considerably older than the theoretical optimal slaughter age (Carlsson and Segerkvist 2018) and one month older than in the model. Therefore, an alternative model was developed based on the same rations as in Ahlgren et al

(2022) but with a production of 1.19 lamb per ewe and a 10% higher consumption of roughage to lamb to cater for a slower growth [S10].

Table 12 Feed use for autumn lamb

	Per sheep	Per lamb	Ram	Recruitment	All
Permanent pasture DM	359.4	49.4	18.2	89.8	526.3
Pasture on arable land DM	51.9	102.9	0.0	13.0	187.4
Compound feed	21.8	26.3	1.5	5.5	60.1
Silage DM	241.4	1.0	18.2	60.4	321.1
Mineral feed	5.2	2.1	0.4	1.3	9.3
sum	**679.7**	**179.5**	**37.9**	**169.9**	**1104.2**

The total feed thus calculated was divided with the total quantity of meat produced according to public statistics.

5.1.2 Production of sheep and lamb meat

According to the public statistics the average production of lamb meat was 4,320 ton and other sheep meat was 1,110 ton carcass weight. This includes an estimated 9% home slaughter.

5.1.3 Defining edible meat

The relationship between carcass weight, edible meats and potentially edible meat was calculated in a similar way as for cattle, see table 13. Data for lamb was used for all sheep meat, for lack of other sources. It should be noted that because of the small quantity of sheep and lamb slaughtered, the low consumption of lambs meat and the small size of certain edible cuts (e.g. a lambs tongue weigh around 100 g), it is uncertain to what extent the edible meat and potentially edible meat fractions are actually taken care of. Sheep and lamb is popular foods among many immigrants and therefore the use of those meats in Sweden can be expected to increase, however.

Table 13 Edible meat as part of carcass weight and live weight of lamb

	kg	Accumulated kg	Share of CW	Share of LW
Live weight	45.2			
Carcass weight	19.0			
Boneless meat from carcass	15.7		83.0%	34.9%
Edible meats, not part of carcass	1.00	16.75	88.3%	37.1%
Potentially edible meats, not part of carcass	2.5	19.26	101.5%	42.6%

The economic value of the by-products at slaughter (not including pelt, see below) is estimated to 0.05% of the value of the meat in the scenario for potentially edible meat and 0.43% for edible meat.

Comparison with other research

Leon et al (2020) developed the following scheme (table 16) for partition of the live weight of sheep and lamb in France. Their share of edible food is slightly higher than in this research.

Table 14 Partitioning of sheep and lamb, France

Use	Biophysical Partition	Mass Partition	Economic Partition
Pet Food	3%	1%	<1%
Processed Animal Proteins (blood, bones etc.)	22%	28%	0%
Skin tannery	23%	18%	5%
Human food	52%	52%	95%

Edman et al (2023) calculates with a lower share of boneless meat of the live weight, 33.5% compared to our 37.1%. They calculate with a higher share of edible meats, 4% as opposed to 2.3% in our study. They also calculate with a higher carcass weight share of live weight, 44% compared to our 42%.

5.1.4 By-products and allocation

It could be possible to use biophysical allocation for sheep. The guidelines from FAO (2016) recommend this and show an example with wool from New Zealand where 37% of the feed is allocated to wool. Presumably it would be quite similar for lamb pelt. Considering that wool for most producers is a waste without value[7] it would be difficult to do this under Swedish condition. In addition we don't have access to relevant data for a biophysical partitioning relevant for Swedish sheep production. Therefore, an economic allocation is chosen here.

For sheep and lamb the value of by-products varies a lot depending on breed and time of slaughter. Notably, some races have more valuable wool and others have more valuable pelt, while some has neither (but mostly produce more meat). The Gotland sheep has valuable pelt and is the most popular sheep in Sweden (Elitlamm 2023). Wool currently has low value and has been assigned a rather low lump sum of SEK10. The partitioning of feed has been made according to estimated economic value. The total allocation to meat is 82.2% (table 15).

Table 15 Income per sheep

Per sheep per year	Kg	Price/kg	Income	Share of income
Sheep	5.66	17.36	98.30	5.7%
Ram	0.13	17.36	2.29	0.1%
Lamb	22.60	58.24	1316.50	76.3%
wool			10.00	0.6%
Hide		297.89	297.89	17.3%
Total per sheep	**28.40**		**1724.97**	**100.0%**

[7] There have been several projects over the years to develop the market for Swedish wool, but it is still under-developed.

5.1.5 Comparison of calculated feed rations with feed availability and use data.

The total quantity of feed for sheep and lamb is too small to make a comparison with the feed availability, even more so as most of the feed is pasture and silage for which the statistics are not very reliable. The calculated compound feed match, however, quite well with the data from the feed industry.

According to Einarsson et al 2022, the total quantity of feed used by sheep would amount to 278 812 ton compared to this research total of 263,969 ton for the producing sheep and 12,790 ton for "hobby sheep". This is in turn based on Cederberg and Henriksson (2020) and the assumption that each ewe + lamb consume 890 kg DM annually. Their research is based on the year 2018 when the number of sheep was slightly higher, so their results are essentially the same (even though they don't make the calculation of feed per kg meat).

5.2 Results

With the economic allocation as elaborated above 41 kg of dry matter is used to produce 1 kg of edible sheep/lamb meat (table 17).

Table 16 Feed use for 1 kg of sheep/lamb meat

DM per CW	36.2
DM per edible meat	41.0
DM per potentially edible meat	35.7

Approximately 95% of the feed is grazing or roughage and 5% is grain and concentrates (primarily rape seed cake). Approximately half of the feed is pasture on either permanent pastures or croplands depending on the local conditions.

5.2.1 Variations

The feed use per kg meat is considerably lower for spring lamb production, i.e. lamb born in winter and slaughtered in spring (Ahlgren et al 2022, Länsstyrelsen Västra Götaland 2023). That production is based on much more concentrated feed and less grazing and heavier breeds are mostly used. However, as the ewes have no lamb in summer they can graze dry and poor lands, while autumn lamb require good grass for both ewe and lamb (Stömne 2023).

5.2.2 Comparisons with other research and discussion

Considering the huge variation in Swedish sheep production, with many very extensive operations and even many operations that don't produce any lambs at al one could consider to allocate some of the feed to landscape management (see section 4.9).

6 Pork

The pig production in Sweden is fairly specialized with approximately 1200 farms having some pigs (not counting household pigs) and the average pig farm had 942 pigs for slaughter, 715 piglets and/or 175 sows 2021. Organic pig production had a 2.7% share of the production 2020. The market share for Swedish pork was 82.7% year 2021. (SBA 2022e). 97% of all pork meat comes from the slaughter pigs, the rest mainly from sows (SBA statistic database 2023a). More than 2/3 of the pigs are located in Götaland (SBA statistic database 2023f).

The share of feed produced on farm is fairly high in Swedish pig production. A quarter of all feed is complete feed, 41% of the production is based on own feed + premix and 36% on own feed and concentrates. It is more common with complete feed in the sow (33%) and piglet (38%) production than for slaughter pigs (19%) (Landquist et al 2020).

6.1 Method and calculations

The main source of information has been the LCA by Landquist et al (2020) and an update by Landquist (2023). That LCA is based on actual practices collected from pig advisors working with almost half of all pig producers in Sweden and data from the management and monitoring program WinPig (PigVision) from 2017. The whole Swedish pig sector was the boundary for their calculations which includes all sows, piglets, farrows and swine for slaughter as well as the meat from all these animals. Some important data for the calculations were (table 17):

Table 17 Relevant data input for Swedish pig production

Replacement	55%
Mortality sows	2.0%
Mortality piglets after weaning	2.0%
Mortality slaughter pigs	1.8%
Weaning age (days)	33
Number of piglets per sow and year	24.7
Number of litters per year	2.24
Share of gilt litter	24.8%

Mortality for piglets before weaning which was estimated to 16.9 percent by Landquist et al (2022), is not considered as it doesn't affect the feed calculation, their feed is included in the sow's feed.

As Landquist et al (2020) did use the whole sector as the boundary and adjusted their results to the data from the feed industry and the slaughter statistics, the method is the same as recommended here. Therefore there has been few modifications to their overall feed calculations. The blanket feed loss of 0.5% is added to all feed ingredients that are not by-products. In addition a mortality rate of 0.27% as a result of the average of mass culling caused by contagious disease 2018-2022 was included [S12].

6.1.1 Live weight, carcass weight, boneless meat and edible meat

As 97% of all pork meat comes from slaughter pigs, the calculations are based on slaughter pigs and not sows. There might be some difference in carcass composition between pigs and sows, but as the share of meat from sows is so small it would make no big difference. In addition, almost no literature provides separate information on carcass composition for sows and slaughter pigs.

The carcass weight of pigs is in the range of 75 percent of the live weight. The bone share of the carcass according to various sources is between 9.6% and 15%. Here is used 12%. To calculate the share of edible meat and potentially edible meat the data from Strid et al (2022) was supplemented by industry data and other sources. The share of edible by-products is high for pork and the calculated quantity of potentially edible meat is even 8% higher than the carcass weight (table 18). The value of by-products are based on industry sources and as most of the pig can be realised as human food, by-products has a low value.

Table 18 Carcass weight, boneless meat, edible meat and by-products, pigs

	Edible meat	Potentially edible
"Boneless meat" share of carcass weight	88%	88%
Boneless meat weight (kg)	217,373,138	217,373,138
Food by-products (kg)	37,834,353	48,710,683
Total "edible meat"/potentially edible meat	255,207,491	266,083,821
"Edible" meat as share of carcass weight	103%	108%
By products value of total value	1.7%	0.1%

Sweden exported in average 15,000 ton pig meat details for an average export price of SEK25 and 20,000 ton organs with an average price of around SEK6 per kg, a clear indication that these products are used for food purposes (SBA 2022b).

Comparison with other research

The research by Strid et al (2022) reports that 105% of the CW is theoretically edible and that 94% is actually used as food. Also based on Strid et al 2022, Edman et al (2023) calculate that 84% of the CW is composed of food products. The difference doesn't derive from the by-products but from the percentage calculated for bone-free meat of the carcass with 68% instead of this study's value of 86%. The 86% is a calculation based on the actual bone contents, while the 68% appears to be based on the making of retail cuts. Most of the trimmings of a pig carcass can, however, be used for food.

Al-Zohairi et al (2022) found that 84% of the live weight is used as food, corresponding to 112% of the carcass weight. In their calculation bones are included in food, while some of the fat (rendering) is not included (table 19).

Table 19 Comparison between mass allocation and economic allocation for pigs in Denmark

	Weight	**value**
Live weight	100.0%	100.0%
A. Muscle meat	64.0%	83.5%
B. Food grade bones	11.4%	12.4%
C. Other food uses (liver, kidney, blood, fat etc.)	8.7%	3.1%

D. Feed for pets	4.3%	0.4%
E. Feed for fur	3.2%	0.4%
F. Rendering	7.2%	0.0%
G. Pharma	0.2%	0.1%
H. Biogas	1.0%	0.1%
Food use (A+B+C)	*84%*	*99%*
Other use (D+E+F+G+H)	*15.9%*	*1.0%*
After Al-Zohairi et al 2022		

Another research article by Al-Zohairi et al (2023) compares a Danish, German, Swedish and Polish slaughter house where 85.4%, 87.9%, 71.5% and 74.6% of the LW is products for human consumption. Laisse et al (2018) estimates that 83% of the live weight of pigs in France is edible. The basis for their calculation is almost identical to what is called "potentially edible" in this report. According to their research 80% of the live weight is actually sold as food, that is 106% of the CW. They also calculate that 87% of the protein and 93% of the feed energy is in the consumable part of the animal. The comparison with other research indicates that the quantification of edible meat and potentially edible meat seems realistic.

6.1.2 Feeding rations pork

The feeding rations for sows, piglets and slaughter pigs were gathered from Landquist et al (2020) and slightly modified and re-calculated to DM. The feed is dominated by grain and with a considerable share of by products, mostly from grain based industries (mills, ethanol, spirits, brewing) and dairy (table 20).

Table 20 The use of feed, in dry matter, in the Swedish pig sector

Grain	527,932	61.1%
Protein feed ex soy	62,328	7.2%
Soy	34,552	4.0%
Pulses	48,573	5.6%
By products	146,937	17.0%
Other	43,802	5.1%
Total (DM)	**864,124**	100.0%

6.2 Production of pork meat

The production of pork meat is derived from the slaughtering statistics. In average, 247,015 ton of carcass weight was produced in 2018-2022. There are very small variations over the years (just a few percent) so any mismatch in year between the data for feed use and production is of marginal importance [S15].

6.2.1 Variations

This study doesn't include any comparison of the use of feed between conventional pigs and organic. However, Zira at el (2021) compared organic rations with the same dataset used here (Landquist et al

2020) and concluded that the organic pigs for slaughter use 6% more feed and that the lactating sows used 25% more feed (the weaning age for organic pigs was 33% higher) and dry sows 5% more feed. This didn't include the consumption of forage which can be considerable, but hard to measure. In addition, the organic feed rations didn't include food industry by-products as they rarely are kept separate in organic quality.

6.2.2 Comparison of calculated feed rations with feed availability and use data.

The calculated feed use was compared with data from the feed industry, Einarsson et al (2022) and Rundgren (2021). The feed use is considerably higher than when using the feed industries calculation and adding grain. This is most likely the result of that a considerable quantity of by-products are supplied directly from industries and possibly that many pig farmers also use own protein feeds, such as peas and rape seed. There is good agreement with the research of Einarsson et al (2022) and Rundgren (2021), which is logical as they both use the same main source.

6.3 Results

The feed use for 1 kg of edible meat from pigs is 3.21 kg DM and for 1 kg of potentially edible meat 3.13 (table 21).

Table 21 Feed use for pigs

	DM feed per kg	Allocation to by-products	Net DM per kg
Kg DM per kg CW	3.37	0.13	3.25
Kg DM per kg edible meat	3.27	0.05	3.21
Kg DM per kg potentially edible meat	3.13	0.00	3.13

6.3.1 Comparison with other research

Moberg et al (2019) calculates with 4.2kg feed (use weight) per kg CW which is approximately a 6% higher feed use than this study. As their figures are based on an lca using data from 2005 such a difference seems reasonable. Dorca-Preda et al (2021) concludes that 2.69 kg of feed (actual weight) was used per kg live weight in Danish pork production 2016. The exact composition of the feed is not investigated by the author and thus not the exact DM weight. But it is probably around 2.3 kg DM per kg LW, which in turn corresponds to or 3.1 DM per kg CW, i.e. 10% less than in this research. Danish pig producers use a higher share of protein feed and less by-products and they produce 30 slaughtered pig per sow compared to the Swedish average of 24.7, which can explain the difference (Landquist et al 2020).

7 Chicken meat

Note: In English the term broiler is often used for chicken raised for meat, here the word chicken is used.

7.1 The chicken meat system

With the exception of a very small production of land race chicken or backyard chicken production, chicken production in Sweden is highly standardized and large-scale. Feed is normally purchased from the feed industry. Legislation requires that feed for poultry has been heat treated to at least 75°C (this is to reduce risk of salmonella), even if it is permitted to mix own grain (not other feed) with bought-in feed (SJVFS 2011:40). An average producer has 7-8 holds of 85,000 chicken which are raised for approximately five weeks (Edman et al 2021). The producers buy day old chicks from special breeders.

7.2 Method and calculations

The feed rations for chicken and the parents are collected based on industry data from 2021 and the report of Edman et al (2021). The rations and the quantity used apply for the dominating breed Ross 308 by members of Svensk Fågel (Swedish Poultry Meat Association) that organise 100 of the Swedish chicken producers and 99% of the production. Mortality and other factors affecting feed use have been considered in their calculations. The feed use is summarized and compared with the total chicken feed available. The relationship between edible meat and carcass weight is calculated and the total quantity of feed is divided with the total quantity of edible meat from chicken and their parents [S9].

7.2.1 Feed use

A typical feed ration for chicken is composed of mostly grain, protein feed and limestone (table 22).

Table 22 Feed rations for chicken

Feed ration for chicken	**%**
Wheat	57.2
Other grain	7.6
Rape seed	5.9
Rape cake	2.8
Sun flower cake	0.6
Soy cake	18.0
Maize gluten	2.7
Fats and oils	1.4
Calcium carbonate	1.8
Synthetic amino acids, Minerals, vitamins	2.0

A total quantity of 1.52 kg of feed (use weight) is used per kg of LW chicken. The LCA by Edman et al (2021) doesn't relate all the data used for this calculation and the industry association has not been able or willing to supply all the details needed to ensure that the data reflects the actual total use of feed. The author has assumed that the feed use includes the mortality of chicken (3.2%) but not chicken discarded at the point of slaughter (2.6%). Mass culling of chicken as a result of disease in the year 2018-2022 amounted to an average of 175,759 per year with an in-year variation of 0-423,638 (SBA, Animal Health Unit 2023, S18). The feed used for these chicken has been added, and results in a slightly higher use of feed per kg than those of Edman et al.

In addition to the feed for the chicken, the parent chicken also need feed. Here data from the industry association and from the main parent chicken breeder was used (Donis 2023 , Ljungkvist 2023). It had a rather big number for “other feed” and the author distributed that other feed with a close eye to the feed for laying hens; after all the chicken parents are just (less efficient) laying hens. The quantity of feed used for parents and chicken was provided by Röös (2023) based on industry data. Feed for the grandparents was added with a 1% of the feed for the parents. The number of hatched eggs was supplied by Ljungkvist (2023).

7.2.2 Catering for variation and inefficiency

The basis for the feed use calculation by Edman (et al 2021) is feed recipes from the feed industry and production data from three producers using the dominating hybrid Ross 308. According to Svensk Fågel, the results coincides with their database “Tuppen” (Donis 2023). Aggregating the feed data on a national level, gives a result that doesn’t correspond to the average reported feed supplied from the food industry 2018-2022 (Foder och Spannmål 2023). Therefore some additional considerations are made, see below.

There are alternative breeds and management systems which use more feed per kg. The production of organic chicken is small, approximately 1% (Andresen et al 2023). The share of slower growing races is estimated to 2% of the total number (Donis 2023). A brief survey of online offers shows that those also mostly are slaughtered at a higher weight. In total their feed use will be considerably higher (see more below) and might increase feed use for the average chicken with a few percent. In addition, there might be extraordinary events and a considerable variation in feed use and mortality even for a streamlined production such as chicken. For instance, research from Denmark (Nielsen et al 2011) showed that the chicken producers used between 1.48 and 2.13 kg of feed per kg LW, compared to the 1.52 kg which is the basis for the calculation in this study. An “inefficiency factor” of 8% is therefore applied. It should be noted that Svensk Fågel disagreed with this assumption (Donis 2023). Considering the good match with feed industry data, a similar inefficiency factor is not applied to the breeding of the parents.

7.2.3 Comparison of calculated feed rations with feed availability and use data.

Summing up the feed rations for chicken leads to a total feed use of 412,000 ton. The feed industry reports 350,857 ton of feed for poultry for slaughter 2021 of which 39,676 is concentrate and the rest is complete feed. Recalculating the concentrate to full feed by adding grain (which will be added by the producers themselves), the total reaches 432,000 ton. This figure includes feed for turkey, duck, and geese. Chicken represents 97% of the slaughtered poultry in weight, not including hens for egg production (SBA statistic database 2023c). If one assume 50 % higher feed use for other poultry, 19,000 ton of feed would be used for them. In that case, there is reasonable coherence between bottom up and top down calculation and it supports the assumed “inefficiency” factor of 8%.

The feed industry report that 55,654 ton of feed is used for the parent hens. Our calculation lands at 56,000 tons, a very good match. This represents 0.50 kg feed per hatched egg. The egg thus constitutes 13% of the total feed use for the chicken.

7.2.4 Defining live weight, carcass weight, edible meat and potentially edible meat for chicken

The carcass constitutes approximately 68% of the live weight (Donis 2023). Sources give quite differing figures of the share of bones in chicken carcass ranging from 38% (USDA ERS 2023) to 23% (Clune 2010). Here the figure 29% is used according to calculations by Noe et al 2017. Liver and heart are directly edible products which leads to that 75% of the CW is edible. Adding potentially edible products (excluding the bone share) feet, head, blood, neck, neck skin and gizzard results in that 88% of the CW is potentially edible (see table 23).

Table 23 Chicken body composition

Chicken composition	% of live weight	Bone free in % of CW	
Carcass	68.0	71.0%	
Heart	0.5	0.7%	edible
Liver	2.0	2.9%	edible
Feet	5.0	1.8%	potentially edible
Head	3.0	1.8%	potentially edible
Blood	3.0	4.4%	potentially edible
Neck	2.0	0.7%	potentially edible
Neck skin	1.5	2.2%	potentially edible
Gizzard	1.5	2.2%	potentially edible
Feathers	5.5	0.0%	non-food, fertilizer
Other intestines, gut and gut content	8.0	0.0%	biogas

According to the official statistics, poultry organs were exported for an average price of SEK4.3 per kg 2019-2021 and almost 80,000 ton of poultry meat details were exported annually for an average price of SEK5.1 per kg. This quantity corresponds to 50% of the total carcass weight, indicating that considerable share of the carcasses also are exported (SBA 2022b). Nevertheless, they are mostly used as human foods (Donis 2023).

Comparison with other research

Research in France (Laisse et al 2018) concludes that 62% of the live weight, or 88% of the carcass weight of a chicken is fit for human consumption. This equals our calculations of "potentially edible".

7.2.5 Production of chicken meat

165,200 ton of chicken is slaughtered annually (average 2018-2022). 2.6% of the chicken were discarded at the point of slaughter, presumably used for biogas or pet food, leaving actual production to 160,900 ton CW. The average carcass weight of a chicken was 1.51 kg.

According to a recent study by Edman et al (2021) of chicken production, by-products have 3% of the total value of the slaughtered chicken. Here the 3% value is used for by-products compared to CW and reduced to 2% and 1% when edible foods and potentially edible foods are calculated.

In addition to the slaughtered chicken, the parents are also slaughtered and enter the food web. The calculated number of parent animals and their estimated weight at slaughter yields 2,728 ton, representing 1.6% of the total poultry slaughter. Most of the chicken parents are exported live and used for food. Here it is assumed that the share of edible meat is the same for parent animals as for the chicken for slaughter. The meat from the parent animals is thus added to the total quantity of meat.

7.3 Result

The calculated feed use for 1 kg of edible chicken meat is 3.26 kg of dry matter and 2.80 kg dry matter for 1 kg of potentially edible meat (table 24).

Table 24 Feed use for chicken

	Carcass weight	Edible meat	Potentially edible
Feed use in DM per kg	2.41	3.26	2.80
With economic allocation for by-products	*3%*	*2%*	*1%*

7.3.1 Comparison with other research

The feed use per kg CW is the same as calculated by Einarsson et al (2022). An EU wide estimate from 2018 by Sporchia et al (2023) calculate the average feed use in the EU to be 1.64 kg per kg LW, which is slightly higher than our figure just for the chicken of 1.52 kg (use weight) per kg LW. Public statistics (DEFRA 2023) from the UK show a feed use of 2.6 kg per kg CW, not including the feed for parents, i.e. considerably higher than our results.

8 Egg

Egg production in Sweden is mostly large scale, even though there are a considerable number of smaller scale operations. Of the 2,912 egg producers 2021, 2495 producers had 1-49 hens and 183 of the producers had more than 5,000 hens (SBA statistic database 2023d). Legislation requires that feed for poultry has been heat treated to at least 75°C (this is to reduce risk of salmonella), even if it is permitted to mix own grain (not other feed) with bought-in feed (SJVFS 2011:40). Approximately 15% of the producers mix own feed (Odelros 2023). Most eggs, 78.5%, in Sweden are produced in deep litter indoor housing systems, 2% of the eggs are produced in enriched cage systems, 8% are free-range eggs and 11.5% are organic (Lönneskog Hogstadius 2023).

8.1 Method and calculation

A lifecycle assessment was made for Svenska Ägg by Rise in 2020, but this is not made available. Data for the feed composition of laying hens as well as the pullets (recruitment hens) were obtained from the feed industry (Foder & Spannmål 2023). Svenska Ägg (The Swedish Egg Association) provided data for quantity feed used for laying hens, 2.1 kg feed per kg egg, as well as for pullets, 5 kg per hen which is based on interviews with producers. The author has not been presented with a detailed account of how this has been calculated which has made the further calculation challenging with uncertainty about what is included and what is not included. A survey of 68 production units by Svenska Ägg 2015 reports feed use averages ranging from 2.1kg for hens in cages to 2.3 for free-range hens. Supposedly, the data takes into account mortality of both the pullets and the hens. Pullets are raised on contract so one pullet is produced per hen put in production. Because of disease prevention new hens are not replacing those who die in a hold.

In the case of disease such as salmonella, bird flu or Newcastle, whole flocks may be culled. This varies a lot between the years. In average 284,259 birds were culled yearly 2018-2022, of which more than a million were culled in 2021. The average rate of culling corresponds to 3.31% of the total flock [S18]. It is assumed (for lack of data) that mass culling takes place in average at the middle of the production period, meaning that their average feed use per kg of egg will be higher (the feed for the pullet will be distributed on fewer eggs to express it in another way).

The total feed used for the egg used to produce the pullets was derived from the feed use per egg, including recruitment, but adding 20% feed for cocks and for the fact that not all eggs result in a chicken. This represented 0.3% of the total feed use, indicating that there would be little meaning in going back one more generation.

The weight of the shell is deducted from the weight of the egg in the final calculations, meaning that the feed use is calculated for "edible egg" to be consistent with the calculations for meat, where bone is excluded.

On the farm level, approximately 1% of the eggs are not sellable (Sandqvist 2023). Of this some is wasted and some is donated to charities and thus consumed, half of each was estimated. In the packaging operations 0.7% of the eggs are spoiled and sent to biogas or feed for a low value, while 3%-4% are second grade sold to the food industry and thus consumed as food (Petterson 2023). A total waste of 1.2% is therefore estimated.

When the laying hen has produced approximately 415 eggs and reached an age of 90 weeks, she is normally taken out of production. Approximately 40% are slaughtered and sold as food ingredient or mink feed. The rest is going to biogas or destruction. The value of this is very low.

8.1.1 Feed rations

The following feed ration per kg egg (table 26) for the producing hens was used as the basis for calculations.

Table 25 Model feed ration for production of 1 kg of egg

Feed ingredient	Share of feed (%)	Per kg egg
Wheat	46.3	0.972
Oats	6.8	0.143
Pulses	2.7	0.057
Sunflower meal	3.9	0.082
Mill by-products	0.4	0.008
Rape seed	9.4	0.197
Soy meal	9.4	0.197
Maize	4.7	0.099
Limestone	10.6	0.223
Vegetable fat	2.2	0.046
Barley	0.5	0.011
Maize gluten	0.3	0.006
Distillers grains	0.3	0.006
Minerals, vitamins	2.5	0.053
Total	**100**	**2.100**

8.1.2 Variations

Laying hens in cage system need less feed and free-range and organic layers will use more feed (Hendrix Genetics 2023, Odelros 2023). Brown laying hens also use more feed than white hens. The calculations here have taken into account the distribution of various housing systems as well as a 5% share of brown egg layers. In total the calculated feed use was increased with 0.84% to include such variations (table 26). The share of organic egg production was assessed to 11.5% by Svenska Ägg (Lönneskog Hogstadius 2023) but was 13.4% year 2022 according to the SBA statistics (2023i). The difference has not been investigated further and the value from Svenska Ägg has been used.

Table 26 Feed consumption variations compared with indoor free range white hens.

Production system	Share of production	Variation in feed use
In-door barn	78.50%	
Organic	11.50%	4.50%
Free range outdoor	8%	3.00%
Cages	2%	-7.00%
Brown egg layers	5%	4.50%

8.1.3 Comparison of calculated feed rations with feed availability and use data

When comparing the resulting total feed use according to the calculations above with data from the feed industry, there was a 10% discrepancy for the feed for layers and 20% for the pullets. The total feed use per egg from the pullets according to the numbers for amount of feed used per hen put in production (5kg for 5.6 million pullets) and the number of eggs produced would not amount to more than 28,000 tons, while the feed industry data showed a total use of pullet feed of 35,000 tons. Even if one would deduct some feed use for smaller scale egg production and other uses of pullet feed, the difference was far too big.

Our assumption is then that there is variation in the production and management and the average feed use is higher than the estimates supplied by the egg industry. Producers that mix their own feed will often use more feed and some might have higher mortality or lower production for one or the other reason. To cater for inefficiency and variations, feed use was increased with a factor of 8%. Even with that factor, the total calculated feed use is 19,000 tons lower than the data from the feed industry. It should be noted that Svenska Ägg didn't agree with this (Lönneskog Hogstadius 2023, Odelros 2023), but it was also not able to explain the differences.

8.1.4 Egg production

The average annual egg production in the period 2018-2022 was 142,134 ton, including an estimated 11 percent sold outside of the wholesale market. During 2021 the production dropped considerably because of major outbreaks of disease.

8.1.5 By-products and allocation

With a biophysical allocation, based on the food energy content of hen meat and eggs respectively and the low share (40%) of hens that are actually used for food, 1.2% of the feed is allocated to the hen and 98.8% to the eggs. With an economic allocation, the share allocated to the hen is even lower as the value of a slaughtered hen is very low. Here is chosen to use the biophysical allocation. The value of the by-products (organs) from the slaughtered hens is neglected as it will be marginal.

8.2 Results

The total feed requirement for 1 kg of egg for food, excluding weight of shell, is calculated to 2.44 kg DM for eggs from commercial egg production in Sweden. The general composition of the feed in use weight is seen in table 27.

Table 27 Feed use in DM for the production of 1 kg of egg without shell

Wheat	1.146	47%
Other grain	0.297	12%
Grain by products	0.033	1%
Pulses	0.075	3%
Rape seed	0.220	9%
Soy meal	0.220	9%
Other oil seed cake	0.097	4%
Other (limestone, vitamins, minerals and fat)	0.354	14%
	2.443	**100%**

8.2.1 Variations

The variations caused by the different housing systems is explained above and incorporated in the calculation. For the production of eggs from landraces and backyard egg production, the feed requirements per kg egg is certainly higher. The extent of such production is very small and not included in the calculations.

8.2.2 Comparison with other research

Pelletier (2017) calculated the feed use for pullets (the young hens destined to become laying hens) to be in average 5.92 (3.62-7.45) kg (normal weight) per pullet in Canada, based on surveys of 31 facilities producing >1 million pullets. Feed use for the layers was 2.00 kg per kg egg in average with a variation from 1.64 to 2.82, based on 62 facilities producing 516 million eggs. Turner et al (2022b), similarly from Canada, based on a sample of 200 egg producers, assessed the feed use for caged layers to 1.92 kg, for enriched cages 1.95, free run indoors 2.06, free range outdoor 2.42 and organic 2.25 kg feed per kg eggs. This is very similar to the starting point of 2.1 kg feed per kg egg used in our calculations (not including the young hens, waste, parent egg etc.). The total use of feed is slightly lower than the research by Einarsson et al (2022) and the distribution of the main feed groups is also very similar. That the use of feed is lower is mainly a result of that their research is based on figures from 2005.

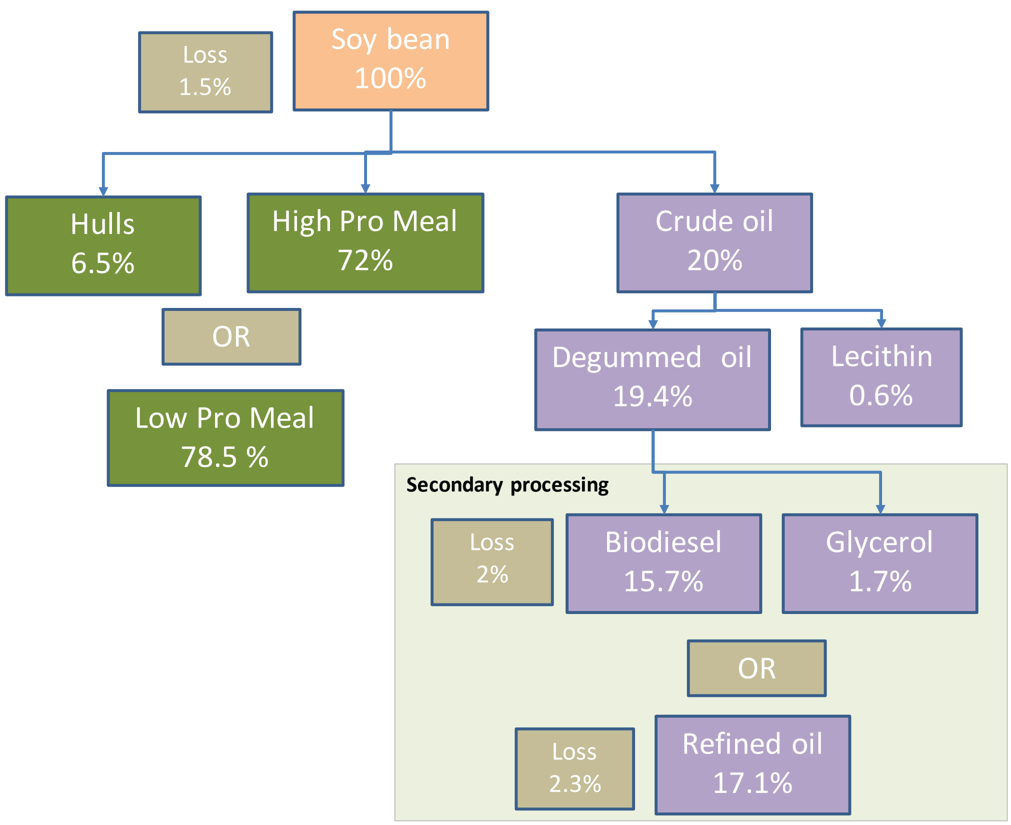
9 Use of soy beans

Note: All soy used in animal feed in Sweden is covered by some kind of certification (Proterra, organic, RTRS or verified soy from Canada) according to Foder & Spannmål (2023).

9.1 Soy bean processing

Most, in the range of 90%, soybeans go through soy mills (Fraanje and Garnett 2020, USDA FAS 2023) where the bean is de-hulled (hulls represent approximately 6.5% of the weight) and processed into soy oil (19%), (High Pro) soil meal (72%), lecithin (1%) and losses 1.5%[8] (figure 3). The meal is almost exclusively used as animal feed (but it is also increasingly used for making novel human soy products). In some processes the hull and the meal are kept together, resulting in more soy meal but with lower protein content (Low Pro). The Low Pro meal is mostly used for ruminants and the High Pro meal for monogastric animals (Roundtable on Responsible Soy Association 2023).

Figure 3 Soy processing flow chart



Gunnar Rundgren 2023, after Roundtable on Responsible Soy Association (RTRS) 2023

[8] Note that the moisture content will be reduced in processing so there is also a weight loss. Also, there is a cleaning procedure at the reception when foreign matter is taken out, representing in average 1.5% of the weight (Roundtable on Responsible Soy Association (RTRS) 2023).

The oil is primarily used as vegetable oil for human consumption but approximately 20% is used for biofuels (Fraanje and Garnett 2020). For the soy that goes through the mills, the human food market and the animal feed market can't be separated; the oil and the meal are co-products and both must have a market for the production to be profitable. The oil has also a considerable higher price, often three times higher, than the meal, which means that the oil and meal is of more or less equal importance for the soy industrial complex (Roundtable on Responsible Soy Association 2023, USDA FAS 2023).

9.2 Soya as a feed

Soy bean meal is a very important feed, in particular for monogastric animals and high yielding dairy production. It is reasonably priced from the perspective of the feed industry and it is readily available in a standardized quality. The main advantage of soy meal, compared to other protein sources, is that its high protein content and favourable composition of amino acids makes it an ideal complement to grain, which are cheap and the backbone in animal feed for the monogastric animals (Karlson et al 2021, Spröndly 2021). In addition, the proportion of meal is much higher than from the other important oilseeds meaning that there is ample supply. This has made soy meal to the dominating protein feed in global markets, supplying some 70% of the protein feed derived from oilseeds (table 28). Oilseeds supply most of the animal protein feed even if there are other sources such as pulses, fish meal and various by products from other food and bio-energy industries.

Table 28 Global production, oilseeds, meal and oil

Million metric tons average 2019-2023

	Total	Meal	%	Oil	%
Coconut	5.95	1.93	0.6%	3.66	1.7%
Cotton	42.13	15.03	4.4%	4.93	2.4%
Olive		0.00	0.0%	2.99	1.4%
Oil palm		10.10	2.9%	82.79	39.5%
Peanut	49.89	7.82	2.3%	6.37	3.0%
Rapeseed	76.95	42.53	12.3%	29.87	14.2%
Soybean	359.75	246.37	71.4%	58.92	28.1%
Sunflower	53.00	21.44	6.2%	20.20	9.6%
Total		**345.21**	**100.0%**	**209.72**	**100.0%**

Oil from oil palm includes both palm oil and palm kernel oil as they come from the same plant.
Sum of oil and meal is mostly lower than total production as many crops are also seeds and some (in particular peanuts, but also sunflower and soybeans) are consumed whole.
Cotton's main product is fibre.
Source USDA FAS 2023, Oilseeds: World Markets and Trade, June 2023

9.3 Calculations

For the calculation of soy use, the feed rations used in this report has formed the basis. These have been compared with data from the feed industry (Foder och Spannmål 2023) and other sources (Rundgren 2021, Statistics Sweden 2023).

For cattle the used feed rations have not separated between soy and other protein feed, but with the data from the feed industry and the other sources the share of soy has been established and distributed between dairy cows and others.

The data from the feed industry doesn't separate the different qualities of soya that is used, but some of the feed rations have. As they have varying protein content they need to be recalculated into soy equivalents, either soya bean equivalents or soy meal equivalents, based on the protein content. In this case soy meal equivalents is the more appropriate metric content.[9] 0.64 kg soy concentrate equals 1 kg soymeal and 1.25 kg soybeans equals 1 kg of soy meal. There has been no information available regarding if soy meal is High Pro or Low Pro and the calculations are based on that all soy meal is High Pro.

The considerations regarding allocation are the same for soy use in feed as for feed use in general. For cheese, the calculation is based on the dry matter allocation as related above.

For sheep the data was not sufficient to elaborate on soy use, it is likely even lower than for beef with the exception of spring lamb. The use of soy for sheep, goats, horses, non-chicken poultry (ducks, turkey and geese), dogs, cats etc. is estimated to be 10% of all soy use. Note that the use of soy for fish, which can be substantial, is not included in these figures, the figures from the feed industry or the trade statistics as fish feed is imported as compound feed. The figures in the table is 10% lower than the data from the feed industry 2019-2021. Some of this is as a result of the recalculation of whole beans into soy meal equivalents [S20].

Table 29 The use of soy in Swedish livestock production

	Total use, ton	Soy as share of feed (DM)	Soy per kg edible product with allocation
Egg	31,227	9.0%	0.247
Chicken	77,295	16.8%	0.443
Milk	46,464	2.3%	0.016
Cheese with solids allocation			*0.068*
Beef	5,500	0.2%	0.047
Pork	38,823	4.2%	0.150
Other (sheep, goats, horses, pets, non-chicken poultry)	22,522		
Total	**221,830**		

9.4 Variations

In organic production the use of soy is mostly higher. This is mainly a result of that there is not sufficient quantities of other protein feeds available and that the industry will mostly not keep separate organic by-products from various industries such as oil pressing or milling (Rundgren 2020). For organic

[9] The Roundtable on Responsible Soy Association (2023), Soy Conversion Factors Technical supporting document elaborates in detail on various conversion factors for soy.

production of dairy and poultry, a considerable share of the soy used is composed of whole soy beans and not soy meal (Sommerfeldt 2023). Approximately 10% of the soy import is whole beans (roasted or not).

There is a much higher use of soy in organic milk production than in conventional production and as organic milk production also has a high share (approximately 17%) it has an impact on the total. Andresen et al 2023 estimate that 27,000 tons of soy is used in the organic dairy production, i.e. 45% of all soy in dairy production. According to Zira et al 2021, organic slaughter pigs get 12% soybeans in their feed and piglets and lactating sows, 20% soy in their feed, a much higher share than for non-organic pigs. The share of organic pig production is very low, however, in average 2.5% 2018-2022 (SBA statistic database 2023h). For egg, the use of soy in organic production is higher than for conventional production and as the share of organic production is in the range of 11% it has some impact. In organic chicken production the use is slightly higher than in conventional (Andresen et al 2023).

9.5 Comparison with other research

The use of soy in Swedish livestock farming has gone down from a high in the 1990s (SLU 2023), and seems to be quite stable in the range of 200,000 to 250,000 tons the last decade. Notably the use of soy in Sweden dropped to under 200,000 ton in 2022 (Foder och Spannmål 2023). The results in our study are very similar to the research of Einarsson et al (2022).

The use of soy in Swedish livestock farming is lower than in many other comparable countries (table 30). It should be noted that the figures might not be fully comparable as other studies may define the functional unit differently and apply other principles for allocation, or even use other principles for determining how various qualities of soy are recalculated. This has not been investigated in any detail.

Table 30 Use of soy in gram per kg compared with other research

	Global average	EU	Sweden 2015	This research
Beef	450	440	200	47
Milk	37	70	24	16
Salmon	640	**380**	400	
Chicken	760	650	550	443
Egg	530	170	380	247
Pork	510	770	180	150

Sourcses: Global: RTRS Soy Calculator och Swensson 2015
EU: Karlsson et al 2021, for salmon (Norwegian) NOFIMA 2019
Sweden 2015: Swensson 2015

10 Human edible protein

Apart from the calculation of feed use for kg of meat, egg and cheese, the study should also try to express the protein efficiency of the products expressed as human edible protein, i.e. protein that humans can digest. In order to do that one first has to ascertain the human edible protein content of the calculated rations and then compare them with the human edible protein content in the products and thus establish an edible protein conversion ratio (EPCR). Note that the scientific community has not yet agreed on a common metric for this as some (e.g. Laisse et al 2018) put the feed in the numerator and the food in the denominator while others (e.g. Hennesy et al 2021) do the opposite. There are also several other terms used such as Human-edible protein conversion efficiency (HePCE) and Net protein contribution (NPC).

10.1 Edible crops and plant products

Similar as for the animal products, there is clearly a distinction between what is theoretically human edible, what is actually human edible in the sense that the products to some extent are eaten, and what is commercially human edible. Rape seed cake (which is around 60% of the rape seed and 100 % of the protein) is for example theoretically human edible, but it is not eaten at all in almost any culture and it is certainly not commercially eaten. In this study we use human edible in line with the definition for human edible meat elaborated above, i.e. products which are actually consumed as food either in Sweden or for exports. The protein fractions that are not part of the end product used by humanity (food, biofuel etc.) are *de facto* not human edible under current conditions.

For the farmers and the grain industry, in almost all cases the human food market pays better than the animal feed market, which means that the industry will always try to valorise as much as possible of the production for the food market. For many plants there is simply not a market for all that is produced, e.g. the wheat consumption for human food is just a fraction of the total Swedish harvest and the direct global consumption of soybeans for human food is not even ten percent of the harvest (Fraanje and Garnett 2020). By and large, the use of human edible food as animal feed (or for biofuel) is a result of overproduction of those crops compared to demand for direct human use. And clearly, there is no human food market that could swallow all the crops that is now fed to animals, i.e. only a smaller share of the feed that is now eaten by animals *could* be eaten by humans, even if it was classified as “human-edible”. But in this study this is not considered.

One could also explore the possibility of replacing crops which are not or only partially human edible, e.g. ley, with crops that are almost totally human edible (potatoes) or if one through technological development can produce human edible foods from raw materials which are currently not edible, e.g. by making human food out of grass, rape seed cake or dregs. There is also such a development for animal by-products, so if one factor in such a development on one side of the equation, one should do it on the other side as well. In this study this is also not considered.

Even with those limitations and boundaries it is not simple to establish the correct figures for human edible protein. The steps used here is to determine:

1. The current use of various crops, divided in human food processing, animal feed and other uses (e.g. biofuel, industrial). For some crops, e.g. wheat, maize and oil crops, there is a large use of the crop for other purposes than human food or animal feed.
2. Establishing the by-products from the various processes and to what extent they are used as animal feed.
3. Establishing the net share of the crop protein that goes to human food (e.g. wheat flour) and the net share that goes to animal feed (e.g. most of the wheat bran).
4. Quality limitations for the use as human food; if a crop has too low quality for the food industry's needs, the protein thereof can't be classified as human edible.

For some crops, e.g. wheat, maize and soy there are many different streams which complicates matter even more [S21].

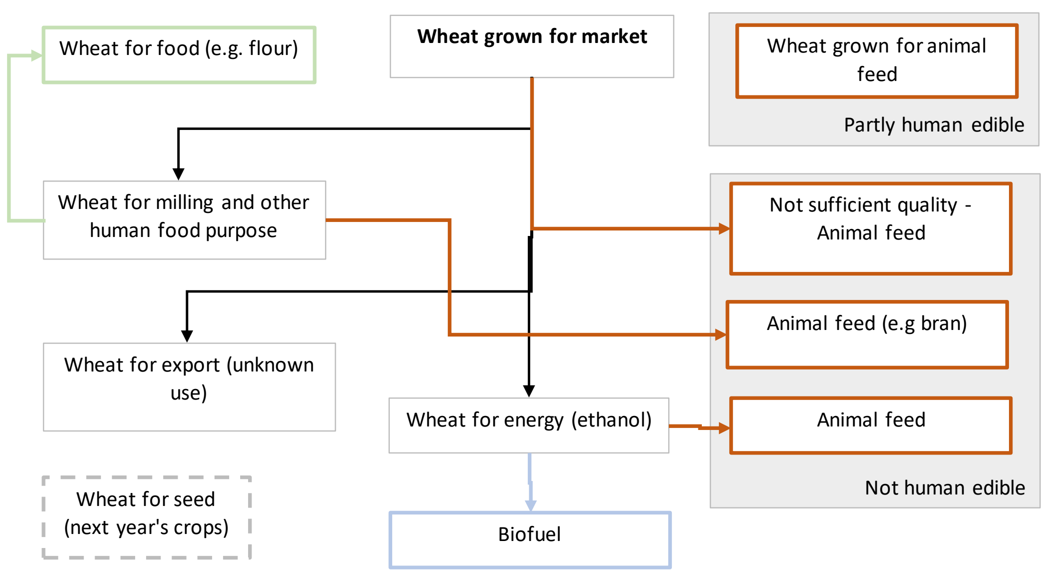
10.1.1 Grain

Wheat

For wheat the whole kernel is theoretically edible but if it is used as white flour approximately 79% is used for flour, 2% is wheat germ that also is used for food (FAO 2000). The wheat bran can be edible, but only a smaller quantity is actually eaten. The protein content of wheat flour is in the range of 8.5 to 10.5 while the protein content of the wheat bran is 16.6%. In addition to bran there is some other milling waste. In total 31% of the protein wheat used for milling ends up in animal feed.

Figure 4

Use of wheat harvest



If wheat is used to produce alcohol approximately 2/3 is converted to alcohol and carbon dioxide (Drivkraft Sverige 2023) while the distillers' grain, which has all the protein, is used as animal feed. Currently about half of the Swedish wheat, excluding exports and seed use, is used for animal feed while half is used for human food, spirits and alcohol for biofuel. All considering, it is not obvious how one should estimate the potential human edible protein in the wheat consumed by animals. The higher estimate, where sprits is excluded, would be that 73% of the wheat protein in *mill wheat* used as animal feed is human edible. A low estimate, based on that the wheat currently used as animal feed would be used for food, spirits and biofuel in the same proportions as today would be that only 32% of the protein is human edible.

Here we use a calculation that includes the wheat used for milling and for the *domestic consumption* of liquor (Sweden is a rather big exporter of liquor) which results in that 55% of the protein in wheat used as animal feed could be eaten by humans. The by-products of the secondary processing of wheat into bread, pastries, pasta etc. which are used as feed today are all qualified as not human edible.

In addition, those that produce wheat for the market are normally aiming at the food market, but it is not always the quality is satisfactory for the food market. *This means that more wheat has to be grown for human consumption than the actual consumption/use.* There is no reliable data on how big share of the wheat harvest that is grown for the market and how big share that is grown for feeding own animals. According the estimates of the SBA some 60% of the wheat acreage is "wheat for milling" which means that approximately 1.8 million ton of wheat is grown for human food purposes, three times the domestic (food and drink) consumption. A survey among 15 wheat growers estimated that 2.9% of their harvest was not good enough for the mills (Hovmalm 2023). Country wide, that would correspond to 52,000 ton, i.e. 10% of what is actually used for human food. A bad year a much lower share can hold the necessary quality; in 2008, only 15% of the wheat and rye harvested in Sweden had the quality demanded by the mills (Lantmännen 2008). In Finland, 54% of the spring wheat harvest and 72% of the winter wheat harvest 2005-2022 did not reach the quality limits of hectolitre weight ≥78 kg, falling number ≥180 and protein content ≥12.5 % (Finnish Food Authority 2023). It seems, therefore, pertinent to calculate with at least 15% extra production for human use, compared to the actual use, to cater for quality deficiencies.

Combining the share of wheat protein that is human edible (55%, as discussed above) and the need for extra production (15%) the share of protein that is actually human edible in wheat grown for human food is approximately 49% (S22).

Other grains

30% of the oats in Sweden goes to human consumption. The outer shell is not human edible, the rest is edible. If you make oat drink there is an oat slurry as by-product. This should, theoretically be edible, but is in practice used as animal feed. When oat drink is produced around 50% of the oat is commercially edible, while if rolled oats are made approximately 2/3 of the oats is edible (Rundgren 2019). The oat hull has low protein content but the other oat by products have high protein content compared to the raw material, a larger share of the protein end up in the by-products of oats.

25% of the barley production goes to human consumption, mostly as malt. Barley has approximately 7% hulls which are not edible and 19% bran (FAO 2000). The bran is edible but barley used for muesli or pearl barley (*korngryn*) will be cleaned from the bran as well, which means that it is approximately 75% of the kernel that is used as food (Cerealia 2023). If the barley is used for malt (for beer or whisky) less than 75% of the weight and almost no protein goes to the drink and the rest is animal feed. Approximately 260,000 ton barley is used for malt annually in Sweden. Malt is also exported (Rundgren 2021). Pearl barley is a really minor product. Here we calculate that the use of barley has an alternative use as pearl barley, not including malt in the calculation. Pearl barley has a lower protein content than the unprocessed barley kernel.

In average, one fifth of the Swedish harvest of oats and malt barley will not fulfil the market specifications for human uses (Rundgren 2019). This means that more has to be grown than the final use. E.g. if one needs 100 ton of barley or oats for human consumption the production has to be 125 ton an average year.

Rye is almost only grown for human food purpose and approximately 20% of the weight is bran. Whole rye has around 10% protein while the bran has 16% protein content (Feedipedia). Here is assumed that half of the rye is used as whole grain flour. Also for rye there are quality limits for the milling industry. In Finland 74% of the rye harvested 2005-2022 had a falling number ≥120 and a hectoliter weight ≥71 kg, quality requirements which are quite similar to those in Sweden. Also for rye it is pertinent to calculate with a need of a 25% overproduction to satisfy the human food market.

Maize (corn) is globally a very important feed crop. It is also an industrial crop like soya and is the basis for an industry that produces starch, oil, sweeteners and biofuel. 13% of the maize (excluding losses and seeds) is used directly as human food, 60% as animal feed, the remainder is processed into a multitude of products according to FAOSTAT (2023). The industry is mainly using the starch and the protein is in various by- or co-products (corn gluten, dregs etc.) which are used as animal feed. Considering the small use of corn as feed in Sweden we have not made any own elaboration of maize use and have settled to use the 60% human edible value established by CAST (1999) for whole kernel and 0% for the by-products. Based on French conditions Laisse et al (2018) put the human edible protein share for maize on just 15%. There seems to be a need for a more thorough exploration of maize in this context.

10.1.2 Pulses

Pulses, except for soy beans, which is normally discussed as an oil seed crop, do not play a big role either as human food or animal feed in Sweden. The two main crops are peas and fava beans. There are special varieties of peas for feed, but most of the peas grown in Sweden are yellow peas which are edible. Most of the pea harvest is used for animal feed, the main reason for this is not quality specifications but lack of demand and logistics (Jeppsson 2023). Peas are often damaged by insects, in particular pea moth. Some facilities can sort the peas and still get a product fit for human consumption, but sometimes it is better to use the whole lot for animal feed (Jeppsson 2023, Erlandsson 2023). When peas are used as flour or other processed products the shell is mostly taken away and just 80% of the weight remains. Here is calculated that 75% of the protein in peas is human edible. Fava beans are frequently (25%-35%) damaged by the bean (seed) beetle leading to a loss as human food. In addition, for use as human food one will normally shell the bean which represent 30% of the weight (Erlandsson 2023). Here is calculated with that 50% of the protein in fava beans is human edible. The relative protein content of the fractions of beans and peas has not been investigated and are therefore assumed to be identical in this research.

10.1.3 Oil seeds

In general, most oil seeds such as rape (canola), sunflower and soy are grown for the production of oil and a meal/cake used as animal feed. The proportion between oil and feed differs a lot and is determined by the composition of the crops (see table 28). Olive has no animal feed and palm oil very little (only from the palm kernel fraction). The soya bean on the other hand, has a rather low oil content and the production of meal is thus almost four times larger than the production of oil. Soy bean meal is also the totally dominating oil seed meal. Peanuts are clearly edible as they are and so is sunflower seed. On the other hand they are used for oil production because there is a huge demand for vegetable oils. Oils seed meals are here considered not edible, with the exception of soy bean meal.

Soybeans

Humans can eat whole soybeans, meanwhile the soy oil is the second most used vegetable oil in the world with a 28% market share. Increasingly, industry is finding ways to make the soy meal into human edible products. Theoretically, the whole soy bean crop, with the exception of low grades (the extent of which has not been investigated) could therefore be used as human food. In reality as consumption patterns stand now, approximately 20 % of the soy bean harvest is used for food and the rest for animal feed (Fraanje and Garnett 2020)[10]. On a protein basis, a much higher share is dedicated to animal feed as the oil contains no protein.

If humans were to eat all soybeans, approximately 40 kg per person and year globally (USDA FAS 2023), there would be a need for more vegetable oil production from other crops, most of which also produce considerable quantities of protein meal used as animal feed. It is therefore not straight forward to count the protein in the soy bean cake as "human edible" as defined in this paper. Even if humans consumed whole beans, they would not consume the whole seed as soy beans for human consumption will be hulled and graded, assumingly with a real rate of use of around 80% as for other pulses. In addition, even if humans can eat whole soybeans most soy for human consumption is consumed as processed products such as tofu, soy milk, soy sauce and increasingly as extruded soy products. In a scenario where soy is used primarily for food there are still numerous by-products which are or can be used as animal feed.

Soy hull is the fibrous outer layer of soybeans that accounts for approximately 5-7% of total soybean weight. Protein content is 11-15%, this means that approximately 3% of the protein in all soy that is further processed is lost in hulls. Soy hull is used as animal feed. Soy okara is by-product from processing soymilk, tofu, and soy yogurt. Soy okara is used as animal feed. In the production of soy milk and tofu approximately one third of the protein from the dehulled soy beans is in the okara (Berk 1992, Meija et al 2017). Soy-whey is a by-product generated during the processing of soy-yogurt, tofu, soy protein isolates, soy protein concentrate, and other fermented soy products. Soy-whey contains a high amount of water and is often wasted in the sewage even though it could be used as animal feed (Singh and Krishnaswamy 2022).

Soymeal has between 44 and 49% crude protein (soybean, 38–45%). It is not consumed as it is as human foods for several reasons. It contains some anti-nutritional factors which impair the digestion and absorption of nutritional component. Through heat extrusion techniques, anti-nutritional factors can be eliminated and soy meal used for the production of pasta, noodles, soy chunks, meat analogues, textured soy protein, ground meat extenders and many other products. Many plant-based meat alternatives use soy protein isolate (SPI) to replicate the texture and nutritional profiles of a variety of meats. SPI uses soybean meal as a feedstock, which undergoes mechanical and chemical processing.

[10] Note that it is a complex discussion how to quantify this and that figures like this should not be taken out of context.

Approximately 1/3 of the protein in the soy beans will be in the various by-products (hulls, okara and whey) (Berady et al 2015, Berk 1992) also for the production of SPI.

Laisse et al (2018) puts soy bean protein edible share to 60% and the Council for Agricultural Science and Technology (1999) puts it at 70%. Taking into account hulling of all beans before processing and the estimated loss of one third in processing, 65% seems to be a realistic value, and thus used here. For whole soybeans, a somewhat higher factor, 70%, is used taking into consideration the minor share of soy for human consumption that is consumed as whole soybeans.

10.1.4 Other crops and feeds

A sugar beet is perhaps (?) edible but in real life sugar beets are converted into sugar (with no protein) whereas the rest will become animal feed. There is a considerable production of potato starch where the rest product, containing all the protein, is used as animal feeds. By and large, by products that are used today as animal feed are counted as non human-edible.

There are also animal by-products which are used as animal feed. Many of them could also be used as human food directly (whey, blood, bone, fat). In this discussion they are not considered as they would introduce a kind of double counting, as they already are a result of the use of animal feed.

There is a certain use of synthetic amino acids in feed for pigs and poultry. There are at least 20 different such acids in the market and they use either biomass or fossil fuels as feedstock. It has not been possible to explore to what extent these amino acids are human edible or produced by human edible feedstock (Sturm et al 2022). They have thus been counted as non human-edible.

Globally it is estimated that 90% of the fishmeal from whole fish (much fish meal is also made from by-products) is potentially edible (Cashion et al 2017). Fish meal has, however, in this report been counted as non human-edible as there is no basis for calculating what share of the fishmeal that could be considered human edible under Swedish conditions. The use of fish meal in Swedish livestock production is also very low, less than 1% of the protein feed, approximately 4,000 ton (SBA 2023d).

10.1.5 Summing up

Based on the above discussion the following factors (table 31) are used to determine how much human edible protein various feed stuffs contain.

Table 31 Share of protein that is human edible protein

Wheat	49%
Wheat by-products	0%
Oats	32%
Oats by products	0%
Barley	45%
Barley by-products	0%
Rye	67%
Maize/corn	60%
Maize by-products	0%
Peas	75%
Fava Beans	50%
Soy beans	70%
Rape seed	0%
Oil seed cakes (not soy)	0%
Soy meal	65%
Roughage	0%
Fish meal	0%

10.2 Human edible protein in animal products

Here we base the calculation of the definition of human edible used throughout this report. As for protein content there are differences between the different parts of the animal. The proportion of fat in the meat makes the main difference as there is no protein in fat. Bone and feathers also have a lot of protein, one third of the bone mass is made up of protein (Tsagari 2020). There are, new and old, technologies to convert them into edible food products, e.g. collagen (Pap et al 2022, Sandström et al 2022), but this is not considered here in a similar way as plant by-products which are not eaten are not counted. Skin has a lot of protein and it is included in the calculation for those products which are consumed with skin (chicken and partly pork). By and large offal has similar protein content as meat. The values used for protein content here are (table 32, S21):

Table 32

Pig	17%
Cattle	19%
Lamm	17%
Ckicken	18%
Egg without shell	12%
Milk	3.40%

10.3 Edible protein conversion ratio of animal products

Combining the share of human edible protein in feed with the share of human edible protein in animal products with the feed use per unit human edible food gives us a human edible protein conversion ratio (EPCR, table 34). For sheep there are too many uncertainties involved for making a reasonable calculation. Considering the very low use human edible feed in the sheep rations, still taking into account the overall lower feed use efficiency, the EPCR is probably higher for sheep than for beef, at least for autumn lamb.

Table 33 Edible protein conversion ratio

Egg	0.67
Chicken	0.68
Milk	2.39
Beef	0.90
Pork	0.82

Most of the protein in the milk ends up in the cheese. Using the allocation factor of 46% for cheese means that the edible protein conversion ratio of cheese would be more than double the protein conversion ratio of milk. This is a slightly absurd result. The conclusion is that it makes no sense to define an edible protein conversion ratio for cheese different than the one for milk.

The relationship between human edible protein conversion ratio and feed use are almost opposing, i.e. the production with the highest feed use has a favourable protein conversion and those with the lowest feed use have the highest use of human edible protein. The most extreme cases are ruminants on a grass fed diet, which use much feed but no human edible protein at al.

10.3.1 Protein quality

The protein quality in plants is generally (with a few exceptions) not equal to protein in animal products, both in terms of composition and bio-availability (e.g. Berrazaga et al 2019, Herzler et al 2020). Making an additional step in the calculation to take that into consideration would improve the protein conversion ratio of animal products. Such a calculation is outside the scope of this study and would also have to be based on a number of assumptions such as if and how proteins from various sources are, or can be, combined and in that way compensate for lower quality. Ertl, Knaus and Zolltisch (2016) did assess the protein quality of feed rations using the protein digestibility-corrected amino acid score (PDCAAS) and the digestible indispensable amino acid score (DIAAS). Depending on the method used, EPCRs were between 1.40 and 1.87 times higher for the animal products than for the potentially human-edible plant protein input. When taking protein quality (DIAAS) into account, the FPCR of pork in Australia went from 0.70 to 3.26 according to v Barneveld et al (2023).

10.3.2 Comparison with other research

Laisse et al (2018) makes a similar calculation as ours based on French conditions. Their results are, in summary, that the brut protein conversion ratio for many animal products, especially for ruminants, is very low but the EPCR is around 1 for many animal products, lower for beef and higher for milk (table 34). The feed rations for broiler and egg were very similar to those in our study, rations for dairy cows with a high concentrate diet as well, but with maize silage as prominent silage. The low concentrate dairy production was based on 90% roughage.

Table 34 Edible protein conversion ratio under French conditions

Production	EPCR
Dairy production, high concentrate diet	1.01
Dairy production, low concentrate diet	2.57
Beef, high concentrate diet	0.67
Beef, medium concentrate diet	0.71
Sheep, high concentrate diet	0.34
Sheep, low concentrate diet	1.28
Pigs (two different systems)	1.06/1.23
Broiler	0.88
Egg	1.02

Wilkingson (2011) comes to quite different conclusions with a protein net protein conversion ratio of 0.43 for eggs, 0.48 for broilers, 0.38 for pork, 0.33-1.09 for three systems of beef and two systems of lamb and 1.41 for foraged based milk. The main difference is that he base the calculation on carcass weight and use considerably higher proportion of human edible protein for feeds (see above). Hennesy et al (2021) include protein quality (DIAAS) in the calculations and conclude that the FPCR is 4.5 for milk, 3.4 for suckler beef and 0.66 for pork under Irish conditions. Notably, both milk and beef production in Ireland are based on pasture. Swensson et al (2016) calculated human edible protein output in cow's milk per unit human-edible protein input in feed for five regionally adapted and feed rations fed to Swedish dairy in high-yielding, intensive production. All scenarios except one (which had a high share of faba beans in the diet) showed a protein conversion ratio of >1 for human-edible protein. Higher milk yield led to a decrease in protein conversion ratio, regardless of diet. In their calculations they used Wilkinsson's ratios for the proportion of human edible protein in feed.

All the research related above, except Hennesy et al, are based on models and not country average data as ours. Our calculations and results are more similar to those of Laisse et al than Wilkinsson's.

10.3.3 Discussion

While there is some merit in the calculation of edible protein conversion ratio, the value thereof should not be exaggerated and the conclusions should not be drawn to far. There are a number of considerations that should be added. Those include:

The "loss" of protein in the conversion of feed to animal products is also a reason for why the recycling of manure is valuable in the production of crops. A large share of the nitrogen (a main building block in proteins and the major crop nutrient) in the feed consumed is recirculated to the fields in the form of manure even though some is lost as emissions to water and the atmosphere (Einarsson et al 2022).

As livestock feed crop production is linked to considerable environmental pressures and there are animal welfare issues to consider, one could argue that EPCR should be well above 1 in order to be encouraged. It is too easy to equate an EPCR below 1 as wasteful, however. The protein conversion ratio in a food and agriculture system without animals would not be 1 as a result of losses, conversion of food, other uses and consumer preferences. In addition, livestock doesn't only produce protein but also many other important nutrients (e.g. FAO 2023). The quality of the protein is also important as discussed above, which means that an ECPR<1 still can be a net gain depending on the overall diet of the person.

The alternative use of land which is currently used for animal feed production also has to be taken into account. Assuming that there would be land over if all the human edible raw materials presently used for feed would be consumed by people, landowners are likely to still want the land to be productive in one way or the other – conversion to nature reserves will be dependent that the public will buy up the land. The primary use of that would probably be for bio-energy, derived from wheat, rape seed, sugar cane, maize, soybeans and oil palm. If there were no animals, they could not consume the leftovers and, *on an aggregate level*, the edible protein conversion ratio of the agriculture system might become very low in such a scenario.

11 Discussion

Hopefully, this report can be used as a basis for other investigations of feed use in Sweden and in other countries, based on the same methodology or at least to be the basis for a discussion about how to define and calculated feed use, feed use efficiency, edible foods and protein conversion.

11.1 The merit of using country-wide data.

The report demonstrates that using models based on optimal situations or data from a few farms will not give an accurate picture of the average feed use for the livestock production in a country, and that there is a need to cross-check data with various methods.

11.2 The implication and relevance of choice of functional unit and allocation.

In several cases, the allocation choice makes a huge difference for the result. There is not *one* correct allocation method and there are value judgments involved in the choice of allocation method. Even the choice of functional unit has a lot of impact on the results as presented which is demonstrated by the impact of how meat is defined. When LCA studies are used internally as tools for analysis of the production and for internal improvements – which was their original scope (Björn et al 2018) - this is not very problematic as the commissioners of the study can chose the allocation method and functional unit that makes sense for them or even disregard allocation all together depending on the circumstances.

The feed use according to this research is mostly higher than those used in most life cycle assessments as they are mostly based on optimized models or single farm studies and not the total livestock production in a country. When the results of this report are compared with other research it is important to consider this, the functional unit (kg human edible product, carcass weight, boneless meat or live weight), the indicator (dry matter) as well as allocation choices. In addition, this study includes parent animals and many other considerations which are mostly not included in studies of feed use.

11.3 How reliable are the results?

The result of feed use as such are most likely within a (not statistically calculated) 5% uncertainty margin for the use of grain and feed industry feeds. For roughage the uncertainty is bigger. The results should be more reliable in the sectors which are more homogenous and less reliable for those sectors which are very fragmented and often small-scale, as beef cattle and sheep. Meanwhile, the homogenous sectors, in particular poultry, are less transparent than others which makes it difficult to access data. The distribution of various feeds *within* the broader feed groups, such as grains and oilseed meal can change rather rapidly as they are subject to market fluctuations. As one example the use of soy in Sweden shrank with 19% between 2021 and 2022 (Foder och Spannmål 2023).

The weakness in the top-down calculations are mainly: uncertainties in the statistics of the harvest of roughage as that is not systematically recorded; uncertainties of the proportion of on farm feed grain in the rations and some uncertainty regarding if by-products are delivered directly from food and bio energy industries to farms or go via the feed industry as well as some of the dry matter values for by-products. In total, the difference between the top down and the bottom up calculations was estimated to 4.53% of which 3.81 percentage units were attributed to roughage [S7].

The starting point for the calculations for beef, milk and pork were based on national data both for production and feed availability in addition to model rations. The starting point for sheep, eggs and chicken were various models or surveys which had not been validated through national data for production and feed availability. This resulted in considerable modifications of the calculations for sheep, eggs and chicken to make the calculations bottom up and top down to coincide. The inefficiencies, compared to optimal situations, built into the calculation for pigs and cattle are, however, much bigger than those for egg and chicken.

The use of seed is not included in the calculations. Grains and pulses have big seeds and 2%-10% (highest for peas and beans and lowest for winter wheat as a result of the high yield) of the harvest may be used for seeds depending on crop and yield level (Lantmännen 2023b). Seed use is very seldom, or ever, included in calculation of feed use efficiency (it can be seen as similar to including parents to animals). Would seed use be added, the result would be that feed use (and soy use) would be approximately 3%-4% higher for monogastric animals. Including seed use would further complicate how to consider by-products. When discussing protein conversion, seed use is not relevant as the seed use is the same for crops regardless if they are used for food or for feed.

When comparing results with similar research in other countries it is important to note the low use of corn (maize) and high use of wheat in Swedish livestock production, the importance of perennial leys for the production of forage for ruminants on 44% of all arable land, and the relative low use of grazing in cattle production. In addition, the Swedish food market has been oriented to whole meats and the consumption of innards and other speciality meats has been small.

11.4 Outstanding questions that would need more examination or research

It is not clarified how a lower or higher carcass weight affects the proportional weight of the edible products which are not part of the carcass or the bone percentage of the carcass.

The actual and potential use of animal fat is not properly mapped in this study but it is of rather big relevance for the calculation of the yield of human food from livestock. Historically, animal fat was much appreciated as food. Nutritional expertise has for a period discouraged the consumption of most animal fats, even if this is contested. The use of casings in the food industry has also not been properly investigated. Casings from sheep and pigs have been used for sausage making, but the author failed to get any information about this. Swedish casings are exported according to industry sources (2023).

One possible alternative method of calculating *actual feed consumed* would be to collect age, breed and weight of the animals slaughtered and counting backwards according to models of growth, metabolism and body composition. Such models exists for cattle and sheep (Johnson et al 2012). Such models would have to be supplemented with data of waste, mortality and possibly other factors though.

The edible protein conversion ratio for *plant products* should be more researched, both to improve the calculation of EPCR for animal products and for putting the results in a realistic context compared to animal products. The protein share of edible meat should also need some research, the data used here is from an old source (Föreningen Svensk Kötthandel 1983) using unclear methodology.

The use of synthetic amino acids and soy protein isolate in livestock feed has increased. To use such concentrated feed clearly has the potential to reduce feed use per kg animal, egg or milk, but there seems to be little research on this and the possible trade-offs involved or the impact of their production.

As demonstrated in this report, some of the allocation principles for LCAs, such as system expansion, are not feasible for the determination of feed use. Further research is needed to determine *if and how* it is at all appropriate to apply a method for allocation for the impact of the final product, e.g. climate impact of meat, if the same allocation method is not applicable for feed use to produce that product.

When LCA is used for comparison of different products the choice of functional unit and allocation can have a massive impact of the results and naturally becomes contentious. In addition, the methodology doesn't capture the linkages in the agriculture and food system. On contrary, it intentionally excludes such linkages, e.g. by separating meat from milk or pelt from meat. One could question if the LCA methodology is suited for comparisons which are communicated to consumers or the wider public as one-dimensional figures.

11.5 How can the results be useful for the Meat guide?

Most LCAs for environmental impacts have been based on either rather generic assessments of the feed use or on pure model rations, mostly optimized. This report calculates the feed used based on actual production with the whole Swedish production as the boundary. The methodology used gives a more realistic view than using models or single farm studies. It is clear from this report that the real feed use often is considerably higher than model data. This also means that the results here should not be used for comparisons with data from other countries unless they are derived with a similar methodology as well as similar allocation principles. The study also, mostly, applies the same allocation principles for the different products which is a pre-conditions for fair comparisons, be it between different products in Sweden or between Swedish production and production in other countries.

Some of the examples in this report shows that allocation choices can have a huge impact and that calculating feed use for a product that has gone through several steps of allocation, such as cheese, is really challenging. This is applies equally if one want to define the impact of the product. The author see no particular reason for why allocation principles on the farm level should be different for feed used than for impacts (on climate, eco-toxicity etc.) caused by the use of feed.

The report has interesting results for the relationship between carcass weight and edible meat and demonstrates that there is a big potential to increase the share of the animal that is consumed by people. It is clearly a low-hanging fruit when it comes to lower the footprint of livestock production if a bigger part of the animal is actually consumed.

It is apparent from this study that low feed use per kg product is not a desirable property *per se* as a low use of feed is linked to a low edible protein conversion ratio. A focus on feed use stimulates the use of more concentrated and higher quality feeds and discourages the recycling of food waste as well as the use of roughage and grazing. This seems to be valid within each line of production as well as in comparisons between different livestock products and it applies also on a global level (Mottet et al 2017).

Agriculture and food systems are complex and there is a lot of interaction between different parts of them. The more circular and sustainable the production is, the more connections and linkages there will be. The use of by-products as animal feed, the recirculation of manure to the fields, the soil health and higher yields of human edible crops as a result of the growing of ley to ruminants or better crop rotations are examples of complexities that are hard to capture by the traffic light signal system.

Annex 1: References

Ag decision maker VOL. 26 NO. 2 / December 2021, Strong by-product values lift cattle prices, Iowa state university.

Agriculture and Horticulture Development Board 2023a, EU (excluding UK) wholesale product prices, https://ahdb.org.uk/dairy/eu-wholesale-prices accessed 29 March 2023.

Agriculture and Horticulture Development Board 2023b, UK wholesale product prices, https://ahdb.org.uk/dairy/eu-wholesale-prices accessed 29 March 2023.

Ahlgren et al 2022, Miljöpåverkan av svensk nöt- och lammköttsproduktion, RISE Rapport 2022:143.

Alsterberg, Erik 2012, Animaliska restprodukter vid köttproduktion. Examensarbete Uppsala universitet.

Al-Zohairi et al 2023, Utilizing animal by-products in European slaughterhouses to reduce the environmental footprint of pork products, Sustainable Production and Consumption, Volume 37, 2023, 306-319.

Al-Zohairi, Selma et al 2022, Environmental impact of Danish pork—effect of allocation methods at slaughtering stage, The International Journal of Life Cycle Assessment, https://doi.org/10.1007/s11367-022-02089-y.

Andresen N. et al 2023. Ekologiska foderstater med lokala eller globala proteinråvaror – konsekvenser för odling, foderstat, ekonomi och marknaden. Pågående projekt HIR-Skåne.

Arla Foods 2023, Arla foods klimatberäkningsrapport 2022.

Autret, M., Bocobo, D.L., Hsu, P.C., Rao, K.K.P.N., Veen, A.G. van, Reh, E., Vergara, A., 1953. Food composition tables for international use.

Bennetoft, L. och Lindahl, D. (2016). Kycklingproduktion – En analys av produktiongrenens ekonomiska förutsättningar (examensarbete). Uppsala: Institutionen för ekonomi, Sveriges Lantbruksuniversitet. https://stud.epsilon.slu.se/9414/1/bennetoft_l_lindahl_d_160704.pdf.

Berardy Costello and Seager 2015. Life Cycle Assessment of Soy Protein Isolate Proc. ISSST.

Bergsten, Hans, Lyckeby, personal messsage 2021-02-21.

Berlin, Johanna, 2002, Environmental life cycle assessment (LCA) of Swedish semi-hard cheese, International Dairy Journal, Volume 12, Issue 11, 2002, Pages 939-953.

Berk, Zeki 1992, Technology of production of edible flours and protein products from soybeans, FAO Agricultural services bulletin No. 97.

Bernesson and Strid 2011, Svensk spannmålsbaserad drank - alternativa sätt att tillvarata dess ekonomiska, energi- och miljömässiga potential, SLU rapport 032.

Bertilson et al 2012, Svinn inom brödindustrin Materialförluster i försörjningskedjan, Institutionen för teknikens ekonomi och organization, Chalmers.

Berrazaga I, Micard V, Gueugneau M, Walrand S. 2019, The role of the anabolic properties of plant- versus animal-based protein sources in supporting muscle mass maintenance: a critical review. Nutrients. 2019;11(8):1825.

Bjørn, A., Owsianiak, M., Molin, C., Hauschild, M.Z. (2018). LCA History. In: Hauschild, M., Rosenbaum, R., Olsen, S. (eds) Life Cycle Assessment. Springer, Cham. https://doi.org/10.1007/978-3-319-56475-3_3.

Blomberg, S. 2022, Slaktutbyte och köttutbyte i nöt-och lammslaktkroppar. Kandidatarbete. Sveriges lantbruksuniversitet, institutionen för husdjurens miljö och hälsa.

Brankatschk and Finkbeiner 2014, Application of the Cereal Unit in a new allocation procedure for agricultural life cycle assessments,,Journal of Cleaner Production Volume 73,2014, Pages 72-79.

Broekema and Kramer 2014, LCA of Dutch semiskimmed milk and semi-mature cheese, Blonk Consultants.

Carbell, E, Styckningskalkyler och prissättning inom detaljhandeln in Karlsson, Göran, (ed) Boken om kött, Bengt Forsbergs förlag.

Carlsson and Segerkvist 2018, Lammlyftet, Identifikation av faktorer som är viktiga för lammkötts kvalitetsegenskaper. SLU.

Carlsson, Annelie SLU 2023, personal message 2023-05-16.

Cashion T, le Manach F, Zeller D, Pauly D. Most fish destined for fishmeal production are food-grade fish. Fish. 2017; 18(5): 837-844.

Cederberg and Henriksson 2020, Gräsmarkernas användning i jordbruket, Chalmers.

Cerealia 2023, message from customers service 2023-04-05.

Conroy et al 2010, Predicting beef carcass, meat, fat and bone proportions form carcass conformation and fat scores or hindquaters dissection, Animal 4:2 234-241.

Council for Agricultural Science and Technology 1999. Animal agriculture and global food supply, Task Force Report 135.

Dahl, Olle 1953, Köttets kemi in Karlsson, Göran, (ed) Boken om kött, Bengt Forsbergs förlag.

DEFRA (Department for Environment, Food & Rural Affairs) 2023, 'Latest poultry and poultry meat statistics', https://www.gov.uk/government/statistics/poultry-and-poultry-meat-statistics, Last updated 17 August 2023.

Donis, Maria, Svensk Fågel, personal messages.

Dorca-Preda, et al 2021. Environmental impact of Danish pork at slaughterhouse gate – a life cycle assessment following biological and technological changes over a 10-year period. Livest. Sci. 251, 104622.

Drivkraft Sverige 2023, Beräkningsfaktorer, https://drivkraftsverige.se/fakta-statistik/berakningsfaktorer/ acessed 13 march 2023.

Edman, Frida, Wallman, Magdalena and Nilsson, Katarina 2022, Klimatavtryck av Svensk Fågels kycklingproduktion 2021, version 3. RISE Rapport 2022:84.

Edman et al 2023, Kött- och slakutbyte – data och metoder vid beräkningar av miljöpåverkan, Rise rapport 2023:38.

Einarsson, Rasmus et al 2022, The nitrogen footprint och Swedish food consumption, Environ. Res Lett 17 (2022).

Elitlamm 2023, Årsstatistik för besättningar och djur registrerade i Elitlamm under år 2022.

Energimyndigheten 2019, Drivmedel 2018, ER 2019:14.

Erlandsson, Thomas (Nordisk Råvara) 2023, personal message 2023-06-23.

Ertl P, Knaus W, Zollitsch W. An approach to including protein quality when assessing the net contribution of livestock to human food supply. Animal. 2016 Nov;10(11):1883-1889.

FAO 2000, Technical Conversion Factors, http://www.fao.org/economic/the-statistics-division-ess/methodology/methodology-systems/technical-conversion-factors-for-agricultural-commodities/en/.

FAO 2016. Greenhouse gas emissions and fossil energy use from small ruminant supply chains: Guidelines for assessment. Livestock Environmental Assessment and Performance Partnership. FAO, Rome, Italy.

FAO 2023, Contribution of terrestrial animal source food to healthy diets for improved nutrition and health outcomes – An evidence and policy overview on the state of knowledge and gaps. https://doi.org/10.4060/cc3912en.

FAOSTAT 2023, Food Balance 2020.

Feedipedia 2023, Animal Feed Resources Information System - INRAE CIRAD AFZ and FAO, https://www.feedipedia.org.

Finnish Food Authority 2023, Kvalitet av spannmålsskörden 2005-2022, https://www.ruokavirasto.fi/sv/laboratorietjanster/undersokningar-om-vaxter/spannmals-kvalitet-och-sakerhet/ accessed 2023-08-05.

Fjelkner-Modig, Stina 1983, Näringsfakta om kött och chark in Stora Köttboken, Föreningen Svensk Kötthandel.

Flysjö et al 2012, The interaction between milk and beef production and emissions from land use change e critical considerations in life cycle assessment and carbon footprint studies of milk, Journal of Cleaner Production 28 (2012) 134 -142.

Flysjö et al. 2014, Method to assess the carbon footprint at product level in the dairy industry, International Dairy Journal 34 (2014) 86e92.

Foder och Spannmål 2019 , Foderstatistik 2018 (opublicerat).

Foder och Spannmål 2023, Foderstatistik 2018-2022 (opublicerat).

Fraanje, Walter and Garnett, Tara 2020, Soy: food, feed, and land use change, 30 Jan 2020, https://tabledebates.org/building-blocks/soy-food-feed-and-land-use-change#SOYBB2.

Franke et al 2016, Food losses and waste in primary production, Nordic council of ministers 2016. DOI:10.6027/TN2016-529.

Fransson, Jesper (Jordbruksverket) 2023, personal message 20 June 2023.

Föreningen Svensk Kötthandel 1983, Stora Köttboken.

Gård & Djurhälsan 2018, Dikoåret.

Hammar et al 2022, Time-dependent climate impact of beef production – can carbon sequestration in soil offset enteric methane emissions?, Journal of Cleaner Production 331 (2022) 129948.

Hayse and Marion 1973, Eviscerated Yield, Component Parts, and Meat, Skin and Bone Ratios in the Chicken Broiler, Poultry Science 52(2):718-722.

Heijungs et al 2021, System Expansion and Substitution in LCA: A Lost Opportunity of ISO 14044 Amendment 2, Front. Sustain., 02 June 2021.

Hendrix Genetics 2020, Nutrition Guide.

Hennessy DP et al 2021. The net contribution of livestock to the supply of human edible protein: the case of Ireland. The Journal of Agricultural Science 159,463–471.

Henriksson, Cederberg och Swensson 2014, Carbon footprint and land requirement for dairy herd rations: impacts of feed production practices and regional climate variations, Animal (2014), 8:8, pp 1329–1338.

Henryson et al 2022, Higher carbon sequestration on Swedish dairy farms compared with other farm types as revealed by national soil inventories, Carbon Management, 13:1, 266-278.

Hertzler SR, Lieblein-Boff JC, Weiler M, Allgeier C. Plant Proteins: Assessing Their Nutritional Quality and Effects on Health and Physical Function. Nutrients. 2020 Nov 30;12(12):3704. doi: 10.3390/nu12123704. PMID: 33266120; PMCID: PMC7760812.

Hessle, A and Danielsson, R 2023. Number of cattle required to obtain good ecological status in Swedish grasslands and livestock's methane emissions. Swedish University of Agricultural Sciences Report 60, Department of Animal Environment and Health.

Hietala et al 2021, Environmental life cycle assessment of Finnish beef – cradle-to-farm gate analysis of dairy and beef breed beef production Agricultural Systems 194 (2021) 103250.

IDF 2004, Bulletin of the IDF N° 390/2004 - Methods for Calculating Milk Equivalents.

Hovmalm 2023, Livsmedelsförluster vid produktion av kvarnvete, Jordbruksverket Rapport 2023:1.

Hushållningssällskapet. (2021). Resurseffektivisering på gården. Retrieved 5 May 2023, https://jordbruksverket.se/utveckla-foretagande-palandsbygden/konkurrenskraft/resurseffektivisering-pa-garden.

IDF (2015) A common carbon footprint approach for the dairy sector. The IDF guide to standard life cycle assessme nt methodology vol 479. International Dairy Federation, Brussels, Belgium.

Industry 2023, interviews, data and emails from several industry sources not wishing to be identified.

Jansma, Arne Agroetanol, personal message, 2020-12-18.

Jeppson, Mikael (Lantmännen) 2023, personal message 2023-07-03.

Johansson, E 2020, Påverkas kalven av kons utfodring under dräktigheten? Sveriges lantbruksuniversitet, SLU, Husdjurens utfodring och vård.

Johnson et al 2012, A generic model of growth, energy metabolism, and body composition for cattle and sheep, J. Anim. Sci 2012.90:4741-4751.

Karlson, Ola (Foderlotsen AB) 2023, personal message.

Karlsson, Anna-Karin, Norrmejerier, personligt meddelande 2021-02-25.

Karlsson Johan et al 2021, Halting European Union soybean feed imports favours ruminants over pigs and poultry. Nat Food 2, 38–46.

Kite, Cindy Polarbröd, personal message 2021-04-20.

Klingberg, Jenny (Arla Foods) 2023, personal message.

Koljonen, Raimo Viking malt AB, personal message 2021-03-25.

Kyttä et al 2021, Review and expert survey of allocation methods used in life cycle assessment of milk and beef, The international journal of Life Cycle Assessment (2022) 27:191-204.

Laisse, S et al 2018, L'efficience nette de conversion des aliments par les animaux d'élevage : une nouvelle approche pour évaluer la contribution de l'élevage à l'alimentation humaine, INRA Prod. Anim.,

2018, 31 (3), 269-288.

Landquist 2023, Komplettering till RISE Rapport 2020:59: Uppdaterad och utökad livscykelanalys av svensk grisproduktion, 2023-03-31.

Landquist et al, 2020 Uppdaterad och utökad livscykelanalys av svensk grisproduktion. Rise.

Lantmännen 2008, 'Stora problem med svensk brödspannmål', https://www.lantmannen.se/om-lantmannen/press-och-nyheter/pressmeddelanden/2008/stora-problem-med-svensk-brodspannmal/ accessed 2023-08-07.

Lantmännen 2023a, 'Agrow Feed 90', https://www.lantmannenagroetanol.se/en/produkter/foder/agrow-feed-90/.

Lantmännen 2023b, 'Rätt utsädesmängd vid sådd' https://www.odla.lantmannenlantbruk.se/utsadebetning/utsadesmangd/.

Le Féon, Aubin, Gac et al. 2020 / Data in Brief 33 (2020) 106558.

Leip, et al 2019, The value of manure – manure as co-product in life cycle assessment,Journal of Environmental Management 241 (20199) 293-304.

Lindgren, Hans, Spendrups bryggerier, personal message 2021-03-17.

Lindmark Månson, Helena 2012, Den svenska mejerimjölkens sammansättning 2009, Svensk mjölk 2012.

Lindow, Karin et al 2021, Livsmedelsförluster i Sverige, Metoder för ökad kunskap om livsmedelsproduktionens förluster och resurser, Jordbruksverket.

Ljungkvist, Ida, Scandi Standard 2023, personal messages.

Lonergan et al 2019, Chapter 6 - Growth curves and growth patterns in The Science of Animal Growth and Meat Technology (Second Edition).

LRF statistikplatform, Nöt, gris och får 2023, uppdaterad 2023-03-31, https://www.lrf.se/om-lrf/lrfs-branschavdelningar/lrf-kott/statistik/

Länstyrelsen Västra Götaland, Bidragskalkyler 2021.

Länstyrelsen Västra Götaland, Bidragskalkyler 2023.

Lönneskog Hogstadius, Marie 2023, Svenska Ägg, personal messages.

Mannerheim, Lena 2021, Gäverstad gård, personal message 2021-04-02.

Mejia, Alfredo & Harwatt, Helen & Jaceldo-Siegl, Karen & Sranacharoenpong, Kitti & Soret, Samuel & Sabaté, Joan. (2017). Greenhouse Gas Emissions Generated by Tofu Production: A Case Study. Journal of Hunger & Environmental Nutrition. 13. 1-12. 10.1080/19320248.2017.1315323.

Miranda et al 2015, Egg and Egg-Derived Foods: Effects on Human Health and Use as Functional FoodsNutrients 2015, 7, 706-729; doi:10.3390/nu7010706.

Mottet et al 2017, Livestock: On our plates or eating at our table? A new analysis of the feed/

food debate, Global Food Security 14 (2017) 1–8.

Nielsen, N.I., Jørgensen, M., Bahrndorff, S., 2011. Greenhouse gas emission from the Danish broiler production estimated via LCA methodology, Knowledge Centre for Agriculture. Aarhus.

Nilsson and Bernesson 2009, Halm som bränsle, del 1 tillgångar och skördetidpunkter, SLU rapport 011.

Nilsson et al 2023, Effect of short-term perennial leys on life cycle environmental performance of cropping systems: An assessment based on data from a long-term field experiment, European Journal of Agronomy, Volume 149, 2023, 126888, ISSN 1161-0301.

Nilsson, Katarina (Rise) 2023, personal message.

Nofima 2019, Resource utilization of Norwegian salmon farming in 2016, https://nofima.no/publikasjon/1713971/.

Odelros, Åsa 2023, Svenska ägg, personal messages.

Olsson, Viktoria (Arla Foods) 2023, personal messages.

Pap et al 2022, A. Optimization of Valorization of Chicken MDCM to Produce Soluble Protein and Collagen Peptides. Appl. Sci. 2022, 12, 1327.

Pelletier 2017, Life cycle assessment of Canadian egg products, with differentiation by hen housing system type. J. Clean. Prod. 152, 167–180.

Petterson, Sundberg och Westlin, 2009. Maskiner och metoder i vallodling. JTI 377.

Pettersson, Erik 2023, KGs ägg, personal message.

Phyllis, Database for the physico-chemical composition of (treated) lignocellulosic biomass, micro- and macroalgae, various feedstocks for biogas production and biochar, https://phyllis.nl/.

Poeplau, C., Bolinder, M. A., Eriksson, J., Lundblad, M., and Kätterer, T 2015.: Positive trends in organic carbon storage in Swedish agricultural soils due to unexpected socio-economic drivers, Biogeosciences, 12, 3241–3251, https://doi.org/10.5194/bg-12-3241-2015, 2015.

Roundtable on Responsible Soy Association 2023, Soy Conversion Factors Technical supporting document, undated downloaded 2023-07-28 from https://responsiblesoy.org/rtrs-soy-and-corn-footprint-calculator?lang=en#calculadora-soja-iframe.

Rundgren, Gunnar 2019, Mjölkprodukter och vegetabiliska alternativ till mjölkprodukter – miljö, klimat och hälsa, Matlust.

Rundgren, Gunnar 2020, Hur svensk är svensk mat, Ekomatcentrum, http://ekomatcentrum.se/wp-content/uploads/2020/08/Hur-svenskt-%C3%A4r-svenskt-orginal-2020.pdf.

Rundgren, Gunnar 2021, Koll på kolet - Kolflödet i det svenska jordbruks och livsmedelssystemet, KSLAT 2-2021.

Sommerfeldt, Marcus 2023, Lantmännen, personal message.

Spannmålsbönderna 2023, survey in social media group Spannmålsbönderna 7 July 2023.

Röös, Elin 2023, SLU, personal message.

Sandqvist Per, 2023, Landsberga gård, personal message.

Sandström et al.2022, Food system by-products upcycled in livestock and aquaculture feeds can increase global food supply. Nat Food 3, 729–740 (2022).

SCB 2021, Utrikeshandel med varor, Varuimport och varuexport efter handelspartner och varugrupp SITC rev3/rev4, ej bortfallsjusterat, sekretessrensad.

Schulz, Lee 2021, Strong by-product values lift cattle prices, Ag decisionmaker, VOL. 26 NO. 2 / DECEMBER 2021.

Schulz, Lee 2023, personal message (clarification of data from Schulz 2021).

Shurtleff, W. and A. Aoyagi 2007 'History of Soybeans and Soyfoods: 1100 B.C. to the 1980s', Soyinfo Center, www.soyinfocenter.com..

Singh and Krishnaswamy, 2022 Sustainable zero-waste processing system for soybeans and soy by-product valorization, Trends in Food Science & Technology, Volume 128, 2022, Pages 331-344.

SLU 2023, 'Soja i fodret till våra husdjur', https://www.slu.se/institutioner/husdjurens-utfodring-vard/nyheter-huv/soja-till-husdjur/.

SJVFS 2004:88 Föreskrifter om ändring i Statens jordbruksverks föreskrifter (SJVFS 1998:127) om klassificering av slaktkroppar.

SJVFS 2011:40 Statens jordbruksverks föreskrifter och allmänna råd om foder.

Sporchia et al 2023, The environmental footprints of the feeds used by the EU chicken meat industry, Science of the Total Environment 886 (2023) 163960.

Spörndly, R och Nylund, R 2017, Minskade förluster vid ensilering av grovfoder, SLU vallkonferensen 2017.

Spröndly, Rolf, personal message 2021-01-04.

Statistics Sweden 2023, Trade statistics SITC level 5.

Stenberg et al 2020. Carcass characteristics and meat quality attributes in lambs reared indoors, on cultivated pasture, or on semi-natural pasture. Agricultural and Food Science, 29 (5), 432–441, https://doi.org/10.23986/afsci.91706.

Strid, Ingrid et al 2022, Livsmedelsförluster vid slakt av grisar och nötkreatur, SBA Rapport 2022:18.

Strid, Röös and Tidåker 2014, Förluster av svenskt nötkött inom primärproduktion och slakt. Jordbruksverket rapport 2014:07.

Strömne, Titti 2023, personal messages.

Sturm, Viktoriya, Martin Banse and Petra Salamon 2022, The role of feed-grade amino acids in the bioeconomy: Contribution from production activities and use in animal feed, Cleaner Environmental Systems, Volume 4, 2022, 100073.

Svenska Ägg 2015, Nulägesanalys svensk äggproduktion .

2015 Swedish Board of Agriculture 2018, Skörd av spannmål, trindsäd, oljeväxter, potatis och slåttervall 2017, JO 16 SM 1801.

Swedish Board of Agriculture 2019a, råvaror som ingår i foderblandningar som fodertillverkare rapporterar till Jordbruksverket, data från 2018, utskriven 2019-09-06.

Swedish Board of Agriculture 2019b, tillverkad/importerad kvantitet foderblandningar, data från 2018, utskriven 2019-04-29.

Swedish Board of Agriculture 2021a, Grain balance 2018 (unpublished).

Swedish Board of Agriculture 2021b, Jordbruksverkets statistic database, direktkonsumtion livsmedel 2018.

Swedish Board of Agriculture 2021b, Konsumtion och förbrukning av kött, https://Jordbruksverket.se/mat-och-drycker/hallbar-produktion-och-konsumtion-av-mat/konsumtion-och-forbrukning-av-kott 2021-03-09.

Swedish Board of Agriculture 2021c. Utdrag från CDB, avlidna nötkreatur 2021-03-12 (opublicerat).

Swedish Board of Agriculture 2022a, Nötkreaturssektorns uppbyggnad En analys av struktur och slakt i nötkreaturssektorn, https://jordbruksverket.se/om-jordbruksverket/jordbruksverkets-officiella-statistik/jordbruksverkets-statistikrapporter/statistik/2022-02-01-notkreaturssektorns-uppbyggnad--en-analys-av-struktur-och-slakt-i-notkreaturssektorn#h-Slakt.

Swedish Board of Agriculture 2022b, Sveriges utrikeshandel med jordbruksvaror och livsmedel 2019–2021, Rapport 2022:11.

Swedish Board of Agriculture 2022c, Förluster av griskött, nöt-kött och mjölk på gården, Rapport 2022:19.

Swedish Board of Agriculture 2022d, Marknadsrapport ägg – utvecklingen till och med 2021.

Swedish Board of Agriculture 2022e, Marknadsrapport griskött – utvecklingen till och med 2021.

Swedish Board of Agriculture 2023a, Priser och marknads-information för livsmedel, https://jordbruksverket.se/mat-och-drycker/handel-och-marknad/priser-och-marknadsinformation-for-livsmedel accessed 2023-04-18.

Swedish Board of Agriculture 2023b, ”Miljöersättning för skötsel av betesmarker och slåtterängar 2023” https://jordbruksverket.se/stod/jordbruk-tradgard-och-rennaring/jordbruksmark/betesmarker-och-slatterangar/skotsel-av-betesmarker-och-slatterangar 2023-05-25.

Swedish Board of Agriculture 2023c, ”Djursmittoersattning”, personligt meddelande Smittbekämpningsenheten Jordbruksverket.

Swedish Board of Agriculture 2023d, tillverkad/importerad kvantitet foderblandningar 2019-2022, opublicerat.

Swedish Board of Agriculture statistic database 2021a, antal djur 1 juli 2018.

Swedish Board of Agriculture statistic database 2021d, Slakt av större lantbruksdjur vid slakteri efter Djurslag.

Swedish Board of Agriculture statistic database 2023a, Slakt av större lantbruksdjur vid slakteri efter Djurslag.

Swedish Board of Agriculture statistic database 2023b, Avräkningspriser, år fr.o.m. 2010.

Swedish Board of Agriculture statistic database 2023c, Slakt av fjäderfä vid slakteri efter Djurslag, Tabelluppgift och År.

Swedish Board of Agriculture statistic database 2023d, Antal djur och jordbruksföretag med djur efter Storleksgrupp, Kategori, Variabel, Tabelluppgift och År.

Swedish Board of Agriculture statistic database 2023e, partihandelns invägning av ägg.

Swedish Board of Agriculture statistic database 2023f, Antal djur och jordbruksföretag med djur efter Produktionsområde.

Swedish Board of Agriculture statistic database 2023g, Mejeriproduktion.

Swedish Board of Agriculture statistic database 2023h, Andel ekologisk slakt av den totala slakten i procent efter Djurslag, Variabel och År.

Swedish Board of Agriculture statistic database 2023i, Andel ekologisk produktion av mjölk, mejeriprodukter och ägg av den totala produktionen efter Variabel och År.

Swedish Food Agency 2022, food database, version 2022-05-24, https://www7.slv.se/SokNaringsinnehall/.

Swensson, C 2015, Sojaavtrycket i livsmedel från animalieproduktion, Mjölk Special 2015-10-28.

Tillgren, Beatrice, 2021, Cereals as 'leftover biomass', Master thesis, Swedish University of Agricultural Sciences, SLU Agricultural Programme – Food Science Molecular Sciences, 2021:05.

Tradingeconomics.com 2023, "EU Carbon Permits", https://tradingeconomics.com/commodity/carbon 2023-05-20.

Tsagari A. 2020, Dietary protein intake and bone health. J Frailty Sarcopenia Falls. 2020 Mar 1;5(1):1-5. doi: 10.22540/JFSF-05-001. PMID: 32300728; PMCID: PMC7155358.

Turner et al 2022a, Environmental impact mitigation potential of increased resource use efficiency in industrial egg production systems, Journal of Cleaner Production 354 (2022) 131743.

Turner et al 2022b, Life cycle assessment of contemporary Canadian egg production systems during the transition from conventional cage to alternative housing systems: Update and analysis of trends and conditions, Resources, Conservation & Recycling 176 (2022) 105907.

USDA 2020, Oilseeds; World Market and Trade, November 2020.

USDA ERS 2022, using data from various sources as documented on the Food Availability Data System home page. Data last updated October 1, 2022.

USDA FAS 2023, Oilseeds: World Markets and Trade, June 2023.

Wallgren et al 2011, Life Cycle Assessment of Swedish Lamb Production, SIK-rapport Nr 831.

Wennerberg, Eric 1953, Recept i Karlsson, Göran, (red) Boken om kött, Bengt Forsbergs förlag.

Wiedemann et al 2015, Application of life cycle assessment to sheep production systems: investigating co-production of wool and meat using case studies from major global producers, Int J Life Cycle Assess (2015) 20:463–476.

Wilkinson JM 2011, Re-defining the efficiency of feed use by livestock. Animal 5:1014–1022 (2011).

Wik, E 2015, När och varför dör smågrisarna under diperioden?, Examensarbete / SLU, Institutionen för husdjursgenetik.

van Barneveld R. J., Hewitt R. J. E., D'Souza D. N. (2023) Net protein contribution from an intensive Australian pork supply chain. Animal Production Science. Published online: 25 May 2023.

Wolf, J. et al 2015. Biogenic carbon fluxes from global agricultural production and consumption. Global Biogeochem. Cycles 29, 1617–1639. https://doi.org/10.1002/2015GB005119.

von Greyertz et al 2023, A large share of climate impacts of beef and dairy can be attributed to ecosystem services other than food production, al. Journal of Environmental Management 325 (2023) 116400.

Växa 2022a, Cattle health statistics 2020–2021.

Växa 2022b, Långlivade kor kan ge högre lönsamhet, https://www.vxa.se/nyheter/2022/langlivade-kor-kan-ge-hogre-lonsamhet/.

Växa 2023, Husdjursstatistik 2022.

Zira et al 2021, A life cycle sustainability assessment of organic and conventional pork supply chains in Sweden, Sustainable Production and Consumption 28 (2021) 21-38.